Draft Regulatory Impact Analysis:

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

EPA United States
Environmental Protection
Agency

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

EPA United States Environmental Protection Agency

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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 proposed rulemaking (NPRM) to establish standards for light-duty highway vehicles that will reduce greenhouse gas emissions (GHG) and improve fuel economy. EPA is proposing greenhouse gas emissions standards under the Clean Air Act, and NHTSA is proposing Corporate Average Fuel Economy standards under the Energy Policy and Conservation Act (EPCA), as amended. These proposed standards apply to passenger cars, light-duty trucks, and medium-duty passenger vehicles, covering model years (MY) 2017 through 2025. The proposed 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 proposed GHG program. These proposed 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 proposed National Program will result in approximately 1,967 million metric tons of CO_2 equivalent emission reductions and approximately 3.9 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 NPRM 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 $22/ton SCC Value[a,b,c,d]
(Billions of 2009 dollars)

Lifetime Present Value[c] – 3% Discount Rate	
Program Costs	$140
Fuel Savings	$444
Benefits	$117
Net Benefits[d]	$421
Annualized Value[e] – 3% Discount Rate	
Annualized costs	$6.43
Annualized fuel savings	$20.3
Annualized benefits	$5.36
Net benefits	$19.3
Lifetime Present Value[c] - 7% Discount Rate	
Program Costs	$138
Fuel Savings	$347
Benefits	$101
Net Benefits[d]	$311
Annualized Value[e] – 7% Discount Rate	
Annualized costs	$10.64
Annualized fuel savings	$26.7
Annualized benefits	$6.35
Net benefits	$22.4

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 2009 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] 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 2009 dollar terms). The lifetime present values shown here are the present values of each MY in its first year summed across MYs.

[d] Net benefits reflect the fuel savings plus benefits minus costs.

[e] 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 draft Regulatory Impact Analysis (DRIA) contains supporting documentation to the EPA rulemaking. NHTSA has prepared their own preliminary RIA (PRIA) in support of their rulemaking (this can be found in NHTSA's docket for the rulemaking, NHTSA-2010-0131). While the two rulemakings 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 and EISA, 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—e.g., development of technology costs and effectiveness—the supporting documentation is contained in the draft joint Technical Support Document (draft joint TSD can be found in EPA's docket EPA-HQ-OAR-2010-0799). Therefore, this DRIA should be viewed as a companion document to the draft 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 draft 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 draft Joint TSD.

Chapter 2: The development and application of the EPA vehicle simulation tool 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 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. For the off-cycle credits, EPA based its analysis on manufacturer data, 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. The credit will be 0.6 g/mile for cars and 1.0 g/mile for trucks when the reduction in aerodynamic drag is around 3%.

Chapter3: This chapter provides the methodology from and results of the technical assessment of the future vehicle scenarios presented in this proposal. 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: This chapter documents EPA's analysis of the emission, fuel consumption and safety impacts of the proposed emission standards for light duty vehicles. This proposal, if finalized, will 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 proposed rule. This analysis quantifies the proposed 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. DRIA 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. The program costs and fuel savings associated with EPA's proposed 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 (and fuel savings) of the proposal through 2050 and for each of the model years 2017 through 2025 that are effected by the proposal. 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 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 up-front costs in less than four years for people purchasing new vehicles with cash. 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.

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 proposed 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 proposed 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 DRIA 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 proposed standards. To adequately assess these impacts, full-scale photochemical air quality modeling is necessary to project changes in atmospheric concentrations of $PM_{2.5}$, ozone and air toxics. The length of time needed to prepare the necessary emissions inventories, in addition to the processing time associated with the modeling itself, has precluded us from performing air quality modeling for this proposal. However, for the final rule, a national-scale air quality modeling analysis will be performed to analyze the impacts of the vehicle standards on $PM_{2.5}$, ozone, and selected air toxics (i.e., benzene, formaldehyde, acetaldehyde, acrolein and 1,3-butadiene).

The atmospheric chemistry related to ambient concentrations of $PM_{2.5}$, ozone and air toxics is very complex, and making predictions based solely on emissions changes is extremely difficult. However, based on the magnitude of the emissions changes predicted to result from the proposed vehicle standards (as shown in Chapter 4), we expect that there will be an improvement in ambient air quality, pending a more comprehensive analysis for the final rule.

Chapter 7: Other Economic and Social Impacts. This Chapter outlines a number of additional impacts that contribute to the overall costs and benefits associated with the proposed GHG standards. These impacts affect people outside the markets for vehicles and their use; these effects are termed “external” and include the climate impacts, energy security impacts, and the effects on traffic, accidents, and noise due to additional driving.

Energy Security Impacts: A reduction of U.S. petroleum imports reduces both financial and strategic risks associated with a potential disruption in supply or a spike in cost of a particular energy source. This reduction in risk is a measure of improved U.S. energy security.

SCC and GHG Benefits: EPA uses four estimates of the dollar value of marginal reductions in CO_2 emissions—known as the social cost of carbon—to calculate total monetized CO_2 benefits. Specifically, total monetized benefits in each year are calculated by multiplying the SCC by the reductions in CO_2 for that year. EPA uses four different SCC values to generate different estimates of total CO_2 benefits and capture some of the uncertainties involved in regulatory impact analysis. The central value is the average SCC across models at the 3 percent discount rate. For purposes of capturing the uncertainties involved in regulatory impact analysis, we emphasize the importance and value of considering the full range. Chapter 7 also presents an analysis of the CO_2 benefits over the model year lifetimes of the 2017 through 2025 model year vehicles.

Other Impacts: There are other impacts associated with the GHG emissions standards and associated reduced fuel consumption. Lower fuel consumption would, presumably, result in fewer trips to the filling station to refuel and, thus, time saved. The rebound effect, discussed in detail in Chapter 4 of the draft joint TSD, produces additional benefits to vehicle owners in the form of consumer surplus from the increase in vehicle-miles driven, but may also increase the societal costs associated with traffic congestion, motor vehicle crashes, and noise. These effects are likely to be relatively small in comparison to the value of fuel saved as a result of the standards, but they are nevertheless important to include.

Chapter 7 also presents a summary of the total costs, total benefits, and net benefits expected under the proposed rule. Table 2 presents these economics impacts. We note that several of the cost and benefit categories we would typically discuss in an RIA are considered joint economic assumptions shared between EPA and NHTSA and are therefore discussed in more detail in EPA and NHTSA's draft Joint TSD Chapter 4.

Table 2 Monetized Benefits Associated with the Proposed Program (Millions, 2009$)

	2017	2020	2030	2040	2050	NPV, 3%[a]	NPV, 7%[a]
Technology Costs	$2,300	$8,470	$35,700	$39,800	$44,600	$551,000	$243,000
Fuel Savings	$570	$7,060	$85,800	$144,000	$187,000	$1,510,000	$579,000
Total Annual Benefits at each assumed SCC value [b]							
5% (avg SCC)	$101	$1,240	$15,600	$29,000	$40,700	$275,000	$124,000
3% (avg SCC)	$141	$1,730	$22,000	$40,400	$55,600	$413,000	$263,000
2.5% (avg SCC)	$173	$2,120	$26,700	$48,700	$65,900	$534,000	$384,000
3% (95th %ile)	$250	$3,100	$40,500	$75,100	$102,000	$764,000	$614,000
Monetized Net Benefits at each assumed SCC value [c]							
5% (avg SCC)	-$1,630	-$166	$65,600	$133,000	$183,000	$1,230,000	$460,000
3% (avg SCC)	-$1,590	$325	$72,000	$144,000	$198,000	$1,370,000	$599,000
2.5% (avg SCC)	-$1,560	$712	$76,800	$153,000	$208,000	$1,490,000	$719,000
3% (95th %ile)	-$1,480	$1,690	$90,500	$179,000	$244,000	$1,720,000	$950,000

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] DRIA Chapter 7.2 notes that SCC increases over time. For the years 2012-2050, the SCC estimates range as follows: for Average SCC at 5%: $5-$16; for Average SCC at 3%: $23-$46; for Average SCC at 2.5%: $38-$67; and for 95th percentile SCC at 3%: $70-$140. DRIA Chapter 7.2 also presents these SCC estimates.

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

Chapter 8: Vehicle Sales and Employment. 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. We discuss how the payback period expected for the proposed standards (less than 3 years in 2021, less than 4 years in 2025) is expected to affect vehicle sales. 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 to increased production of fuel-saving technologies; employment in the auto industry will also be affected by changes in vehicle sales and by the labor intensity of the new technologies relative to the old technologies. Effects on other sectors vary. Employment for auto dealers as well as auto parts manufacturing will be affected by any changes in vehicle sales. Parts manufacturers may face increased labor demand due to production of the new technologies. Employment is expected to be reduced in petroleum-related sectors due to reduced fuel demand. 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. It should be noted that none of these analyses was used in the benefit-cost analysis of the proposed standards, but they provide a fuller picture of the impacts of this rule.

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

1 Technology Packages, Cost and Effectiveness

1.1 Overview of Technology

The proposed 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 2017-2025 timeframe at reasonable per vehicle cost 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.

It is well known that CO_2 is a stable compound produced by the complete combustion of the 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, 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 that were described in the 2012-2016 rule (TSD and RIA) that are also common to this rule. While we expect significant penetration of these technologies within the 2016 timeframe, there will be some technologies that will have continued improvement, and others that are only partially implemented into the fleet by 2016. We describe those technologies for which we expect to see continued improvement—engine friction reduction, lower rolling resistance tires—in Chapter 3 of the draft 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 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 MY 2012-2016 standards . There are also other advanced technologies under development (that were not projected to be available to meet 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 it is likely 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 (2017 through 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 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 our 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, 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 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 2012-2016 final rule and this proposal. The vast majority of the emission reductions associated with this proposal would result from the increased use of these technologies. EPA also believes the proposal would 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 proposal 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 2012-2016 FRM, the 2010 Technical Assessment Report (TAR), tear-down analysis done by FEV and the 2008 as well as 2010 Ricardo studies. In addition, we considered confidential data submitted by vehicle manufacturers in response to NHTSA's request 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 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. 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 proposal as described in detail in Chapter 3 of the draft 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 draft joint TSD. There we present direct manufacturing costs, indirect costs and total costs for each technology in each MY 2017 through 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.

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 draft Joint TSD. For the majority of the other technologies considered in this proposal, the agencies have relied on the 2012-2016 final rule and sources described there for estimates of DMC.

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 draft Joint TSD Chapter 3.2.2. Stranded capital is also discussed in this draft RIA at Chapter 3.8.7 and Chapter 5.1.

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 recent heavy-duty GHG final rule (see 76 FR 57320). Our old 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 draft 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 1.2-14 present the costs associated with the technologies we believe would be the enabling technologies for compliance with the proposed 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 proposal. That is, technologies such as lower rolling resistance tires and level 1 aerodynamic treatments are expected to exceed 85 percent penetration by 2016 so they cannot be added "again" to comply with the 2017-2025 proposed 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 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 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 the proposal. 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 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 1.2-14 presents 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 1.2-8 through Table 1.2-12). 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 for 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 of the draft joint TSD. We note that the approach described there is a departure from our earlier efforts where the weight increase of the electrification components was not fully recognized. Importantly, that had little impact on the analysis used to support the 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 draft joint TSD, along with a more detailed description of the comprehensive technical evaluation underlying the estimates.

Table 1.2-1 Costs for Engine Technologies (2009$)

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	$45	$42	$42	$41	$40	$40	$39	$38
CCP-OHC-V	$91	$90	$84	$83	$82	$80	$79	$78	$76
CCP-OHV-V	$46	$45	$42	$42	$41	$40	$40	$39	$38
CVVL-OHC-I4	$240	$237	$216	$212	$209	$206	$203	$200	$197
CVVL-OHC-V6	$440	$434	$396	$389	$383	$377	$372	$366	$360
CVVL-OHC-V8	$480	$473	$432	$425	$418	$412	$405	$399	$393
DCP-OHC-I	$94	$92	$84	$83	$81	$80	$79	$78	$77
DCP-OHC-V	$201	$198	$181	$178	$175	$173	$170	$167	$165
DCP-OHV-V	$102	$101	$92	$90	$89	$87	$86	$85	$84
Deac-V6	$192	$189	$173	$170	$167	$165	$162	$160	$157
Deac-V8	$216	$213	$194	$191	$188	$185	$182	$180	$177
DVVL-OHC-I4	$160	$158	$144	$142	$139	$137	$135	$133	$131
DVVL-OHC-V6	$232	$229	$209	$205	$202	$199	$196	$193	$190
DVVL-OHC-V8	$332	$327	$298	$293	$289	$284	$280	$276	$271
EFR1-I3	$44	$44	$42	$42	$42	$42	$42	$42	$42
EFR1-I4	$58	$58	$56	$56	$56	$56	$56	$56	$56
EFR1-V6	$87	$87	$84	$84	$84	$84	$84	$84	$84
EFR1-V8	$116	$116	$111	$111	$111	$111	$111	$111	$111
EFR2-I3	$95	$95	$95	$95	$95	$95	$95	$95	$91
EFR2-I4	$124	$124	$124	$124	$124	$124	$124	$124	$119
EFR2-V6	$182	$182	$182	$182	$182	$182	$182	$182	$175
EFR2-V8	$240	$240	$240	$240	$240	$240	$240	$240	$230
EGR-I	$303	$298	$294	$290	$285	$281	$277	$274	$247
EGR-V	$303	$298	$294	$290	$285	$281	$277	$274	$247
LUB	$4	$4	$4	$4	$4	$4	$4	$4	$4
Stoich GDI-I4	$274	$270	$246	$242	$238	$234	$231	$227	$224
Stoich GDI-I4>I3	$274	$270	$246	$242	$238	$234	$231	$227	$224
Stoich GDI-V6	$413	$407	$370	$364	$359	$353	$348	$343	$338
Stoich GDI-V8	$497	$490	$445	$438	$431	$425	$418	$412	$406
V6 OHV to V6 DOHC	$676	$661	$599	$585	$571	$558	$549	$540	$532
V6 SOHC to V6 DOHC	$212	$209	$190	$187	$184	$181	$179	$176	$173
V8 OHV to V8 DOHC	$740	$724	$656	$640	$625	$611	$601	$592	$583
V8 SOHC 3V to V8 DOHC	$153	$151	$137	$135	$133	$131	$129	$127	$125
V8 SOHC to V8 DOHC	$245	$241	$219	$216	$212	$209	$206	$203	$200
VVTI-OHC-I	$46	$45	$42	$42	$41	$40	$40	$39	$38
VVTI-OHC-V	$91	$90	$84	$83	$82	$80	$79	$78	$76
VVTI-OHV-V	$46	$45	$42	$42	$41	$40	$40	$39	$38

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 (2009$)

Technology	BMEP	2017	2018	2019	2020	2021	2022	2023	2024	2025
I4 to I3 wT	18 bar	$424	$420	$357	$353	$350	$346	$342	$338	$335
I4 to I3 wT	24 bar	$685	$677	$650	$642	$635	$627	$620	$613	$547
I4 to I3 wT	27 bar	$1,205	$1,189	$1,155	$1,140	$1,126	$1,111	$1,097	$1,083	$972
I4 DOHC to I4 DOHC wT	18 bar	$478	$472	$418	$412	$407	$401	$396	$390	$385
I4 DOHC to I4 DOHC wT	24 bar	$738	$728	$710	$701	$692	$683	$674	$665	$598
I4 DOHC to I4 DOHC wT	27 bar	$1,259	$1,241	$1,216	$1,199	$1,183	$1,167	$1,151	$1,135	$1,022
V6 DOHC to I4 wT	18 bar	$248	$250	$159	$161	$163	$164	$166	$168	$170
V6 DOHC to I4 wT	24 bar	$509	$507	$451	$449	$448	$446	$444	$442	$382
V6 DOHC to I4 wT	27 bar	$1,029	$1,019	$957	$948	$939	$930	$921	$913	$807
V6 SOHC to I4 wT	18 bar	$330	$329	$251	$250	$250	$249	$248	$247	$246
V6 SOHC to I4 wT	24 bar	$591	$586	$544	$539	$535	$530	$526	$522	$459
V6 SOHC to I4 wT	27 bar	$1,111	$1,098	$1,049	$1,037	$1,026	$1,014	$1,003	$992	$884
V6 OHV to I4 DOHC wT	18 bar	$903	$887	$805	$789	$775	$760	$749	$737	$726
V6 OHV to I4 DOHC wT	24 bar	$1,163	$1,143	$1,097	$1,078	$1,060	$1,042	$1,026	$1,012	$938
V6 OHV to I4 DOHC wT	27 bar	$1,683	$1,656	$1,602	$1,576	$1,551	$1,526	$1,504	$1,482	$1,363
V8 DOHC to V6 DOHC wT	18 bar	$741	$733	$631	$624	$616	$609	$602	$595	$588
V8 DOHC to V6 DOHC wT	24 bar	$1,180	$1,165	$1,124	$1,110	$1,097	$1,084	$1,071	$1,058	$946
V8 DOHC to I4 DOHC wT	27 bar	$787	$792	$716	$720	$725	$729	$726	$723	$622
V8 SOHC to V6 DOHC wT	18 bar	$835	$824	$738	$727	$717	$707	$697	$687	$677
V8 SOHC to V6 DOHC wT	24 bar	$1,274	$1,256	$1,231	$1,214	$1,197	$1,181	$1,165	$1,149	$1,035
V8 SOHC to I4 DOHC wT	27 bar	$906	$905	$842	$842	$841	$840	$834	$828	$724
V8 SOHC 3V to V6 DOHC wT	18 bar	$800	$790	$698	$688	$679	$670	$661	$652	$644
V8 SOHC 3V to V6 DOHC wT	24 bar	$1,238	$1,222	$1,191	$1,175	$1,160	$1,144	$1,130	$1,115	$1,002
V8 SOHC 3V to I4 DOHC wT	27 bar	$861	$863	$795	$796	$797	$799	$793	$788	$686
V8 OHV to V6 DOHC wT	18 bar	$1,323	$1,301	$1,180	$1,159	$1,138	$1,118	$1,101	$1,084	$1,067
V8 OHV to V6 DOHC wT	24 bar	$1,762	$1,733	$1,673	$1,646	$1,618	$1,592	$1,569	$1,547	$1,426
V8 OHV to I4 DOHC wT	27 bar	$1,155	$1,143	$1,108	$1,097	$1,085	$1,074	$1,061	$1,048	$938

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 (2009$)

Technology	2017	2018	2019	2020	2021	2022	2023	2024	2025
ASL	$32	$32	$30	$29	$29	$28	$28	$27	$27
ASL2	$33	$33	$32	$31	$30	$30	$29	$29	$27
5sp AT	$103	$101	$95	$94	$92	$91	$89	$88	$86
6sp AT	-$9	-$9	-$9	-$9	-$9	-$9	-$8	-$8	-$8
6sp DCT-dry	-$115	-$111	-$130	-$126	-$122	-$118	-$115	-$111	-$108
6sp DCT-wet	-$81	-$78	-$91	-$89	-$86	-$84	-$81	-$79	-$76
6sp MT	-$168	-$163	-$170	-$166	-$162	-$158	-$154	-$150	-$146
8sp AT	$61	$60	$55	$54	$53	$52	$52	$51	$50
8sp DCT-dry	-$16	-$15	-$14	-$14	-$13	-$13	-$12	-$12	-$15
8sp DCT-wet	$47	$46	$46	$45	$44	$44	$43	$43	$38
HEG	$248	$242	$236	$231	$225	$220	$216	$213	$200
TORQ	$29	$29	$27	$27	$26	$26	$25	$25	$24

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 (2009$)

Technology	2017	2018	2019	2020	2021	2022	2023	2024	2025
EPS/EHPS	$108	$106	$100	$98	$96	$95	$93	$92	$90
IACC	$87	$86	$81	$80	$78	$77	$76	$75	$73
IACC2	$141	$139	$131	$129	$127	$124	$122	$120	$118
Stop-start (12V) for Subcompact, Small car	$394	$385	$348	$340	$332	$324	$317	$310	$303
Stop-start (12V) for Large car, Minivan, Small truck	$446	$436	$395	$385	$376	$368	$359	$351	$343
Stop-start (12V) for Large truck	$490	$479	$433	$423	$413	$403	$394	$385	$376

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 (2009$)

Technology	2017	2018	2019	2020	2021	2022	2023	2024	2025
Aero1	$48	$47	$45	$44	$43	$42	$42	$41	$40
Aero2	$210	$207	$201	$198	$195	$192	$190	$187	$173
LDB	$73	$73	$70	$70	$70	$70	$70	$70	$70
LRRT1	$7	$7	$6	$6	$6	$6	$6	$6	$6
LRRT2	$72	$72	$60	$60	$50	$48	$47	$46	$43
SAX	$96	$94	$89	$88	$86	$85	$83	$82	$81

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 (2009$)

Vehicle Class	2017	2018	2019	2020	2021	2022	2023	2024	2025
Subcompact/ Small car	$2,936	$2,893	$2,627	$2,587	$2,547	$2,509	$2,471	$2,433	$2,397
Large car	$3,595	$3,543	$3,218	$3,168	$3,120	$3,072	$3,026	$2,980	$2,936
Minivan	$2,942	$2,900	$2,633	$2,593	$2,553	$2,514	$2,476	$2,439	$2,402
Small truck	$2,967	$2,924	$2,656	$2,615	$2,575	$2,536	$2,497	$2,460	$2,423
Large truck	$4,114	$4,054	$3,682	$3,625	$3,570	$3,515	$3,462	$3,410	$3,359

All costs are incremental to the baseline case.

Table 1.2-7 Costs for P2-Hybird Technology (2009$)

Vehicle Class	Applied WR	Net WR	2017	2018	2019	2020	2021	2022	2023	2024	2025
Subcompact	10%	5%	$3,489	$3,435	$3,027	$2,977	$2,928	$2,880	$2,834	$2,788	$2,595
Subcompact	15%	10%	$3,452	$3,399	$2,995	$2,945	$2,897	$2,850	$2,804	$2,759	$2,567
Subcompact	20%	15%	$3,415	$3,363	$2,962	$2,913	$2,866	$2,819	$2,774	$2,729	$2,540
Small car	10%	5%	$3,665	$3,609	$3,180	$3,128	$3,076	$3,026	$2,977	$2,930	$2,725
Small car	15%	10%	$3,625	$3,569	$3,145	$3,093	$3,042	$2,993	$2,944	$2,897	$2,696
Small car	20%	15%	$3,585	$3,530	$3,110	$3,058	$3,008	$2,959	$2,912	$2,865	$2,666
Large car	10%	5%	$4,196	$4,132	$3,640	$3,580	$3,521	$3,464	$3,408	$3,353	$3,121
Large car	15%	10%	$4,131	$4,068	$3,583	$3,524	$3,466	$3,410	$3,355	$3,301	$3,073
Large car	20%	15%	$4,067	$4,004	$3,527	$3,469	$3,412	$3,356	$3,302	$3,249	$3,025
Minivan	10%	5%	$4,148	$4,084	$3,597	$3,538	$3,480	$3,423	$3,368	$3,314	$3,085
Minivan	15%	10%	$4,092	$4,029	$3,548	$3,489	$3,432	$3,376	$3,322	$3,268	$3,044
Minivan	20%	15%	$4,036	$3,974	$3,498	$3,440	$3,384	$3,329	$3,275	$3,223	$3,002
Small truck	10%	5%	$4,005	$3,943	$3,473	$3,416	$3,360	$3,305	$3,252	$3,200	$2,979
Small truck	15%	10%	$3,953	$3,892	$3,428	$3,371	$3,316	$3,262	$3,209	$3,158	$2,940
Small truck	20%	15%	$3,900	$3,841	$3,382	$3,326	$3,271	$3,218	$3,166	$3,116	$2,901
Minivan-towing	10%	4%	$4,286	$4,219	$3,728	$3,666	$3,606	$3,547	$3,489	$3,433	$3,185
Minivan-towing	15%	9%	$4,228	$4,162	$3,677	$3,616	$3,556	$3,498	$3,441	$3,386	$3,142
Minivan-towing	20%	14%	$4,170	$4,105	$3,626	$3,566	$3,507	$3,450	$3,394	$3,339	$3,099
Large truck	10%	4%	$4,417	$4,349	$3,844	$3,780	$3,717	$3,657	$3,597	$3,539	$3,282
Large truck	15%	9%	$4,358	$4,290	$3,792	$3,728	$3,667	$3,607	$3,548	$3,491	$3,238
Large truck	20%	14%	$4,298	$4,232	$3,739	$3,677	$3,616	$3,557	$3,499	$3,443	$3,194

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

Table 1.2-8 Costs for Plug-in Hybrid Technology with 20 Mile EV Range, or PHEV20 (2009$)

Vehicle Class	Applied WR	Net WR	2017	2018	2019	2020	2021	2022	2023	2024	2025
Subcompact	10%	3%	$11,325	$10,191	$9,521	$8,607	$8,558	$8,510	$8,463	$8,417	$6,976
Subcompact	15%	8%	$11,099	$9,985	$9,332	$8,433	$8,386	$8,339	$8,293	$8,248	$6,832
Subcompact	20%	13%	$10,874	$9,779	$9,143	$8,260	$8,214	$8,168	$8,124	$8,080	$6,688
Small car	10%	3%	$12,143	$10,945	$10,206	$9,240	$9,186	$9,133	$9,081	$9,030	$7,509
Small car	15%	8%	$11,890	$10,714	$9,993	$9,045	$8,993	$8,941	$8,890	$8,841	$7,348
Small car	20%	13%	$11,637	$10,483	$9,781	$8,851	$8,800	$8,749	$8,700	$8,652	$7,187
Large car	10%	3%	$15,448	$13,989	$12,971	$11,793	$11,719	$11,646	$11,575	$11,505	$9,657
Large car	15%	8%	$15,020	$13,597	$12,613	$11,464	$11,392	$11,322	$11,253	$11,185	$9,382

Large car	20%	13%	$14,593	$13,205	$12,255	$11,135	$11,065	$10,997	$10,931	$10,866	$9,107
Minivan	10%	3%	$14,951	$13,511	$12,559	$11,397	$11,327	$11,259	$11,193	$11,127	$9,301
Minivan	15%	8%	$14,577	$13,169	$12,245	$11,110	$11,042	$10,976	$10,911	$10,848	$9,062
Minivan	20%	13%	$14,203	$12,827	$11,932	$10,822	$10,757	$10,693	$10,630	$10,568	$8,824
Small truck	10%	3%	$14,138	$12,766	$11,878	$10,771	$10,706	$10,643	$10,581	$10,520	$8,779
Small truck	15%	8%	$13,796	$12,454	$11,591	$10,508	$10,445	$10,384	$10,323	$10,264	$8,561
Small truck	20%	13%	$13,453	$12,141	$11,304	$10,246	$10,185	$10,125	$10,066	$10,008	$8,344

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

Table 1.2-9 Costs for Plug-in Hybrid Technology with 40 Mile EV Range, or PHEV40 (2009$)

Vehicle Class	Applied WR	Net WR	2017	2018	2019	2020	2021	2022	2023	2024	2025
Subcompact	15%	2%	$14,293	$12,717	$12,043	$10,775	$10,726	$10,677	$10,630	$10,584	$8,571
Subcompact	20%	7%	$14,067	$12,510	$11,854	$10,601	$10,553	$10,506	$10,460	$10,415	$8,427
Small car	15%	3%	$15,655	$13,929	$13,190	$11,802	$11,748	$11,695	$11,643	$11,593	$9,390
Small car	20%	8%	$15,248	$13,568	$12,847	$11,495	$11,443	$11,391	$11,341	$11,291	$9,146
Large car	15%	2%	$20,644	$18,411	$17,386	$15,589	$15,514	$15,441	$15,369	$15,298	$12,450
Large car	20%	7%	$20,000	$17,836	$16,844	$15,102	$15,030	$14,959	$14,889	$14,821	$12,061
Minivan	15%	2%	$19,848	$17,677	$16,720	$14,973	$14,903	$14,835	$14,768	$14,702	$11,932
Minivan	20%	7%	$19,382	$17,257	$16,328	$14,619	$14,551	$14,485	$14,419	$14,356	$11,644
Small truck	15%	3%	$18,637	$16,589	$15,702	$14,054	$13,989	$13,926	$13,864	$13,803	$11,189
Small truck	20%	8%	$18,139	$16,145	$15,282	$13,678	$13,615	$13,553	$13,493	$13,433	$10,888

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

Table 1.2-10 Costs for Full Electric Vehicle Technology with 75 Mile Range, or EV75 (2009$)

Vehicle Class	Applied WR	Net WR	2017	2018	2019	2020	2021	2022	2023	2024	2025
Subcompact	10%	10%	$15,236	$13,009	$13,001	$11,219	$11,211	$11,203	$11,199	$11,194	$8,253
Subcompact	15%	15%	$14,914	$12,718	$12,712	$10,955	$10,949	$10,944	$10,941	$10,937	$8,055
Subcompact	20%	20%	$14,592	$12,427	$12,424	$10,691	$10,688	$10,685	$10,683	$10,681	$7,857
Small car	10%	10%	$16,886	$14,484	$14,466	$12,541	$12,525	$12,508	$12,498	$12,488	$9,245
Small car	15%	15%	$16,442	$14,086	$14,071	$12,183	$12,169	$12,155	$12,146	$12,138	$8,976
Small car	20%	20%	$15,999	$13,688	$13,676	$11,825	$11,813	$11,802	$11,795	$11,788	$8,707
Large car	10%	10%	$20,727	$17,834	$17,805	$15,486	$15,458	$15,432	$15,414	$15,397	$11,430
Large car	15%	15%	$19,962	$17,147	$17,123	$14,867	$14,844	$14,822	$14,807	$14,793	$10,965
Large car	20%	20%	$19,198	$16,460	$16,441	$14,248	$14,229	$14,212	$14,200	$14,189	$10,501
Minivan	10%	10%	$20,440	$17,543	$17,520	$15,198	$15,177	$15,156	$15,142	$15,129	$11,206
Minivan	15%	15%	$19,716	$16,896	$16,877	$14,618	$14,601	$14,584	$14,573	$14,562	$10,772
Minivan	20%	20%	$18,993	$16,249	$16,235	$14,038	$14,025	$14,012	$14,003	$13,995	$10,337
Small truck	10%	10%	$19,874	$17,112	$17,082	$14,868	$14,840	$14,813	$14,795	$14,778	$10,977
Small truck	15%	15%	$19,223	$16,530	$16,504	$14,347	$14,322	$14,299	$14,283	$14,268	$10,587
Small truck	20%	20%	$18,572	$15,949	$15,927	$13,826	$13,805	$13,785	$13,772	$13,759	$10,197

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

Table 1.2-11 Costs for Full Electric Vehicle Technology with 100 Mile Range, or EV100 (2009$)

Vehicle Class	Applied WR	Net WR	2017	2018	2019	2020	2021	2022	2023	2024	2025
Subcompact	10%	4%	$18,157	$15,513	$15,502	$13,385	$13,375	$13,365	$13,359	$13,352	$9,850

Subcompact	15%	9%	$17,733	$15,135	$15,126	$13,046	$13,038	$13,031	$13,025	$13,021	$9,596
Subcompact	20%	14%	$17,309	$14,757	$14,750	$12,707	$12,702	$12,696	$12,692	$12,689	$9,343
Small car	10%	5%	$20,332	$17,433	$17,412	$15,090	$15,071	$15,052	$15,040	$15,028	$11,122
Small car	15%	10%	$19,775	$16,939	$16,922	$14,650	$14,633	$14,617	$14,607	$14,596	$10,793
Small car	20%	15%	$19,219	$16,446	$16,431	$14,210	$14,196	$14,182	$14,173	$14,165	$10,464
Large car	10%	5%	$24,009	$20,660	$20,626	$17,942	$17,910	$17,879	$17,858	$17,839	$13,244
Large car	15%	10%	$23,170	$19,911	$19,881	$17,269	$17,242	$17,215	$17,198	$17,181	$12,740
Large car	20%	15%	$22,331	$19,161	$19,136	$16,597	$16,574	$16,552	$16,537	$16,523	$12,236
Minivan	10%	4%	$24,740	$21,235	$21,207	$18,398	$18,372	$18,346	$18,330	$18,314	$13,566
Minivan	15%	9%	$24,070	$20,634	$20,610	$17,857	$17,835	$17,813	$17,799	$17,785	$13,160
Minivan	20%	14%	$23,400	$20,032	$20,013	$17,316	$17,298	$17,280	$17,269	$17,257	$12,754
Small truck	10%	2%	$24,324	$20,938	$20,902	$18,189	$18,155	$18,123	$18,102	$18,081	$13,428
Small truck	15%	7%	$23,698	$20,378	$20,346	$17,686	$17,656	$17,627	$17,608	$17,590	$13,051
Small truck	20%	12%	$23,072	$19,818	$19,790	$17,183	$17,157	$17,131	$17,115	$17,098	$12,674

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

Table 1.2-12 Costs for Full Electric Vehicle Technology with 150 Mile Range, or EV150 (2009$)

Vehicle Class	Applied WR	Net WR	2017	2018	2019	2020	2021	2022	2023	2024	2025
Subcompact	20%	2%	$23,714	$20,242	$20,230	$17,450	$17,439	$17,428	$17,421	$17,414	$12,836
Small car	20%	3%	$26,621	$22,785	$22,763	$19,691	$19,671	$19,651	$19,639	$19,626	$14,502
Large car	20%	2%	$32,589	$27,974	$27,936	$24,239	$24,204	$24,170	$24,148	$24,127	$17,873
Minivan	20%	2%	$34,229	$29,311	$29,281	$25,342	$25,315	$25,288	$25,270	$25,253	$18,668
Small truck	20%	0%	$33,589	$28,831	$28,793	$24,980	$24,944	$24,910	$24,887	$24,865	$18,419

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

Table1.2-13 Costs for EV/PHEV In-home Chargers (2009$)

Technology	Vehicle Class	2017	2018	2019	2020	2021	2022	2023	2024	2025
PHEV20 Charger	All	$78	$65	$65	$55	$55	$55	$55	$55	$41
PHEV40 Charger	Subcompact	$410	$344	$344	$291	$291	$291	$291	$291	$214
	Small car	$476	$399	$399	$338	$338	$338	$338	$338	$249
	Larger car Minivan Small truck	$521	$437	$437	$369	$369	$369	$369	$369	$272
EV Charger	All	$521	$437	$437	$369	$369	$369	$369	$369	$272
Charger labor	All	$1,009	$1,009	$1,009	$1,009	$1,009	$1,009	$1,009	$1,009	$1,009

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 1.2-14 Costs for 10% and 20% Weight Reduction for the 19 Vehicle Types[a] (2009$)

Vehicle Type	Base Weight	Applied WR	2017	2018	2019	2020	2021	2022	2023	2024	2025
1	2615	10%	$141	$137	$128	$125	$122	$119	$117	$115	$113
		20%	$628	$614	$600	$587	$574	$561	$553	$545	$495
2	2907	10%	$156	$153	$143	$139	$136	$132	$130	$128	$126
		20%	$698	$683	$667	$653	$638	$624	$615	$606	$550
3	3316	10%	$178	$174	$163	$159	$155	$151	$148	$146	$144
		20%	$797	$779	$761	$744	$728	$712	$702	$692	$627
4	3357	10%	$181	$176	$165	$161	$157	$153	$150	$148	$145
		20%	$807	$788	$771	$754	$737	$721	$710	$700	$635
5	3711	10%	$200	$195	$182	$178	$173	$169	$166	$163	$161
		20%	$892	$872	$852	$833	$815	$797	$785	$774	$702
6	4007	10%	$215	$210	$197	$192	$187	$182	$179	$176	$173
		20%	$963	$941	$920	$899	$880	$860	$848	$836	$758
7	3535	10%	$190	$185	$173	$169	$165	$161	$158	$156	$153
		20%	$849	$830	$812	$793	$776	$759	$748	$737	$669
8	3845	10%	$207	$202	$189	$184	$179	$175	$172	$169	$166
		20%	$924	$903	$883	$863	$844	$826	$814	$802	$727
9	4398	10%	$237	$231	$216	$210	$205	$200	$197	$194	$190
		20%	$1,057	$1,033	$1,010	$987	$965	$944	$931	$917	$832
10	4550	10%	$245	$239	$223	$218	$212	$207	$204	$200	$197
		20%	$1,093	$1,069	$1,045	$1,021	$999	$977	$963	$949	$861
11	4784	10%	$257	$251	$235	$229	$223	$218	$214	$211	$207
		20%	$1,149	$1,123	$1,098	$1,074	$1,050	$1,027	$1,012	$998	$905
12	4162	10%	$224	$218	$204	$199	$194	$189	$186	$183	$180
		20%	$1,000	$977	$955	$934	$914	$894	$881	$868	$787
13	5169	10%	$278	$271	$254	$247	$241	$235	$231	$227	$224
		20%	$1,242	$1,214	$1,187	$1,160	$1,135	$1,110	$1,094	$1,078	$978
14	5020	10%	$270	$263	$246	$240	$234	$228	$225	$221	$217
		20%	$1,206	$1,179	$1,153	$1,127	$1,102	$1,078	$1,062	$1,047	$949
15	3598	10%	$193	$189	$177	$172	$168	$164	$161	$158	$156
		20%	$865	$845	$826	$808	$790	$773	$761	$750	$680
16	4389	10%	$236	$230	$215	$210	$205	$200	$196	$193	$190
		20%	$1,055	$1,031	$1,008	$985	$964	$942	$929	$915	$830
17	5271	10%	$283	$277	$259	$252	$246	$240	$236	$232	$228
		20%	$1,267	$1,238	$1,210	$1,183	$1,157	$1,132	$1,115	$1,099	$997
18	4251	10%	$229	$223	$209	$203	$198	$193	$190	$187	$184
		20%	$1,021	$998	$976	$954	$933	$913	$900	$887	$804
19	5269	10%	$283	$276	$258	$252	$246	$240	$236	$232	$228
		20%	$1,266	$1,237	$1,210	$1,183	$1,157	$1,131	$1,115	$1,099	$996

[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 1.2-15 through Table 1.2-19 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 1.2-15 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 applicable)	n.a.	6.5	6.0	4.7	5.7
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 1.2-16 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 1.2-17 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 1.2-18 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 1.2-19 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 often be simply 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 draft joint TSD.

As was done in the 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 this analysis, EPA has used the same 19 vehicle types that were used in the 2010 TAR. 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 seven vehicle classes: Subcompact, Small car, Large car, Minivan, Minivan with towing, Small truck, and Large truck. Note that, for the current assessment and representing an update since the 2010 TAR, EPA has created a new vehicle class called “minivan-towing” or a minivan (or MPV or Multi-Purpose Vehicle) with towing capability (as defined below) which allows for greater differentiation of costs for this popular class of vehicles (such as the Ford Edge, Honda Odyssey, Jeep Grand Cherokee).[B] Note also that our seven 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 our “Minivan” and “Minivan-towing” vehicle classes. We are not attempting to inappropriately mix minivans with SUVs or equating the two in terms of features and utility, but we are grouping them with respect to technology effectiveness and some technology costs. The seven 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 minivan-towing 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 minivan-towing 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 Table1.2-13 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—smaller footprints for smaller vehicles and larger footprints for larger vehicles—which served as the basis for the 2012-2016 GHG standards and the standards in this proposal. 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.

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	1.5L 4V DOHC I4	4sp AT	Subcompact	Subcompact car I4	Ford Focus, Chevy Aveo, Honda Fit	No
2	2.4L 4V DOHC I4	4sp AT	Small car	Compact car I4	Chevy Cobalt, Honda Civic, Mazda	No

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[B] Note the distinction between “vehicle type” and “vehicle class.” We have the same 19 vehicle types as were used in the 2010 TAR but have added a 7th vehicle class where the TAR used six.

					3	
3	2.4L 4V DOHC I4	4sp AT	Small car	Midsize car/Small MPV I4	Ford Fusion, Honda Accord, Toyota Camry	No
4	3.0L 4V DOHC V6	4sp AT	Minivan	Compact car/Small MPV V6	Dodge Caliber, Subaru Impreza, VW Jetta	No
5	3.3L 4V DOHC V6	4sp AT	Large car	Midsize/Large car V6	Dodge Avenger, Ford Fusion, Honda Accord	No
6	4.5L 4V DOHC V8	4sp AT	Large car	Midsize car/Large car V8	BMW 750, Ford Mustang, Cadillac STS	No
7	2.6L 4V DOHC I4 (I5)	4sp AT	Minivan	Midsize MPV/Small truck I4	Jeep Compass, Ford Escape, Nissan Rogue	No
8	3.7L 2V SOHC V6	4sp AT	Small truck	Midsize MPV/Small truck V6	Jeep Liberty, Ford Ranger	No
9	4.0L 2V SOHC V6	4sp AT	Minivan-towing	Large MPV V6	Dodge Durango, Jeep Commander, Ford Explorer	Yes
10	4.7L 2V SOHC V8	4sp AT	Minivan-towing	Large MPV V8	Dodge Durango, Jeep Grand Cherokee, Ford F150	Yes
11	4.2L 2V SOHC V6	4sp AT	Large truck	Large truck/van V6	Dodge Ram 1500, Ford F150	Yes
12	3.8L 2V OHV V6	4sp AT	Large truck	Large truck/MPV V6	Chrysler Town & Country, Chevy Silverado	Yes
13	5.7L 2V OHV V8	4sp AT	Large truck	Large truck/van V8	Dodge Ram 1500, Chevy Silverado	Yes
14	5.4L 3V SOHC V8	4sp AT	Large truck	Large truck/van V8	Ford Explorer, Ford F150	Yes
15	5.7L 2V OHV V8	4sp AT	Large car	Large car V8	Chrysler 300, Chevy Corvette	No
16	3.5L 4V DOHC V6	4sp AT	Minivan-towing	Large MPV V6	Ford Edge, Chevy Equinox, Honda Odyssey	Yes
17	4.6L 4V DOHC V8	4sp AT	Minivan-towing	Large MPV V8	Jeep Grand Cherokee, Nissan Armada, VW Touareg	Yes
18	4.0L 4V DOHC V6	4sp AT	Large truck	Large truck/van V6	Ford F150, Nissan Frontier, Toyota Tacoma	Yes
19	5.6L 4V DOHC V8	4sp AT	Large truck	Large truck/van V8	Nissan Titan, Toyota Tundra	Yes

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 refer 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 in an effort 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-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 2017-2025 reference case (i.e., the fleet as it is expected to exist as a result of the 2012-2016 final rule which serves as the starting point for the larger analysis supporting this proposal). But again, the discussion here is focused solely on building packages. Therefore, while the baseline vehicle that defines the vehicle type is relevant, the baseline and reference case fleets of real vehicles are relevant to the discussion presented later in Chapter 3 of this draft 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 most minivan 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 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

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[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 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. As a result of the discretization of our vehicle types, we believe that some towing vehicle models have been mapped into non-towing vehicle types while some non-towing vehicle models may have been mapped into towing vehicle types. One prime example is the Ford Escape mentioned above. We have mapped all Escapes into non-towing vehicle types. This is done because the primary driver behind the vehicle type into which a vehicle is mapped is 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 would put Atkinson-HEVs on some vehicle models that are 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 have been mapped into a non-towing vehicle type even though they may be towing vehicles (the right column). The table also shows some vehicle models that have been mapped into a towing vehicle type even though they may not be towing vehicles (the left column). The vehicles in the right column may experience some loss of towing 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 may, when converted to HEV, be costlier and slightly less effective (less CO2 reduction) since they would be converted to turbocharged/downsized HEVs rather than Atkinson-HEVs. Accurate data on towing specification is difficult to find, we hope to have better data on towing capacity for the final rule analysis and may create new vehicle types to more properly model towing and non-towing vehicles.

[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

Non-towing vehicles mapped into towing vehicle types	Towing vehicles mapped into non-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

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 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 towing trips. As such, we believe that the buyers will experience no practical loss of utility.

To prepare inputs for the OMEGA model, EPA builds a “master-set” of technology packages. The master-set of packages for each vehicle type are meant to reflect the most likely technology packages manufacturers would consider when determining their plans for complying with future standards. In other words, they are meant to reflect the most cost effective groups of technologies—those that provide the best trade-off of costs versus fuel consumption improvements. This is done by grouping reasonable technologies in all possible permutations and 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 presuming that auto makers would first concentrate efforts on conventional gasoline engine and transmission technologies paired with some level of mass reduction to improve fuel consumption. Mass reduction varied from no mass reduction up to 20 percent as the maximum considered in this analysis.[E]

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 draft RIA and the OMEGA model phase-in caps are shown in Chapter 3.5 of the joint TSD.

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 draft 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 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.[F]

[E] 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 proposed 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 draft RIA.

[F] 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 and to increase their costs since heavier batteries and motors are now part of the packages.

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 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 14 primary categories of conventional gasoline engine technologies. These are:

1. Our "anytime technologies" (ATT).[G] These consist of low friction lubes, engine friction reduction, aggressive shift logic, early torque converter lock-up (automatic transmission only). ATT is broken into two levels:

    - ATT, which consists of our first level of low friction lubes, engine friction reduction, aggressive shift logic, early torque converter lock-up (automatic transmission only) and low drag brakes.

    - ATT2, which consists of our second level of low friction lubes and engine friction reduction (collectively referred to as EFR2), aggressive shift logic, along with the same early torque converter lock-up (automatic transmission only) and low drag brakes that are part of ATT.

2. Our "Other" conventional technologies. These consist of improved accessories, electric power steering (EPS) or electrohydraulic power steering (EHPS, used for large trucks), aerodynamic improvements and lower rolling resistance tires. The "other" technology category is broken into two levels:

[G] 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. This grouping also serves to minimize the number of packages to be considered in our modeling process. As explained in the text, we have built roughly 40,000 packages. Grouping the anytime and other technologies together and treating them, essentially, as four technologies (ATT, ATT2, Other1, Other2) when building packages helps to keep the number of packages lower. If we considered each "anytime" and "other" technology separately, we would have had to build well over 200,000 packages which becomes unworkable given the analytical tools at our disposal.

- Other1, which consists of our first level of improved accessories, our first level of aerodynamic improvements and our first level of lower rolling resistance tires along with EPS/EHPS. This category also includes the high efficiency gearbox technology (HEG).

- Other2, which consists of our second levels of improved accessories, aerodynamic improvements and lower rolling resistance tires along with the same EPS/EHPS and HEG that are part of Other1.

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

4. Variable valve lift (VVL) consisting of discrete variable valve lift (DVVL, for DOHC engines)

5. Cylinder deactivation (Deac, considered for OHV and SOHC engines)

6. Gasoline direct injection (GDI)

7. Turbocharging and downsizing (TDS, which always includes a conversion to GDI) with and without cooled EGR. Note that 27 bar BMEP engines must include the addition of cooled EGR in our analysis.

8. Stop-start

9. Secondary axle disconnect (SAX)

10. Conversion to advance 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.

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

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

12. 6 and 8 speed automatic transmissions (6sp AT/8sp AT)

13. 6 and 8 speed dual clutch transmissions with wet clutch (6sp wet-DCT/8sp wet-DCT)

14. 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 proposed 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. Unlike the TAR analysis, we have limited towing vehicle types to use of automatic transmissions (both 6 and 8 speed). Like 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 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 type 4 and only in packages with 20% weight reduction applied. Only then was this vehicle type light enough to add the dry-DCT.

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 (as 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. This discrepancy is one justification for the adjustment to the 2017-2025 truck curves (in comparison to the 2012-2016 curves) as described in Chapter 2 of the draft joint TSD and in preamble Section III.D.6.b.[H]

[H] While it's also offset by more mass reduction capability on these vehicles, the curve analysis did not assume an uneven distribution of mass reduction throughout the fleet.

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	Subcompact	I4	2615	6/8 speed dry-DCT				
2	Small car	I4	2907	6/8 speed dry-DCT				
3	Small car	I4	3316	6/8 speed dry-DCT				
4	Minivan	V6	3357	6/8 speed wet-DCT				6/8 speed dry-DCT
5	Large car	V6	3711	6/8 speed wet-DCT				
6	Large car	V8	4007	6/8 speed wet-DCT				
7	Minivan	I4	3535	6/8 speed dry-DCT				
8	Small truck	V6	3845	6/8 speed wet-DCT				
9	Minivan-towing	V6	4398	6/8 speed AT				
10	Minivan-towing	V8	4550	6/8 speed AT				
11	Large truck	V6	4784	6/8 speed AT				
12	Large truck	V6	4162	6/8 speed AT				
13	Large truck	V8	5169	6/8 speed AT				
14	Large truck	V8	5020	6/8 speed AT				
15	Large car	V8	3598	6/8 speed wet-DCT				
16	Minivan-towing	V6	4389	6/8 speed AT				
17	Minivan-towing	V8	5271	6/8 speed AT				
18	Large truck	V6	4251	6/8 speed AT				
19	Large truck	V8	5269	6/8 speed AT				

For example, vehicle type 4 is equipped with a 4 speed automatic transmission in the baseline. In a package consisting of a 0% to 15% mass reduction, we believe this vehicle type could convert to a wet-DCT because the lighter weight results in reduced low end torque demand thus making the wet-DCT feasible. Upon reaching 20% mass reduction, the vehicle type could employ a dry-DCT because the even lighter weight (3357 less 20% equals 2686 pounds, which is less than our 2800 pound cutoff) results in further reduction in low end torque demand.

We start by first building a “preliminary-set” of non-electrified (i.e., gasoline and diesel) packages for each vehicle type consisting of nearly every combination of each of the 14 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 ATT but no weight reduction or transmission changes. We then add Other1 (less HEG), again with no weight reduction or transmission changes (we do not consider the addition of HEG without a simultaneous improvement in the transmission itself). The next package would add HEG and a transmission improvement. The subsequent packages would iterate on nearly all possible combinations with the result being just under 2000 packages per vehicle type. Table 1.3-4 shows a subset of packages built for vehicle type 5, a midsized/large car with a 3.3L 4 valve DOHC V6 in the baseline. These are package 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 non-electrified packages built for vehicle type 5.

Table 1.3-4 A Subset of 2025 MY Non-HEV/PHEV/EV Packages Built for Vehicle Type 5 (Midsize/Large car 3.3L DOHC V6)[a]

Prelim Pkg #	Weight rdxn	Package contents	Transmission	2025MY Cost	CO2%
50000	base	3.3L 4V DOHC V6	4sp AT	$0	0%
50001	base	4V DOHC V6 +LUB+EFR1+LDB+ASL	4sp AT	$184	7%
50002	base	4V DOHC V6 +LUB+EFR1+LDB+ASL+IACC+EPS+Aero1+LRRT1	4sp AT	$394	13%
50395[b]	5%	4V DOHC V6 +LUB+EFR1+LDB+ASL+IACC+EPS+Aero1+LRRT1+HEG	6sp DCT-wet	$558	24%
50396	5%	4V DOHC V6 +LUB+EFR1+LDB+ASL+IACC+EPS+Aero1+LRRT1+HEG+ DCP	6sp DCT-wet	$723	27%
50397	5%	4V DOHC V6 +LUB+EFR1+LDB+ASL+IACC+EPS+Aero1+LRRT1+HEG+DCP+DVVL	6sp DCT-wet	$913	29%
50398	5%	4V DOHC V6 +LUB+EFR1+LDB+ASL+IACC+EPS+Aero1+LRRT1+HEG+DCP+GDI	6sp DCT-wet	$1,060	28%
50399	5%	4V DOHC V6 +LUB+EFR1+LDB+ASL+IACC+EPS+Aero1+LRRT1+HEG+DCP+DVVL+GDI	6sp DCT-wet	$1,250	30%
50400	5%	4V DOHC V6 +LUB+EFR1+LDB+ASL+IACC+EPS+Aero1+LRRT1+HEG+ DCP+SS	6sp DCT-wet	$1,066	28%
50401	5%	4V DOHC V6 +LUB+EFR1+LDB+ASL+IACC+EPS+Aero1+LRRT1+HEG+DCP+DVVL+SS	6sp DCT-wet	$1,256	30%
50402	5%	4V DOHC V6 +LUB+EFR1+LDB+ASL+IACC+EPS+Aero1+LRRT1+HEG+DCP+GDI+SS	6sp DCT-wet	$1,404	29%
50403	5%	4V DOHC V6 +LUB+EFR1+LDB+ASL+IACC+EPS+Aero1+LRRT1+HEG+DCP+DVVL+GDI+SS	6sp DCT-wet	$1,593	31%
50404	5%	4V DOHC V6 +LUB+EFR1+LDB+ASL+IACC+EPS+Aero1+LRRT1+HEG+DCP+SAX	6sp DCT-wet	$804	27%
50405	5%	4V DOHC V6 +LUB+EFR1+LDB+ASL+IACC+EPS+Aero1+LRRT1+HEG+DCP+DVVL+SAX	6sp DCT-wet	$993	29%
50406	5%	4V DOHC V6 +LUB+EFR1+LDB+ASL+IACC+EPS+Aero1+LRRT1+HEG+DCP+GDI+SAX	6sp DCT-wet	$1,141	28%
50407	5%	4V DOHC V6 +LUB+EFR1+LDB+ASL+IACC+EPS+Aero1+LRRT1+HEG+DCP+DVVL+GDI+SAX	6sp DCT-wet	$1,331	30%
50408	5%	4V DOHC V6 +LUB+EFR1+LDB+ASL+IACC+EPS+Aero1+LRRT1+HEG+DCP+SS+SAX	6sp DCT-wet	$1,147	28%
50409	5%	4V DOHC V6 +LUB+EFR1+LDB+ASL+IACC+EPS+Aero1+LRRT1+HEG+DCP+DVVL+SS+SAX	6sp DCT-wet	$1,337	30%
50410	5%	4V DOHC V6 +LUB+EFR1+LDB+ASL+IACC+EPS+Aero1+LRRT1+HEG+DCP+GDI+SS+SAX	6sp DCT-wet	$1,484	30%
50411	5%	4V DOHC V6 +LUB+EFR1+LDB+ASL+IACC+EPS+Aero1+LRRT1+HEG+DCP+DVVL+GDI+SS+SAX	6sp DCT-wet	$1,674	31%
50412	5%	4V DOHC I4 +LUB+EFR1+LDB+ASL+IACC+EPS+Aero1+LRRT1+HEG+DCP+GDI+TDS18	6sp DCT-wet	$998	34%
50413	5%	4V DOHC I4 +LUB+EFR1+LDB+ASL+IACC+EPS+Aero1+LRRT1+HEG+DCP+DVVL+GDI+TDS18	6sp DCT-wet	$1,129	35%
50414	5%	4V DOHC I4	6sp DCT-wet	$1,341	35%

		+LUB+EFR1+LDB+ASL+IACC+EPS+Aero1+LRRT1+HEG+ DCP+GDI+SS+TDS18			
50415	5%	4V DOHC I4 +LUB+EFR1+LDB+ASL+IACC+EPS+Aero1+LRRT1+HEG+ DCP+DVVL+GDI+SS+TDS18	6sp DCT-wet	$1,472	36%
50416	5%	4V DOHC I4 +LUB+EFR1+LDB+ASL+IACC+EPS+Aero1+LRRT1+HEG+ DCP+GDI+SAX+TDS18	6sp DCT-wet	$1,079	35%
50417	5%	4V DOHC I4 +LUB+EFR1+LDB+ASL+IACC+EPS+Aero1+LRRT1+HEG+ DCP+DVVL+GDI+SAX+TDS18	6sp DCT-wet	$1,210	36%
50418	5%	4V DOHC I4 +LUB+EFR1+LDB+ASL+IACC+EPS+Aero1+LRRT1+HEG+ DCP+GDI+SS+SAX+TDS18	6sp DCT-wet	$1,422	36%
50419	5%	4V DOHC I4 +LUB+EFR1+LDB+ASL+IACC+EPS+Aero1+LRRT1+HEG+ DCP+DVVL+GDI+SS+SAX+TDS18	6sp DCT-wet	$1,553	36%
50420	5%	4V DOHC I4 +LUB+EFR1+LDB+ASL+IACC+EPS+Aero1+LRRT1+HEG+ DCP+GDI+TDS24	6sp DCT-wet	$1,210	37%
50421	5%	4V DOHC I4 +LUB+EFR1+LDB+ASL+IACC+EPS+Aero1+LRRT1+HEG+ DCP+DVVL+GDI+TDS24	6sp DCT-wet	$1,341	37%
50422	5%	4V DOHC I4 +LUB+EFR1+LDB+ASL+IACC+EPS+Aero1+LRRT1+HEG+ DCP+GDI+SS+TDS24	6sp DCT-wet	$1,554	38%
50423	5%	4V DOHC I4 +LUB+EFR1+LDB+ASL+IACC+EPS+Aero1+LRRT1+HEG+ DCP+DVVL+GDI+SS+TDS24	6sp DCT-wet	$1,685	38%
50424	5%	4V DOHC I4 +LUB+EFR1+LDB+ASL+IACC+EPS+Aero1+LRRT1+HEG+ DCP+GDI+SAX+TDS24	6sp DCT-wet	$1,291	38%
50425	5%	4V DOHC I4 +LUB+EFR1+LDB+ASL+IACC+EPS+Aero1+LRRT1+HEG+ DCP+DVVL+GDI+SAX+TDS24	6sp DCT-wet	$1,422	38%
50426	5%	4V DOHC I4 +LUB+EFR1+LDB+ASL+IACC+EPS+Aero1+LRRT1+HEG+ DCP+GDI+SS+SAX+TDS24	6sp DCT-wet	$1,634	38%
50427	5%	4V DOHC I4 +LUB+EFR1+LDB+ASL+IACC+EPS+Aero1+LRRT1+HEG+ DCP+DVVL+GDI+SS+SAX+TDS24	6sp DCT-wet	$1,765	38%
50428	5%	4V DOHC V6 +EFR2+LDB+ASL2+IACC+EPS+Aero1+LRRT1+HEG	6sp DCT-wet	$646	27%
50429	5%	4V DOHC V6 +EFR2+LDB+ASL2+IACC+EPS+Aero1+LRRT1+HEG+ DCP	6sp DCT-wet	$810	30%
50430	5%	4V DOHC V6 +EFR2+LDB+ASL2+IACC+EPS+Aero1+LRRT1+HEG+ DCP+DVVL	6sp DCT-wet	$1,000	32%
50431	5%	4V DOHC V6 +EFR2+LDB+ASL2+IACC+EPS+Aero1+LRRT1+HEG+ DCP+GDI	6sp DCT-wet	$1,148	31%
50432	5%	4V DOHC V6 +EFR2+LDB+ASL2+IACC+EPS+Aero1+LRRT1+HEG+ DCP+DVVL+GDI	6sp DCT-wet	$1,338	33%
50433	5%	4V DOHC V6 +EFR2+LDB+ASL2+IACC+EPS+Aero1+LRRT1+HEG+ DCP+SS	6sp DCT-wet	$1,153	31%
50434	5%	4V DOHC V6 +EFR2+LDB+ASL2+IACC+EPS+Aero1+LRRT1+HEG+ DCP+DVVL+SS	6sp DCT-wet	$1,343	33%
50435	5%	4V DOHC V6 +EFR2+LDB+ASL2+IACC+EPS+Aero1+LRRT1+HEG+ DCP+GDI+SS	6sp DCT-wet	$1,491	32%
50436	5%	4V DOHC V6 +EFR2+LDB+ASL2+IACC+EPS+Aero1+LRRT1+HEG+ DCP+DVVL+GDI+SS	6sp DCT-wet	$1,681	34%
50437	5%	4V DOHC V6 +EFR2+LDB+ASL2+IACC+EPS+Aero1+LRRT1+HEG+ DCP+SAX	6sp DCT-wet	$891	31%
50438	5%	4V DOHC V6 +EFR2+LDB+ASL2+IACC+EPS+Aero1+LRRT1+HEG+ DCP+DVVL+SAX	6sp DCT-wet	$1,081	33%
50439	5%	4V DOHC V6 +EFR2+LDB+ASL2+IACC+EPS+Aero1+LRRT1+HEG+ DCP+GDI+SAX	6sp DCT-wet	$1,228	32%
50440	5%	4V DOHC V6 +EFR2+LDB+ASL2+IACC+EPS+Aero1+LRRT1+HEG+ DCP+DVVL+GDI+SAX	6sp DCT-wet	$1,418	34%
50441	5%	4V DOHC V6 +EFR2+LDB+ASL2+IACC+EPS+Aero1+LRRT1+HEG+ DCP+SS+SAX	6sp DCT-wet	$1,234	32%

50442	5%	4V DOHC V6 +EFR2+LDB+ASL2+IACC+EPS+Aero1+LRRT1+HEG+ DCP+DVVL+SS+SAX	6sp DCT-wet	$1,424	34%
50443	5%	4V DOHC V6 +EFR2+LDB+ASL2+IACC+EPS+Aero1+LRRT1+HEG+ DCP+GDI+SS+SAX	6sp DCT-wet	$1,571	33%
50444	5%	4V DOHC V6 +EFR2+LDB+ASL2+IACC+EPS+Aero1+LRRT1+HEG+ DCP+DVVL+GDI+SS+SAX	6sp DCT-wet	$1,761	35%
50445	5%	4V DOHC I4 +EFR2+LDB+ASL2+IACC+EPS+Aero1+LRRT1+HEG+ DCP+GDI+TDS18	6sp DCT-wet	$1,058	37%
50446	5%	4V DOHC I4 +EFR2+LDB+ASL2+IACC+EPS+Aero1+LRRT1+HEG+ DCP+DVVL+GDI+TDS18	6sp DCT-wet	$1,189	38%
50447	5%	4V DOHC I4 +EFR2+LDB+ASL2+IACC+EPS+Aero1+LRRT1+HEG+ DCP+GDI+SS+TDS18	6sp DCT-wet	$1,401	38%
50448	5%	4V DOHC I4 +EFR2+LDB+ASL2+IACC+EPS+Aero1+LRRT1+HEG+ DCP+DVVL+GDI+SS+TDS18	6sp DCT-wet	$1,532	39%
50449	5%	4V DOHC I4 +EFR2+LDB+ASL2+IACC+EPS+Aero1+LRRT1+HEG+ DCP+GDI+SAX+TDS18	6sp DCT-wet	$1,138	38%
50450	5%	4V DOHC I4 +EFR2+LDB+ASL2+IACC+EPS+Aero1+LRRT1+HEG+ DCP+DVVL+GDI+SAX+TDS18	6sp DCT-wet	$1,269	39%
50451	5%	4V DOHC I4 +EFR2+LDB+ASL2+IACC+EPS+Aero1+LRRT1+HEG+ DCP+GDI+SS+SAX+TDS18	6sp DCT-wet	$1,481	39%
50452	5%	4V DOHC I4 +EFR2+LDB+ASL2+IACC+EPS+Aero1+LRRT1+HEG+ DCP+DVVL+GDI+SS+SAX+TDS18	6sp DCT-wet	$1,612	39%
50453	5%	4V DOHC I4 +EFR2+LDB+ASL2+IACC+EPS+Aero1+LRRT1+HEG+ DCP+GDI+TDS24	6sp DCT-wet	$1,270	40%
50454	5%	4V DOHC I4 +EFR2+LDB+ASL2+IACC+EPS+Aero1+LRRT1+HEG+ DCP+DVVL+GDI+TDS24	6sp DCT-wet	$1,401	40%
50455	5%	4V DOHC I4 +EFR2+LDB+ASL2+IACC+EPS+Aero1+LRRT1+HEG+ DCP+GDI+SS+TDS24	6sp DCT-wet	$1,613	40%
50456	5%	4V DOHC I4 +EFR2+LDB+ASL2+IACC+EPS+Aero1+LRRT1+HEG+ DCP+DVVL+GDI+SS+TDS24	6sp DCT-wet	$1,744	41%
50457	5%	4V DOHC I4 +EFR2+LDB+ASL2+IACC+EPS+Aero1+LRRT1+HEG+ DCP+GDI+SAX+TDS24	6sp DCT-wet	$1,351	40%
50458	5%	4V DOHC I4 +EFR2+LDB+ASL2+IACC+EPS+Aero1+LRRT1+HEG+ DCP+DVVL+GDI+SAX+TDS24	6sp DCT-wet	$1,482	40%
50459	5%	4V DOHC I4 +EFR2+LDB+ASL2+IACC+EPS+Aero1+LRRT1+HEG+ DCP+GDI+SS+SAX+TDS24	6sp DCT-wet	$1,694	41%
50460	5%	4V DOHC I4 +EFR2+LDB+ASL2+IACC+EPS+Aero1+LRRT1+HEG+ DCP+DVVL+GDI+SS+SAX+TDS24	6sp DCT-wet	$1,825	41%
50461	5%	4V DOHC V6 +LUB+EFR1+LDB+ASL+IACC2+EPS+Aero2+LRRT2+HEG	6sp DCT-wet	$772	29%
50462	5%	4V DOHC V6 +LUB+EFR1+LDB+ASL+IACC2+EPS+Aero2+LRRT2+HEG+ DCP	6sp DCT-wet	$937	31%
50463	5%	4V DOHC V6 +LUB+EFR1+LDB+ASL+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+DVVL	6sp DCT-wet	$1,127	33%
50464	5%	4V DOHC V6 +LUB+EFR1+LDB+ASL+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+GDI	6sp DCT-wet	$1,274	32%
50465	5%	4V DOHC V6 +LUB+EFR1+LDB+ASL+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+DVVL+GDI	6sp DCT-wet	$1,464	34%
50466	5%	4V DOHC V6 +LUB+EFR1+LDB+ASL+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+SS	6sp DCT-wet	$1,280	32%
50467	5%	4V DOHC V6 +LUB+EFR1+LDB+ASL+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+DVVL+SS	6sp DCT-wet	$1,470	34%
50468	5%	4V DOHC V6 +LUB+EFR1+LDB+ASL+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+GDI+SS	6sp DCT-wet	$1,618	33%
50469	5%	4V DOHC V6 +LUB+EFR1+LDB+ASL+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+DVVL+GDI+SS	6sp DCT-wet	$1,807	35%
50470	5%	4V DOHC V6 +LUB+EFR1+LDB+ASL+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+SAX	6sp DCT-wet	$1,017	32%
50471	5%	4V DOHC V6 +LUB+EFR1+LDB+ASL+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+DVVL+SAX	6sp DCT-wet	$1,207	33%

50472	5%	4V DOHC V6 +LUB+EFR1+LDB+ASL+IACC2+EPS+Aero2+LRRT2+HEG+DCP+GDI+SAX	6sp DCT-wet	$1,355	33%
50473	5%	4V DOHC V6 +LUB+EFR1+LDB+ASL+IACC2+EPS+Aero2+LRRT2+HEG+DCP+DVVL+GDI+SAX	6sp DCT-wet	$1,545	34%
50474	5%	4V DOHC V6 +LUB+EFR1+LDB+ASL+IACC2+EPS+Aero2+LRRT2+HEG+DCP+SS+SAX	6sp DCT-wet	$1,361	33%
50475	5%	4V DOHC V6 +LUB+EFR1+LDB+ASL+IACC2+EPS+Aero2+LRRT2+HEG+DCP+DVVL+SS+SAX	6sp DCT-wet	$1,550	34%
50476	5%	4V DOHC V6 +LUB+EFR1+LDB+ASL+IACC2+EPS+Aero2+LRRT2+HEG+DCP+GDI+SS+SAX	6sp DCT-wet	$1,698	34%
50477	5%	4V DOHC V6 +LUB+EFR1+LDB+ASL+IACC2+EPS+Aero2+LRRT2+HEG+DCP+DVVL+GDI+SS+SAX	6sp DCT-wet	$1,888	35%
50478	5%	4V DOHC I4 +LUB+EFR1+LDB+ASL+IACC2+EPS+Aero2+LRRT2+HEG+DCP+GDI+TDS18	6sp DCT-wet	$1,212	38%
50479	5%	4V DOHC I4 +LUB+EFR1+LDB+ASL+IACC2+EPS+Aero2+LRRT2+HEG+DCP+DVVL+GDI+TDS18	6sp DCT-wet	$1,343	39%
50480	5%	4V DOHC I4 +LUB+EFR1+LDB+ASL+IACC2+EPS+Aero2+LRRT2+HEG+DCP+GDI+SS+TDS18	6sp DCT-wet	$1,555	39%
50481	5%	4V DOHC I4 +LUB+EFR1+LDB+ASL+IACC2+EPS+Aero2+LRRT2+HEG+DCP+DVVL+GDI+SS+TDS18	6sp DCT-wet	$1,686	39%
50482	5%	4V DOHC I4 +LUB+EFR1+LDB+ASL+IACC2+EPS+Aero2+LRRT2+HEG+DCP+GDI+SAX+TDS18	6sp DCT-wet	$1,293	38%
50483	5%	4V DOHC I4 +LUB+EFR1+LDB+ASL+IACC2+EPS+Aero2+LRRT2+HEG+DCP+DVVL+GDI+SAX+TDS18	6sp DCT-wet	$1,424	39%
50484	5%	4V DOHC I4 +LUB+EFR1+LDB+ASL+IACC2+EPS+Aero2+LRRT2+HEG+DCP+GDI+SS+SAX+TDS18	6sp DCT-wet	$1,636	39%
50485	5%	4V DOHC I4 +LUB+EFR1+LDB+ASL+IACC2+EPS+Aero2+LRRT2+HEG+DCP+DVVL+GDI+SS+SAX+TDS18	6sp DCT-wet	$1,767	40%
50486	5%	4V DOHC I4 +LUB+EFR1+LDB+ASL+IACC2+EPS+Aero2+LRRT2+HEG+DCP+GDI+TDS24	6sp DCT-wet	$1,424	40%
50487	5%	4V DOHC I4 +LUB+EFR1+LDB+ASL+IACC2+EPS+Aero2+LRRT2+HEG+DCP+DVVL+GDI+TDS24	6sp DCT-wet	$1,555	40%
50488	5%	4V DOHC I4 +LUB+EFR1+LDB+ASL+IACC2+EPS+Aero2+LRRT2+HEG+DCP+GDI+SS+TDS24	6sp DCT-wet	$1,768	41%
50489	5%	4V DOHC I4 +LUB+EFR1+LDB+ASL+IACC2+EPS+Aero2+LRRT2+HEG+DCP+DVVL+GDI+SS+TDS24	6sp DCT-wet	$1,899	41%
50490	5%	4V DOHC I4 +LUB+EFR1+LDB+ASL+IACC2+EPS+Aero2+LRRT2+HEG+DCP+GDI+SAX+TDS24	6sp DCT-wet	$1,505	41%
50491	5%	4V DOHC I4 +LUB+EFR1+LDB+ASL+IACC2+EPS+Aero2+LRRT2+HEG+DCP+DVVL+GDI+SAX+TDS24	6sp DCT-wet	$1,636	41%
50492	5%	4V DOHC I4 +LUB+EFR1+LDB+ASL+IACC2+EPS+Aero2+LRRT2+HEG+DCP+GDI+SS+SAX+TDS24	6sp DCT-wet	$1,848	41%
50493	5%	4V DOHC I4 +LUB+EFR1+LDB+ASL+IACC2+EPS+Aero2+LRRT2+HEG+DCP+DVVL+GDI+SS+SAX+TDS24	6sp DCT-wet	$1,979	41%
50494	5%	4V DOHC V6 +EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG	6sp DCT-wet	$860	32%
50495	5%	4V DOHC V6 +EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG+ DCP	6sp DCT-wet	$1,024	35%

50496	5%	4V DOHC V6 +EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+DVVL	6sp DCT-wet	$1,214	36%
50497	5%	4V DOHC V6 +EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+GDI	6sp DCT-wet	$1,362	35%
50498	5%	4V DOHC V6 +EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+DVVL+GDI	6sp DCT-wet	$1,552	37%
50499	5%	4V DOHC V6 +EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+SS	6sp DCT-wet	$1,367	35%
50500	5%	4V DOHC V6 +EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+DVVL+SS	6sp DCT-wet	$1,557	37%
50501	5%	4V DOHC V6 +EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+GDI+SS	6sp DCT-wet	$1,705	36%
50502	5%	4V DOHC V6 +EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+DVVL+GDI+SS	6sp DCT-wet	$1,895	38%
50503	5%	4V DOHC V6 +EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+SAX	6sp DCT-wet	$1,105	35%
50504	5%	4V DOHC V6 +EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+DVVL+SAX	6sp DCT-wet	$1,295	37%
50505	5%	4V DOHC V6 +EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+GDI+SAX	6sp DCT-wet	$1,442	36%
50506	5%	4V DOHC V6 +EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+DVVL+GDI+SAX	6sp DCT-wet	$1,632	38%
50507	5%	4V DOHC V6 +EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+SS+SAX	6sp DCT-wet	$1,448	36%
50508	5%	4V DOHC V6 +EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+DVVL+SS+SAX	6sp DCT-wet	$1,638	37%
50509	5%	4V DOHC V6 +EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+GDI+SS+SAX	6sp DCT-wet	$1,785	37%
50510	5%	4V DOHC V6 +EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+DVVL+GDI+SS+SAX	6sp DCT-wet	$1,975	38%
50511	5%	4V DOHC I4 +EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+GDI+TDS18	6sp DCT-wet	$1,272	41%
50512	5%	4V DOHC I4 +EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+DVVL+GDI+TDS18	6sp DCT-wet	$1,403	41%
50513	5%	4V DOHC I4 +EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+GDI+SS+TDS18	6sp DCT-wet	$1,615	41%
50514	5%	4V DOHC I4 +EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+DVVL+GDI+SS+TDS18	6sp DCT-wet	$1,746	42%
50515	5%	4V DOHC I4 +EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+GDI+SAX+TDS18	6sp DCT-wet	$1,352	41%
50516	5%	4V DOHC I4 +EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+DVVL+GDI+SAX+TDS18	6sp DCT-wet	$1,483	42%
50517	5%	4V DOHC I4 +EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+GDI+SS+SAX+TDS18	6sp DCT-wet	$1,695	42%
50518	5%	4V DOHC I4 +EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+DVVL+GDI+SS+SAX+TDS18	6sp DCT-wet	$1,826	42%
50519	5%	4V DOHC I4 +EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+GDI+TDS24	6sp DCT-wet	$1,484	43%
50520	5%	4V DOHC I4 +EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+DVVL+GDI+TDS24	6sp DCT-wet	$1,615	43%
50521	5%	4V DOHC I4 +EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+GDI+SS+TDS24	6sp DCT-wet	$1,827	43%
50522	5%	4V DOHC I4 +EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+DVVL+GDI+SS+TDS24	6sp DCT-wet	$1,958	44%
50523	5%	4V DOHC I4 +EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+GDI+SAX+TDS24	6sp DCT-wet	$1,565	43%
50524	5%	4V DOHC I4 +EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG+	6sp DCT-wet	$1,696	43%

		DCP+DVVL+GDI+SAX+TDS24			
50525	5%	4V DOHC I4 +EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+GDI+SS+SAX+TDS24	6sp DCT-wet	$1,908	44%
50526	5%	4V DOHC I4 +EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+DVVL+GDI+SS+SAX+TDS24	6sp DCT-wet	$2,039	44%
50527	5%	4V DOHC I4 +LUB+EFR1+LDB+ASL+IACC+EPS+Aero1+LRRT1+HEG+ DCP+GDI+TDS24+EGR	6sp DCT-wet	$1,457	39%
50528	5%	4V DOHC I4 +LUB+EFR1+LDB+ASL+IACC+EPS+Aero1+LRRT1+HEG+ DCP+DVVL+GDI+TDS24+EGR	6sp DCT-wet	$1,588	39%
50529	5%	4V DOHC I4 +LUB+EFR1+LDB+ASL+IACC+EPS+Aero1+LRRT1+HEG+ DCP+GDI+SS+TDS24+EGR	6sp DCT-wet	$1,801	40%
50530	5%	4V DOHC I4 +LUB+EFR1+LDB+ASL+IACC+EPS+Aero1+LRRT1+HEG+ DCP+DVVL+GDI+SS+TDS24+EGR	6sp DCT-wet	$1,932	40%
50531	5%	4V DOHC I4 +LUB+EFR1+LDB+ASL+IACC+EPS+Aero1+LRRT1+HEG+ DCP+GDI+SAX+TDS24+EGR	6sp DCT-wet	$1,538	40%
50532	5%	4V DOHC I4 +LUB+EFR1+LDB+ASL+IACC+EPS+Aero1+LRRT1+HEG+ DCP+DVVL+GDI+SAX+TDS24+EGR	6sp DCT-wet	$1,669	40%
50533	5%	4V DOHC I4 +LUB+EFR1+LDB+ASL+IACC+EPS+Aero1+LRRT1+HEG+ DCP+GDI+SS+SAX+TDS24+EGR	6sp DCT-wet	$1,881	40%
50534	5%	4V DOHC I4 +LUB+EFR1+LDB+ASL+IACC+EPS+Aero1+LRRT1+HEG+ DCP+DVVL+GDI+SS+SAX+TDS24+EGR	6sp DCT-wet	$2,012	41%
50535	5%	4V DOHC I4 +EFR2+LDB+ASL2+IACC+EPS+Aero1+LRRT1+HEG+ DCP+GDI+TDS24+EGR	6sp DCT-wet	$1,517	42%
50536	5%	4V DOHC I4 +EFR2+LDB+ASL2+IACC+EPS+Aero1+LRRT1+HEG+ DCP+DVVL+GDI+TDS24+EGR	6sp DCT-wet	$1,648	42%
50537	5%	4V DOHC I4 +EFR2+LDB+ASL2+IACC+EPS+Aero1+LRRT1+HEG+ DCP+GDI+SS+TDS24+EGR	6sp DCT-wet	$1,860	43%
50538	5%	4V DOHC I4 +EFR2+LDB+ASL2+IACC+EPS+Aero1+LRRT1+HEG+ DCP+DVVL+GDI+SS+TDS24+EGR	6sp DCT-wet	$1,991	43%
50539	5%	4V DOHC I4 +EFR2+LDB+ASL2+IACC+EPS+Aero1+LRRT1+HEG+ DCP+GDI+SAX+TDS24+EGR	6sp DCT-wet	$1,598	42%
50540	5%	4V DOHC I4 +EFR2+LDB+ASL2+IACC+EPS+Aero1+LRRT1+HEG+ DCP+DVVL+GDI+SAX+TDS24+EGR	6sp DCT-wet	$1,729	43%
50541	5%	4V DOHC I4 +EFR2+LDB+ASL2+IACC+EPS+Aero1+LRRT1+HEG+ DCP+GDI+SS+SAX+TDS24+EGR	6sp DCT-wet	$1,941	43%
50542	5%	4V DOHC I4 +EFR2+LDB+ASL2+IACC+EPS+Aero1+LRRT1+HEG+ DCP+DVVL+GDI+SS+SAX+TDS24+EGR	6sp DCT-wet	$2,072	43%
50543	5%	4V DOHC I4 +LUB+EFR1+LDB+ASL+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+GDI+TDS24+EGR	6sp DCT-wet	$1,671	42%
50544	5%	4V DOHC I4 +LUB+EFR1+LDB+ASL+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+DVVL+GDI+TDS24+EGR	6sp DCT-wet	$1,802	42%
50545	5%	4V DOHC I4 +LUB+EFR1+LDB+ASL+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+GDI+SS+TDS24+EGR	6sp DCT-wet	$2,015	43%
50546	5%	4V DOHC I4 +LUB+EFR1+LDB+ASL+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+DVVL+GDI+SS+TDS24+EGR	6sp DCT-wet	$2,146	43%
50547	5%	4V DOHC I4 +LUB+EFR1+LDB+ASL+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+GDI+SAX+TDS24+EGR	6sp DCT-wet	$1,752	43%
50548	5%	4V DOHC I4 +LUB+EFR1+LDB+ASL+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+DVVL+GDI+SAX+TDS24+EGR	6sp DCT-wet	$1,883	43%
50549	5%	4V DOHC I4 +LUB+EFR1+LDB+ASL+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+GDI+SS+SAX+TDS24+EGR	6sp DCT-wet	$2,095	43%
50550	5%	4V DOHC I4 +LUB+EFR1+LDB+ASL+IACC2+EPS+Aero2+LRRT2+HEG+	6sp DCT-wet	$2,226	44%

		DCP+DVVL+GDI+SS+SAX+TDS24+EGR			
50551	5%	4V DOHC I4 +EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+GDI+TDS24+EGR	6sp DCT-wet	$1,731	45%
50552	5%	4V DOHC I4 +EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+DVVL+GDI+TDS24+EGR	6sp DCT-wet	$1,862	45%
50553	5%	4V DOHC I4 +EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+GDI+SS+TDS24+EGR	6sp DCT-wet	$2,074	46%
50554	5%	4V DOHC I4 +EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+DVVL+GDI+SS+TDS24+EGR	6sp DCT-wet	$2,205	46%
50555	5%	4V DOHC I4 +EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+GDI+SAX+TDS24+EGR	6sp DCT-wet	$1,811	45%
50556	5%	4V DOHC I4 +EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+DVVL+GDI+SAX+TDS24+EGR	6sp DCT-wet	$1,942	45%
50557	5%	4V DOHC I4 +EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+GDI+SS+SAX+TDS24+EGR	6sp DCT-wet	$2,155	46%
50558	5%	4V DOHC I4 +EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+DVVL+GDI+SS+SAX+TDS24+EGR	6sp DCT-wet	$2,286	46%
50559	5%	4V DOHC I4 +LUB+EFR1+LDB+ASL+IACC+EPS+Aero1+LRRT1+HEG+ DCP+GDI+TDS27+EGR	6sp DCT-wet	$1,882	40%
50560	5%	4V DOHC I4 +LUB+EFR1+LDB+ASL+IACC+EPS+Aero1+LRRT1+HEG+ DCP+DVVL+GDI+TDS27+EGR	6sp DCT-wet	$2,013	40%
50561	5%	4V DOHC I4 +LUB+EFR1+LDB+ASL+IACC+EPS+Aero1+LRRT1+HEG+ DCP+GDI+SS+TDS27+EGR	6sp DCT-wet	$2,225	41%
50562	5%	4V DOHC I4 +LUB+EFR1+LDB+ASL+IACC+EPS+Aero1+LRRT1+HEG+ DCP+DVVL+GDI+SS+TDS27+EGR	6sp DCT-wet	$2,356	41%
50563	5%	4V DOHC I4 +LUB+EFR1+LDB+ASL+IACC+EPS+Aero1+LRRT1+HEG+ DCP+GDI+SAX+TDS27+EGR	6sp DCT-wet	$1,963	40%
50564	5%	4V DOHC I4 +LUB+EFR1+LDB+ASL+IACC+EPS+Aero1+LRRT1+HEG+ DCP+DVVL+GDI+SAX+TDS27+EGR	6sp DCT-wet	$2,094	40%
50565	5%	4V DOHC I4 +LUB+EFR1+LDB+ASL+IACC+EPS+Aero1+LRRT1+HEG+ DCP+GDI+SS+SAX+TDS27+EGR	6sp DCT-wet	$2,306	41%
50566	5%	4V DOHC I4 +LUB+EFR1+LDB+ASL+IACC+EPS+Aero1+LRRT1+HEG+ DCP+DVVL+GDI+SS+SAX+TDS27+EGR	6sp DCT-wet	$2,437	41%
50567	5%	4V DOHC I4 +EFR2+LDB+ASL2+IACC+EPS+Aero1+LRRT1+HEG+ DCP+GDI+TDS27+EGR	6sp DCT-wet	$1,942	43%
50568	5%	4V DOHC I4 +EFR2+LDB+ASL2+IACC+EPS+Aero1+LRRT1+HEG+ DCP+DVVL+GDI+TDS27+EGR	6sp DCT-wet	$2,073	43%
50569	5%	4V DOHC I4 +EFR2+LDB+ASL2+IACC+EPS+Aero1+LRRT1+HEG+ DCP+GDI+SS+TDS27+EGR	6sp DCT-wet	$2,285	43%
50570	5%	4V DOHC I4 +EFR2+LDB+ASL2+IACC+EPS+Aero1+LRRT1+HEG+ DCP+DVVL+GDI+SS+TDS27+EGR	6sp DCT-wet	$2,416	43%
50571	5%	4V DOHC I4 +EFR2+LDB+ASL2+IACC+EPS+Aero1+LRRT1+HEG+ DCP+GDI+SAX+TDS27+EGR	6sp DCT-wet	$2,022	43%
50572	5%	4V DOHC I4 +EFR2+LDB+ASL2+IACC+EPS+Aero1+LRRT1+HEG+ DCP+DVVL+GDI+SAX+TDS27+EGR	6sp DCT-wet	$2,153	43%
50573	5%	4V DOHC I4 +EFR2+LDB+ASL2+IACC+EPS+Aero1+LRRT1+HEG+ DCP+GDI+SS+SAX+TDS27+EGR	6sp DCT-wet	$2,365	44%
50574	5%	4V DOHC I4 +EFR2+LDB+ASL2+IACC+EPS+Aero1+LRRT1+HEG+ DCP+DVVL+GDI+SS+SAX+TDS27+EGR	6sp DCT-wet	$2,496	44%
50575	5%	4V DOHC I4 +LUB+EFR1+LDB+ASL+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+GDI+TDS27+EGR	6sp DCT-wet	$2,096	43%
50576	5%	4V DOHC I4 +LUB+EFR1+LDB+ASL+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+DVVL+GDI+TDS27+EGR	6sp DCT-wet	$2,227	43%
50577	5%	4V DOHC I4 +LUB+EFR1+LDB+ASL+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+GDI+SS+TDS27+EGR	6sp DCT-wet	$2,439	44%
50578	5%	4V DOHC I4 +LUB+EFR1+LDB+ASL+IACC2+EPS+Aero2+LRRT2+HEG+	6sp DCT-wet	$2,570	44%

		DCP+DVVL+GDI+SS+TDS27+EGR			
50579	5%	4V DOHC I4 +LUB+EFR1+LDB+ASL+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+GDI+SAX+TDS27+EGR	6sp DCT-wet	$2,177	43%
50580	5%	4V DOHC I4 +LUB+EFR1+LDB+ASL+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+DVVL+GDI+SAX+TDS27+EGR	6sp DCT-wet	$2,308	43%
50581	5%	4V DOHC I4 +LUB+EFR1+LDB+ASL+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+GDI+SS+SAX+TDS27+EGR	6sp DCT-wet	$2,520	44%
50582	5%	4V DOHC I4 +LUB+EFR1+LDB+ASL+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+DVVL+GDI+SS+SAX+TDS27+EGR	6sp DCT-wet	$2,651	44%
50583	5%	4V DOHC I4 +EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+GDI+TDS27+EGR	6sp DCT-wet	$2,156	45%
50584	5%	4V DOHC I4 +EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+DVVL+GDI+TDS27+EGR	6sp DCT-wet	$2,287	45%
50585	5%	4V DOHC I4 +EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+GDI+SS+TDS27+EGR	6sp DCT-wet	$2,499	46%
50586	5%	4V DOHC I4 +EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+DVVL+GDI+SS+TDS27+EGR	6sp DCT-wet	$2,630	46%
50587	5%	4V DOHC I4 +EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+GDI+SAX+TDS27+EGR	6sp DCT-wet	$2,236	46%
50588	5%	4V DOHC I4 +EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+DVVL+GDI+SAX+TDS27+EGR	6sp DCT-wet	$2,367	46%
50589	5%	4V DOHC I4 +EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+GDI+SS+SAX+TDS27+EGR	6sp DCT-wet	$2,579	46%
50590	5%	4V DOHC I4 +EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+DVVL+GDI+SS+SAX+TDS27+EGR	6sp DCT-wet	$2,710	46%
51963	5%	4V DOHC I4 +EFR2+LDB+ASL2+IACC+EPS+Aero1+LRRT1+HEG+ DCP+DSL-Adv	6sp DCT-wet	$3,602	40%
51964	5%	4V DOHC I4 +EFR2+LDB+ASL2+IACC+EPS+Aero1+LRRT1+HEG+ DCP+DSL-Adv+SAX	6sp DCT-wet	$3,683	40%
51965	5%	4V DOHC I4 +EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+DSL-Adv	6sp DCT-wet	$3,816	43%
51966	5%	4V DOHC I4 +EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+DSL-Adv+SAX	6sp DCT-wet	$3,896	43%

[a] Excludes packages with weight reduction of 0%, 10%, 15%, 20% and 8speed DCT.

[b] The jump from package # 50002 to 50395 represents the packages built with 0% weight reduction which are intentionally not included in the table.

As stated, this preliminary-set of packages is meant to maintain utility relative to the baseline vehicle. Having built nearly 2000 packages for each vehicle type suggests 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 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 in Section 3.3.1.11 of the draft 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.

This preliminary-set of conventional gasoline packages (roughly 2000 packages per vehicle type) was then ranked within vehicle type by TARF. This is done by first calculating the TARF of each package relative to the baseline package. The package with the best TARF is selected as OMEGA package #1 (or, more accurately, #501 for vehicle type 5, #101 for vehicle type 1, etc.). The remaining packages for vehicle type 5 are then ranked again by

TARF, this time relative to OMEGA package #501. The best package is selected as OMEGA package #502, etc. Table 1.3-6 illustrates this process, while Table 1.3-5 presents 2008 baseline data used in the TARF ranking process.

Table 1.3-5 Lifetime VMT & Baseline CO2 used for TARF Ranking in the Package Building Process

Vehicle Type	Vehicle class	Base engine	Car/ Truck [a]	Lifetime VMT	Base CO_2 (g/mi)[b]
1	Subcompact	I4	C	190,971	241.0
2	Small car	I4	C	190,971	236.8
3	Small car	I4	C	190,971	274.2
4	Minivan	V6	C	190,971	310.5
5	Large car	V6	C	190,971	335.5
6	Large car	V8	C	190,971	387.7
7	Minivan	I4	T	221,199	309.9
8	Small truck	V6	C	190,971	385.1
9	Minivan-towing	V6	T	221,199	421.7
10	Minivan-towing	V8	T	221,199	437.5
11	Large truck	V6	T	221,199	422.5
12	Large truck	V6	T	221,199	357.6
13	Large truck	V8	T	221,199	447.7
14	Large truck	V8	T	221,199	480.0
15	Large car	V8	C	190,971	386.7
16	Minivan-towing	V6	T	221,199	375.6
17	Minivan-towing	V8	T	221,199	463.3
18	Large truck	V6	T	221,199	403.0
19	Large truck	V8	T	221,199	477.6

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

[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.

Table 1.3-6 Illustration of the TARF Ranking Process, Vehicle Type 5, 2025MY Costs

Prelim Pkg#	Weight rdxn	Package contents	Trans	Cost	Fuel Savings[a]	Net Cost	CO_2 Rdxn (%)	CO_2 Rdxn (grams)	TARF[b]
Round 1 (determine TARF relative to baseline package #50000)									
50000	base	3.3L 4V DOHC V6	4sp AT	$0	$0	$0	0%	0	-
50001	base	4V DOHC V6 +LUB+EFR1+LDB+ASL	4sp AT	$184	$841	-$657	7%	23	-0.1528
50002	base	4V DOHC V6 +LUB+EFR1+LDB+ASL+IACC+EPS+Aero1+LRRT1	4sp AT	$394	$1,567	-$1,173	13%	42	-0.1464
50395	5%	4V DOHC V6 +LUB+EFR1+LDB+ASL+IACC+EPS+Aero1+LRRT1+HEG	6sp DCT -wet	$558	$2,946	$2,388	24%	79	-0.1585
50396	5%	4V DOHC V6 +LUB+EFR1+LDB+ASL+IACC+EPS+Aero1+LRRT1+HEG+ DCP	6sp DCT -wet	$723	$3,349	-$2,626	27%	90	-0.1533
Packages not shown for ease of presentation									
50427	5%	4V DOHC I4 +LUB+EFR1+LDB+ASL+IACC+EPS+Aero1+LRRT1+HEG+ DCP+DVVL+GDI+SS+SAX+TDS24	6sp DCT -wet	$1,765	$4,808	-$3,043	38%	128.7	-0.1238
50428	5%	4V DOHC V6 +EFR2+LDB+ASL2+IACC+EPS+Aero1+LRRT1+HEG	6sp DCT -wet	$646	$3,419	-$2,774	27%	91.6	-0.1586
50429	5%	4V DOHC V6 +EFR2+LDB+ASL2+IACC+EPS+Aero1+LRRT1+HEG+ DCP	6sp DCT -wet	$810	$3,795	-$2,985	30%	101.6	-0.1538
Etc…remaining packages have larger TARFs so are not shown; #50428 becomes the new base; all packages with lower effectiveness than 50428 are eliminated from further consideration									
Round 2 (determine net cost, CO_2 reduction & TARF relative to new base package #50428)									
50428	5%	4V DOHC V6 +EFR2+LDB+ASL2+IACC+EPS+Aero1+LRRT1+HEG	6sp DCT -wet	$0	$0	$0	0%	0.0	-
50427	5%	4V DOHC I4 +LUB+EFR1+LDB+ASL+IACC+EPS+Aero1+LRRT1+HEG+ DCP+DVVL+GDI+SS+SAX+TDS24	6sp DCT -wet	$1,120	$1,388	-$269	11%	37.2	-0.0379
50429	5%	4V DOHC V6 +EFR2+LDB+ASL2+IACC+EPS+Aero1+LRRT1+HEG+ DCP	6sp DCT -wet	$165	$376	-$211	3%	10.1	-0.1099
Packages not shown for ease of presentation									
50623	5%	4V DOHC I4+LUB+EFR1+LDB+ASL+IACC+EPS+Aero1+LRRT1 +HEG+DCP+DVVL+GDI+SS+SAX+TDS24	8sp DCT -wet	$1,234	$1,598	-$364	13%	42.8	-0.0446
50624	5%	4V DOHC V6+EFR2+LDB+ASL2+IACC+EPS+Aero1+LRRT1+HEG	8sp DCT -wet	$115	$365	-$251	3%	9.8	-0.1343
50625	5%	4V DOHC V6+EFR2+LDB+ASL2+IACC+EPS+Aero1+LRRT1+HEG+DCP	8sp DCT -wet	$279	$695	-$416	6%	18.6	-0.1170
Etc…remaining packages have larger TARFs so are not shown; #50624 becomes the new base; all packages with lower effectiveness than 50624 are eliminated from further consideration									
Round 3 (determine net cost, CO_2 reduction & TARF relative to new base package #50624)									
50624	5%	4V DOHC V6+EFR2+LDB+ASL2+IACC+EPS+Aero1+LRRT1+HEG	8sp DCT -wet	$0	$0	$0	0%	0.0	-
Etc. Further ranking rounds not shown for ease of presentation									

[a] Fuel savings calculated based on the effectiveness of the package, the energy content of the fuel and AEO 2011 reference case fuel prices (gasoline, diesel, electric). Fuel savings are considered for the first 5 years of life assuming VMT consistent with our car/truck VMT estimates excluding any rebound driving and are discounted at 3%.

[b] TARF units are $/kg, so a multiplicative factor of 1000 is included to convert g/mile to kg/mile.

As illustrated in Table 1.3-6, the TARF ranking process eliminates most packages in favor of more cost effective packages. The packages that remain after the TARF ranking process are then included in the master-set of packages for each vehicle type. These packages are shown for vehicle type 5 in Table 1.3-7, along with their new OMEGA package # identifier.

Table 1.3-7 Master-set of 2025 MY Non-HEV/PHEV/EV Packages for Vehicle Type 5 (Midsize/Large car 3.3L DOHC V6)

Prelim Pkg#	OMEGA Pkg#	Weight Rdxn	Package contents	Transmission	Cost	CO2%
50000	500	base	3.3L 4V DOHC V6	4sp AT	$0	0%
50428	501	5%	4V DOHC V6 +EFR2+LDB+ASL2+IACC+EPS+Aero1+LRRT1+HEG	6sp DCT-wet	$646	27%
50624	502	5%	4V DOHC V6 +EFR2+LDB+ASL2+IACC+EPS+Aero1+LRRT1+HEG	8sp DCT-wet	$760	30%
50445	503	5%	4V DOHC I4 +EFR2+LDB+ASL2+IACC+EPS+Aero1+LRRT1+HEG+ DCP+GDI+TDS18	6sp DCT-wet	$1,058	37%
50641	504	5%	4V DOHC I4 +EFR2+LDB+ASL2+IACC+EPS+Aero1+LRRT1+HEG+ DCP+GDI+TDS18	8sp DCT-wet	$1,172	39%
50707	505	5%	4V DOHC I4 +EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+GDI+TDS18	8sp DCT-wet	$1,386	43%
51099	506	10%	4V DOHC I4 +EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+GDI+TDS18	8sp DCT-wet	$1,507	44%
51107	507	10%	4V DOHC I4 +EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+GDI+TDS24	8sp DCT-wet	$1,719	46%
51139	508	10%	4V DOHC I4 +EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+GDI+TDS24+EGR	8sp DCT-wet	$1,966	48%
51491	509	15%	4V DOHC I4 +EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+GDI+TDS18	8sp DCT-wet	$1,741	46%
51531	510	15%	4V DOHC I4 +EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+GDI+TDS24+EGR	8sp DCT-wet	$2,200	49%
51883	511	20%	4V DOHC I4 +EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+GDI+TDS18	8sp DCT-wet	$2,048	47%
51923	512	20%	4V DOHC I4 +EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+GDI+TDS24+EGR	8sp DCT-wet	$2,507	51%
51887	513	20%	4V DOHC I4 +EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+GDI+SAX+TDS18	8sp DCT-wet	$2,128	48%
51927	514	20%	4V DOHC I4 +EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+GDI+SAX+TDS24+EGR	8sp DCT-wet	$2,588	51%
51888	515	20%	4V DOHC I4 +EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+DVVL+GDI+SAX+TDS18	8sp DCT-wet	$2,259	48%
51890	516	20%	4V DOHC I4 +EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+DVVL+GDI+SS+SAX+TDS18	8sp DCT-wet	$2,602	49%
51929	517	20%	4V DOHC I4 +EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+GDI+SS+SAX+TDS24+EGR	8sp DCT-wet	$2,931	52%
51961	518	20%	4V DOHC I4 +EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+GDI+SS+SAX+TDS27+EGR	8sp DCT-wet	$3,356	52%
51994	519	20%	4V DOHC I4 +EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+DSL-Adv+SAX	8sp DCT-wet	$4,673	49%

The next packages after the advanced gasoline and diesel packages are the HEVs. We noted above that we have considered applying only the P2 HEV for this analysis. As done with non-electrified packages, we began with a preliminary-set of HEV packages that 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 vehicle types 8 and 15 are SOHC and OHV, respectively,. Therefore, 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 draft Joint TSD. As a result, we have built more HEV packages for towing vehicle types than for non-towing types. Lastly, we built 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 in 2016 allowed in the analysis. This maximum allowed weight reduction was 15% for the 2021MY and 20% for 2025 based on the technology penetration caps set forth and explained i n Chapter 3 of the joint TSD. Table 1.3-8 shows the HEV packages built for vehicle types 5 and, for comparison, 10 which is a towing vehicle type.

Table 1.3-8 HEV Packages Built for Vehicle Types 5 (3.3L DOHC V6) and 10 (4.7L SOHC V8)

Prelim Pkg#	Weight Rdxn	Package contents	Transmission	2025 Cost	CO2%
500	base	3.3L 4V DOHC V6	4sp AT	$0	0.0%
501	20.0%	4V DOHC V6 +LUB+EFR1+LDB+ASL+IACC+EPS+Aero1+LRRT1+HEG+ DCP+DVVL+GDI+ATKCS+HEV	6sp DCT-wet	$4,937	51.9%
502	20.0%	4V DOHC V6 +LUB+EFR1+LDB+ASL+IACC+EPS+Aero1+LRRT1+HEG+ DCP+DVVL+GDI+ATKCS+HEV+SAX	6sp DCT-wet	$5,018	52.3%
503	20.0%	4V DOHC V6 +EFR2+LDB+ASL2+IACC+EPS+Aero1+LRRT1+HEG+ DCP+DVVL+GDI+ATKCS+HEV	6sp DCT-wet	$5,024	54.3%
504	20.0%	4V DOHC V6 +EFR2+LDB+ASL2+IACC+EPS+Aero1+LRRT1+HEG+ DCP+DVVL+GDI+ATKCS+HEV+SAX	6sp DCT-wet	$5,105	54.7%
505	20.0%	4V DOHC V6 +LUB+EFR1+LDB+ASL+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+DVVL+GDI+ATKCS+HEV	6sp DCT-wet	$5,151	55.6%
506	20.0%	4V DOHC V6 +LUB+EFR1+LDB+ASL+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+DVVL+GDI+ATKCS+HEV+SAX	6sp DCT-wet	$5,231	55.9%
507	20.0%	4V DOHC V6 +EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+DVVL+GDI+ATKCS+HEV	6sp DCT-wet	$5,238	57.7%
508	20.0%	4V DOHC V6 +EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+DVVL+GDI+ATKCS+HEV+SAX	6sp DCT-wet	$5,319	58.1%
509	20.0%	4V DOHC V6 +LUB+EFR1+LDB+ASL+IACC+EPS+Aero1+LRRT1+HEG+ DCP+DVVL+GDI+ATKCS+HEV	8sp DCT-wet	$5,051	53.7%
510	20.0%	4V DOHC V6 +LUB+EFR1+LDB+ASL+IACC+EPS+Aero1+LRRT1+HEG+	8sp DCT-wet	$5,132	54.1%

		DCP+DVVL+GDI+ATKCS+HEV+SAX			
511	20.0%	4V DOHC V6 +EFR2+LDB+ASL2+IACC+EPS+Aero1+LRRT1+HEG+ DCP+DVVL+GDI+ATKCS+HEV	8sp DCT-wet	$5,139	56.0%
512	20.0%	4V DOHC V6 +EFR2+LDB+ASL2+IACC+EPS+Aero1+LRRT1+HEG+ DCP+DVVL+GDI+ATKCS+HEV+SAX	8sp DCT-wet	$5,219	56.3%
513	20.0%	4V DOHC V6 +LUB+EFR1+LDB+ASL+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+DVVL+GDI+ATKCS+HEV	8sp DCT-wet	$5,265	57.2%
514	20.0%	4V DOHC V6 +LUB+EFR1+LDB+ASL+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+DVVL+GDI+ATKCS+HEV+SAX	8sp DCT-wet	$5,346	57.5%
515	20.0%	4V DOHC V6 +EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+DVVL+GDI+ATKCS+HEV	8sp DCT-wet	$5,353	59.3%
516	20.0%	4V DOHC V6 +EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+DVVL+GDI+ATKCS+HEV+SAX	8sp DCT-wet	$5,433	59.6%
1000	base	4.7L 2V SOHC V8	4sp AT	$0	0.0%
1001	20.0%	4V DOHC V6 +LUB+EFR1+LDB+ASL+IACC+EPS+Aero1+LRRT1+HEG+ DCP+GDI+TDS18+HEV	6sp AT	$5,749	45.7%
1002	20.0%	4V DOHC V6 +LUB+EFR1+LDB+ASL+IACC+EPS+Aero1+LRRT1+HEG+ DCP+GDI+SAX+TDS18+HEV	6sp AT	$5,829	46.3%
1003	20.0%	4V DOHC V6 +LUB+EFR1+LDB+ASL+IACC+EPS+Aero1+LRRT1+HEG+ DCP+GDI+TDS24+HEV	6sp AT	$6,107	47.8%
1004	20.0%	4V DOHC V6 +LUB+EFR1+LDB+ASL+IACC+EPS+Aero1+LRRT1+HEG+ DCP+GDI+SAX+TDS24+HEV	6sp AT	$6,187	48.3%
1005	20.0%	4V DOHC V6 +EFR2+LDB+ASL2+IACC+EPS+Aero1+LRRT1+HEG+ DCP+GDI+TDS18+HEV	6sp AT	$5,836	48.0%
1006	20.0%	4V DOHC V6 +EFR2+LDB+ASL2+IACC+EPS+Aero1+LRRT1+HEG+ DCP+GDI+SAX+TDS18+HEV	6sp AT	$5,916	48.5%
1007	20.0%	4V DOHC V6 +EFR2+LDB+ASL2+IACC+EPS+Aero1+LRRT1+HEG+ DCP+GDI+TDS24+HEV	6sp AT	$6,194	49.9%
1008	20.0%	4V DOHC V6 +EFR2+LDB+ASL2+IACC+EPS+Aero1+LRRT1+HEG+ DCP+GDI+SAX+TDS24+HEV	6sp AT	$6,274	50.4%
1009	20.0%	4V DOHC V6 +LUB+EFR1+LDB+ASL+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+GDI+TDS18+HEV	6sp AT	$5,963	49.5%
1010	20.0%	4V DOHC V6 +LUB+EFR1+LDB+ASL+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+GDI+SAX+TDS18+HEV	6sp AT	$6,043	50.0%
1011	20.0%	4V DOHC V6 +LUB+EFR1+LDB+ASL+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+GDI+TDS24+HEV	6sp AT	$6,321	51.2%
1012	20.0%	4V DOHC V6 +LUB+EFR1+LDB+ASL+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+GDI+SAX+TDS24+HEV	6sp AT	$6,401	51.7%
1013	20.0%	4V DOHC V6 +EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+GDI+TDS18+HEV	6sp AT	$6,050	51.6%
1014	20.0%	4V DOHC V6 +EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+GDI+SAX+TDS18+HEV	6sp AT	$6,130	52.1%
1015	20.0%	4V DOHC V6 +EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+GDI+TDS24+HEV	6sp AT	$6,408	53.3%
1016	20.0%	4V DOHC V6 +EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+GDI+SAX+TDS24+HEV	6sp AT	$6,488	53.7%
1017	20.0%	4V DOHC V6 +EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+GDI+TDS24+EGR+HEV	6sp AT	$6,655	54.9%
1018	20.0%	4V DOHC V6 +EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+GDI+SAX+TDS24+EGR+HEV	6sp AT	$6,735	55.4%
1019	20.0%	4V DOHC I4 +EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+GDI+TDS27+EGR+HEV	6sp AT	$6,084	55.4%
1020	20.0%	4V DOHC I4 +EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+GDI+SAX+TDS27+EGR+HEV	6sp AT	$6,164	55.8%
1021	20.0%	4V DOHC V6 +LUB+EFR1+LDB+ASL+IACC+EPS+Aero1+LRRT1+HEG+ DCP+GDI+TDS18+HEV	8sp AT	$5,807	47.7%
1022	20.0%	4V DOHC V6	8sp AT	$5,887	48.2%

		+LUB+EFR1+LDB+ASL+IACC+EPS+Aero1+LRRT1+HEG+ DCP+GDI+SAX+TDS18+HEV			
1023	20.0%	4V DOHC V6 +LUB+EFR1+LDB+ASL+IACC+EPS+Aero1+LRRT1+HEG+ DCP+GDI+TDS24+HEV	8sp AT	$6,165	49.6%
1024	20.0%	4V DOHC V6 +LUB+EFR1+LDB+ASL+IACC+EPS+Aero1+LRRT1+HEG+ DCP+GDI+SAX+TDS24+HEV	8sp AT	$6,245	50.0%
1025	20.0%	4V DOHC V6 +EFR2+LDB+ASL2+IACC+EPS+Aero1+LRRT1+HEG+ DCP+GDI+TDS18+HEV	8sp AT	$5,894	49.9%
1026	20.0%	4V DOHC V6 +EFR2+LDB+ASL2+IACC+EPS+Aero1+LRRT1+HEG+ DCP+GDI+SAX+TDS18+HEV	8sp AT	$5,975	50.4%
1027	20.0%	4V DOHC V6 +EFR2+LDB+ASL2+IACC+EPS+Aero1+LRRT1+HEG+ DCP+GDI+TDS24+HEV	8sp AT	$6,252	51.7%
1028	20.0%	4V DOHC V6 +EFR2+LDB+ASL2+IACC+EPS+Aero1+LRRT1+HEG+ DCP+GDI+SAX+TDS24+HEV	8sp AT	$6,333	52.1%
1029	20.0%	4V DOHC V6 +LUB+EFR1+LDB+ASL+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+GDI+TDS18+HEV	8sp AT	$6,021	51.3%
1030	20.0%	4V DOHC V6 +LUB+EFR1+LDB+ASL+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+GDI+SAX+TDS18+HEV	8sp AT	$6,101	51.7%
1031	20.0%	4V DOHC V6 +LUB+EFR1+LDB+ASL+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+GDI+TDS24+HEV	8sp AT	$6,379	52.9%
1032	20.0%	4V DOHC V6 +LUB+EFR1+LDB+ASL+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+GDI+SAX+TDS24+HEV	8sp AT	$6,459	53.3%
1033	20.0%	4V DOHC V6 +EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+GDI+TDS18+HEV	8sp AT	$6,108	53.4%
1034	20.0%	4V DOHC V6 +EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+GDI+SAX+TDS18+HEV	8sp AT	$6,188	53.8%
1035	20.0%	4V DOHC V6 +EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+GDI+TDS24+HEV	8sp AT	$6,466	54.9%
1036	20.0%	4V DOHC V6 +EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+GDI+SAX+TDS24+HEV	8sp AT	$6,547	55.2%
1037	20.0%	4V DOHC V6 +EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+GDI+TDS24+EGR+HEV	8sp AT	$6,713	56.5%
1038	20.0%	4V DOHC V6 +EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+GDI+SAX+TDS24+EGR+HEV	8sp AT	$6,794	56.8%
1039	20.0%	4V DOHC I4 +EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+GDI+TDS27+EGR+HEV	8sp AT	$6,142	56.9%
1040	20.0%	4V DOHC I4 +EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+GDI+SAX+TDS27+EGR+HEV	8sp AT	$6,222	57.2%

Note: Prelim Pkg #s 500-516 are for vehicle type 5, #s 1000-1040 are for vehicle type 10.
Note also that any automatic transmission that has been improved from the base 4sp AT also includes early torque converter lockup even though that technology is not specifically listed in the package contents. This is the only technology that does not appear in the package content descriptions.

We then ranked the preliminary-set of HEV packages according to TARF as described above to generate the most cost effective set of HEV packages for each vehicle type that would then be included in the master-set of packages. The TARF ranking process eliminated most packages in favor of more cost effective packages. These packages are shown for vehicle types 5 and 10 (as examples) in

Table 1.3-9, along with their new OMEGA package # identifier.

Table 1.3-9 Master-set of 2025 MY HEV Packages for Vehicle Types 5 (3.3L DOHC V6) & 10 (4.7L SOHC V8)

Prelim Pkg#	OMEGA Pkg#	Weight rdxn	Package contents	Transmission	2025MY Cost	CO2%
515	520	20%	4V DOHC V6 +EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+DVVL+GDI+ATKCS+HEV	8sp DCT-wet	$5,353	59.3%
516	521	20%	4V DOHC V6 +EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+DVVL+GDI+ATKCS+HEV+SAX	8sp DCT-wet	$5,433	59.6%
1033	1018	20%	4V DOHC V6 +EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+GDI+TDS18+HEV	8sp AT	$6,108	53.4%
1037	1019	20%	4V DOHC V6 +EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+GDI+TDS24+EGR+HEV	8sp AT	$6,713	56.5%
1039	1020	20%	4V DOHC I4 +EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+GDI+TDS27+EGR+HEV	8sp AT	$6,142	56.9%
1034	1021	20%	4V DOHC V6 +EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+GDI+SAX+TDS18+HEV	8sp AT	$6,188	53.8%
1040	1022	20%	4V DOHC I4 +EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG+ DCP+GDI+SAX+TDS27+EGR+HEV	8sp AT	$6,222	57.2%

The last step was to build the PHEVs (also known as REEVs) and EVs for vehicle types 1 through 8 and 15. The other vehicle types were not considered 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 2 primary types of PHEV packages and 3 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 draft 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 1.2-12. Table 1.3-10 shows the PHEV and EV packages built for the 2025MY in this proposal (note that PHEVs are shown as REEVs in the table). Note that the PHEV and EV packages are included directly in the master-set of packages for a 2025MY OMEGA run. We have not built a long preliminary-set of PHEVs and EVs and ranked them based on TARF to determine which packages to include in the master-set. This is because for each MYof interest we built the REEV20/REEV40/EV75/EV100/EV150 with the maximum allowed weight reduction (applied weight reduction) of 20% even though for MYs 2016 and 2021 the maximum allowed weight reduction under our phase-in caps was 10% and 15% for those MYs.[I] We have done this 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 2016 and 2021 MYs than we have considered likely for other vehicle technologies.

Table 1.3-10 Master-set of 2025 MY PHEV (REEV) & EV Packages for all Vehicle Types

OMEGA Pkg#	Applied Weight Rdxn	Package contents	Trans	2025 Cost	CO2%
120	20.0%	4V DOHC I4+EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG+DCP+DVVL+GDI+ATKCS+REEV20	8sp DCT-dry	$9,489	74.8%
121	20.0%	4V DOHC I4+EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG+DCP+DVVL+GDI+ATKCS+REEV40	8sp DCT-dry	$11,402	84.5%
122	20.0%	EV75 mile+IACC2+Aero2+LRRT2+EPS	N/A	$10,056	100.0%
123	20.0%	EV100 mile+IACC2+Aero2+LRRT2+EPS	N/A	$11,542	100.0%
124	20.0%	EV150 mile+IACC2+Aero2+LRRT2+EPS	N/A	$15,036	100.0%
223	20.0%	4V DOHC I4+EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG+DCP+DVVL+GDI+ATKCS+REEV20	8sp DCT-dry	$10,044	75.6%
224	20.0%	4V DOHC I4+EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG+DCP+DVVL+GDI+ATKCS+REEV40	8sp DCT-dry	$12,211	85.0%
225	20.0%	EV75 mile+IACC2+Aero2+LRRT2+EPS	N/A	$10,962	100.0%
226	20.0%	EV100 mile+IACC2+Aero2+LRRT2+EPS	N/A	$12,719	100.0%
227	20.0%	EV150 mile+IACC2+Aero2+LRRT2+EPS	N/A	$16,757	100.0%
323	20.0%	4V DOHC I4+EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG+DCP+DVVL+GDI+ATKCS+REEV20	8sp DCT-dry	$10,121	75.6%
324	20.0%	4V DOHC I4+EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG+DCP+DVVL+GDI+ATKCS+REEV40	8sp DCT-dry	$12,288	85.0%
325	20.0%	EV75 mile+IACC2+Aero2+LRRT2+EPS	N/A	$11,039	100.0%
326	20.0%	EV100 mile+IACC2+Aero2+LRRT2+EPS	N/A	$12,796	100.0%
327	20.0%	EV150 mile+IACC2+Aero2+LRRT2+EPS	N/A	$16,834	100.0%
421	20.0%	4V DOHC V6+EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG+DCP+DVVL+GDI+ATKCS+REEV20	8sp DCT-wet	$12,135	74.8%
422	20.0%	4V DOHC	8sp	$15,186	84.5%

[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 draft RIA.

		V6+EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG+DCP+DVVL+GDI+ATKCS+REEV40	DCT-wet		
423	20.0%	EV75 mile+IACC2+Aero2+LRRT2+EPS	N/A	$12,677	100.0%
424	20.0%	EV100 mile+IACC2+Aero2+LRRT2+EPS	N/A	$15,094	100.0%
425	20.0%	EV150 mile+IACC2+Aero2+LRRT2+EPS	N/A	$21,008	100.0%
522	20.0%	4V DOHC V6+EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG+DCP+DVVL+GDI+ATKCS+REEV20	8sp DCT-wet	$12,485	75.2%
523	20.0%	4V DOHC V6+EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG+DCP+DVVL+GDI+ATKCS+REEV40	8sp DCT-wet	$15,670	84.7%
524	20.0%	EV75 mile+IACC2+Aero2+LRRT2+EPS	N/A	$12,908	100.0%
525	20.0%	EV100 mile+IACC2+Aero2+LRRT2+EPS	N/A	$14,643	100.0%
526	20.0%	EV150 mile+IACC2+Aero2+LRRT2+EPS	N/A	$20,280	100.0%
621	20.0%	4V DOHC V8+EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG+DCP+DVVL+GDI+ATKCS+REEV20	8sp DCT-wet	$12,747	75.2%
622	20.0%	4V DOHC V8+EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG+DCP+DVVL+GDI+ATKCS+REEV40	8sp DCT-wet	$15,931	84.7%
623	20.0%	EV75 mile+IACC2+Aero2+LRRT2+EPS	N/A	$12,964	100.0%
624	20.0%	EV100 mile+IACC2+Aero2+LRRT2+EPS	N/A	$14,699	100.0%
625	20.0%	EV150 mile+IACC2+Aero2+LRRT2+EPS	N/A	$20,336	100.0%
723	20.0%	4V DOHC I4+EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG+DCP+DVVL+GDI+ATKCS+REEV20	8sp DCT-dry	$11,799	74.9%
724	20.0%	4V DOHC I4+EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG+DCP+DVVL+GDI+ATKCS+REEV40	8sp DCT-dry	$14,851	84.5%
725	20.0%	EV75 mile+IACC2+Aero2+LRRT2+EPS	N/A	$12,711	100.0%
726	20.0%	EV100 mile+IACC2+Aero2+LRRT2+EPS	N/A	$15,128	100.0%
727	20.0%	EV150 mile+IACC2+Aero2+LRRT2+EPS	N/A	$21,041	100.0%
822	20.0%	4V DOHC V6+EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG+DCP+DVVL+GDI+ATKCS+REEV20	8sp DCT-wet	$11,747	74.0%
823	20.0%	4V DOHC V6+EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG+DCP+DVVL+GDI+ATKCS+REEV40	8sp DCT-wet	$14,522	84.0%
824	20.0%	EV75 mile+IACC2+Aero2+LRRT2+EPS	N/A	$12,864	100.0%
825	20.0%	EV100 mile+IACC2+Aero2+LRRT2+EPS	N/A	$15,107	100.0%
826	20.0%	EV150 mile+IACC2+Aero2+LRRT2+EPS	N/A	$20,852	100.0%
1521	20.0%	4V DOHC V8+EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG+DCP+DVVL+GDI+ATKCS+REEV20	8sp DCT-wet	$12,670	75.2%
1522	20.0%	4V DOHC V8+EFR2+LDB+ASL2+IACC2+EPS+Aero2+LRRT2+HEG+DCP+DVVL+GDI+ATKCS+REEV40	8sp DCT-wet	$15,854	84.7%
1523	20.0%	EV75 mile+IACC2+Aero2+LRRT2+EPS	N/A	$12,886	100.0%
1524	20.0%	EV100 mile+IACC2+Aero2+LRRT2+EPS	N/A	$14,622	100.0%
1525	20.0%	EV150 mile+IACC2+Aero2+LRRT2+EPS	N/A	$20,259	100.0%

Note that the net weight reduction of these packages as a percent can be determined by cross-referencing the applied weight reduction shown here with the proper cost table (PHEV20/40, EV75/100/150) shown in Section 1.2 and the vehicle class information shown in Table 1.3-1.

The end result is a master-set of roughly 25 packages for each vehicle type. Because of the large number of total packages and the difficulty of presenting them all here, we have placed in the docket (EPA-HQ-OAR-2010-0799) a memorandum that contains the master-set of packages used for our 2016MY, 2021MY and 2025MY OMEGA runs.[2]

The remaining package building step in developing a set of OMEGA inputs is to rank the master-set of packages according to TARF. The end result of this ranking is a ranked-set of OMEGA packages 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. The docket memorandum mentioned earlier also contains a ranked-set of packages for each of the master-sets we have created.[3] The ranked-set also includes the package progression information. 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[4].” 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[5] 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 2012-2016 light duty vehicle GHG and CAFE standards, and has been improved to reflect updates required for the proposed 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 2012-2016 Light Duty Vehicle GHG rule[6], 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[7].

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:

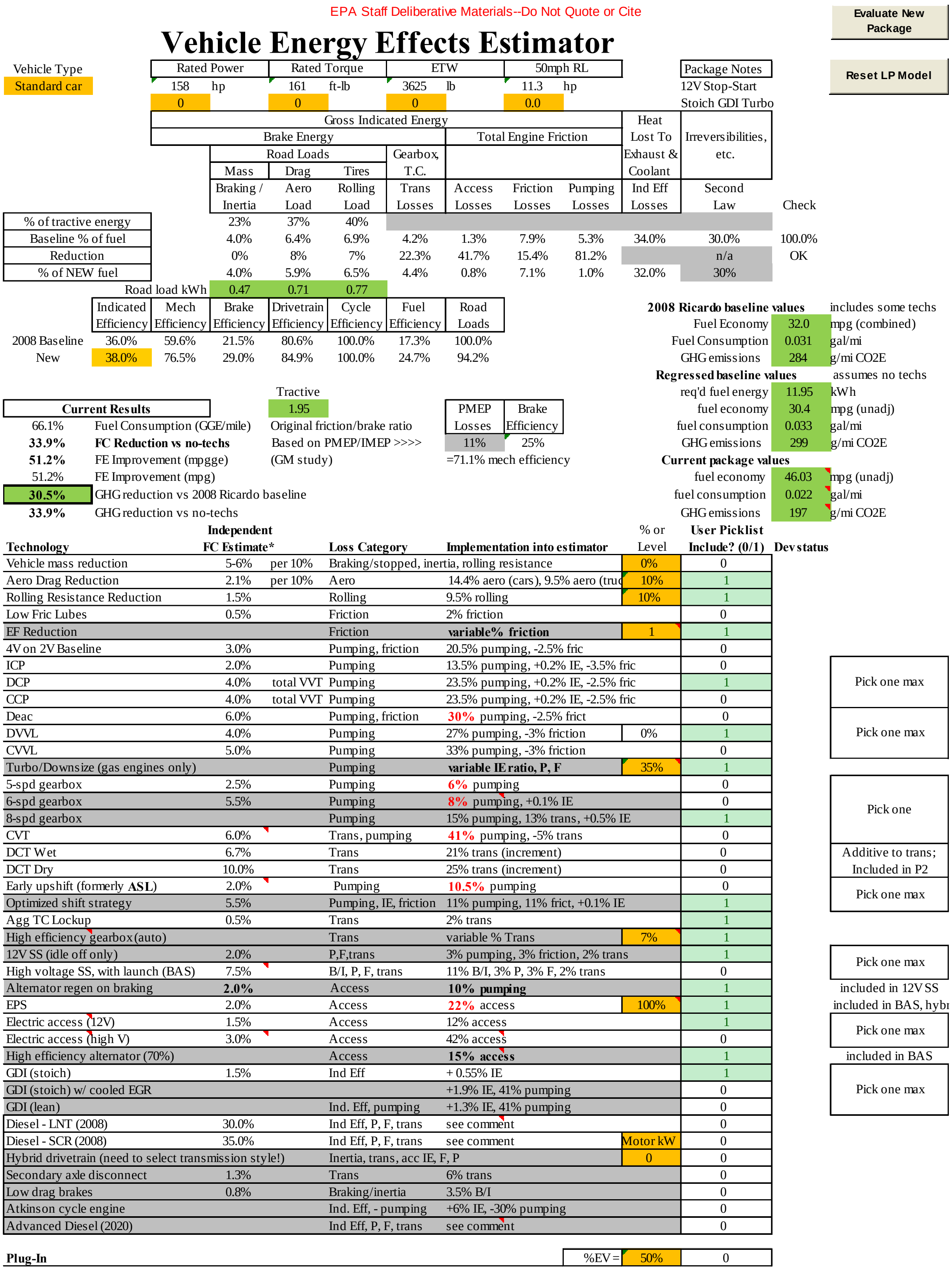
- Second law losses (thermodynamic losses inherent in the combustion of fuel),
- Heat lost from the combustion process to the exhaust and coolant,
- Pumping losses, i.e., work performed by the engine during the intake and exhaust strokes,
- Friction losses in the engine,
- Transmission losses, associated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

[J] 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.



EPA Staff Deliberative Materials--Do Not Quote or Cite

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

	Gross Indicated Energy							Heat Lost To Exhaust & Coolant	Irreversibilities, etc.	
	Brake Energy				Total Engine Friction					
	Road Loads			Gearbox, T.C.						
	Mass	Drag	Tires							
	Braking / Inertia	Aero Load	Rolling Load	Trans Losses	Access Losses	Friction Losses	Pumping Losses	Ind Eff Losses	Second Law	Check
% 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	
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	
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	
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	
DCT Dry	10.0%		Trans	25% trans (increment)		0	
Early upshift (formerly **ASL**)	2.0%		Pumping	**10.5%** pumping		0	
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	
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	
EPS	2.0%		Access	**22%** access	100%	1	
Electric access (12V)	1.5%		Access	12% access		1	
Electric access (high V)	3.0%		Access	42% access		0	
High efficiency alternator (70%)			Access	**15% access**		1	
GDI (stoich)	1.5%		Ind Eff	+ 0.55% IE		1	
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	

Pick one max

Pick one max

Pick one

Additive to trans; Included in P2

Pick one max

Pick one max

included in 12V SS

included in BAS, hybr

Pick one max

included in BAS

Pick one max

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 proposed 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 proposed rulemaking

The LP model was updated in conjunction with this rulemaking to provide more flexibility in assessment of 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 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 2012-2016 light-duty vehicle GHG rule. Further simulation work was conducted by Ricardo from 2010-2011 to support EPA's analysis for the 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[K] vehicle simulation output files for the FTP and HWFE test cycles helped quantify the distribution of fuel energy losses in the baseline LP

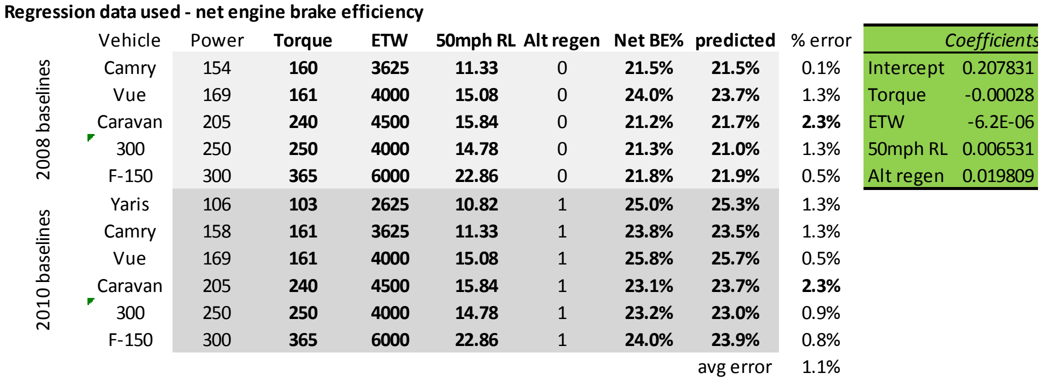
[K] The 2008 baseline vehicles are those originally used in the 2008 Ricardo simulation project and represent actual vehicles in production. The 2010 "baseline" vehicles (from the 2011 Ricardo report) have additional content including stop-start, improved alternator with regenerative capability, and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

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[L]

- 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[8]) and prior success with values used in the LP model for the 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:

[L] 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[M].

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:

[M] 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[N])
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[O]

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

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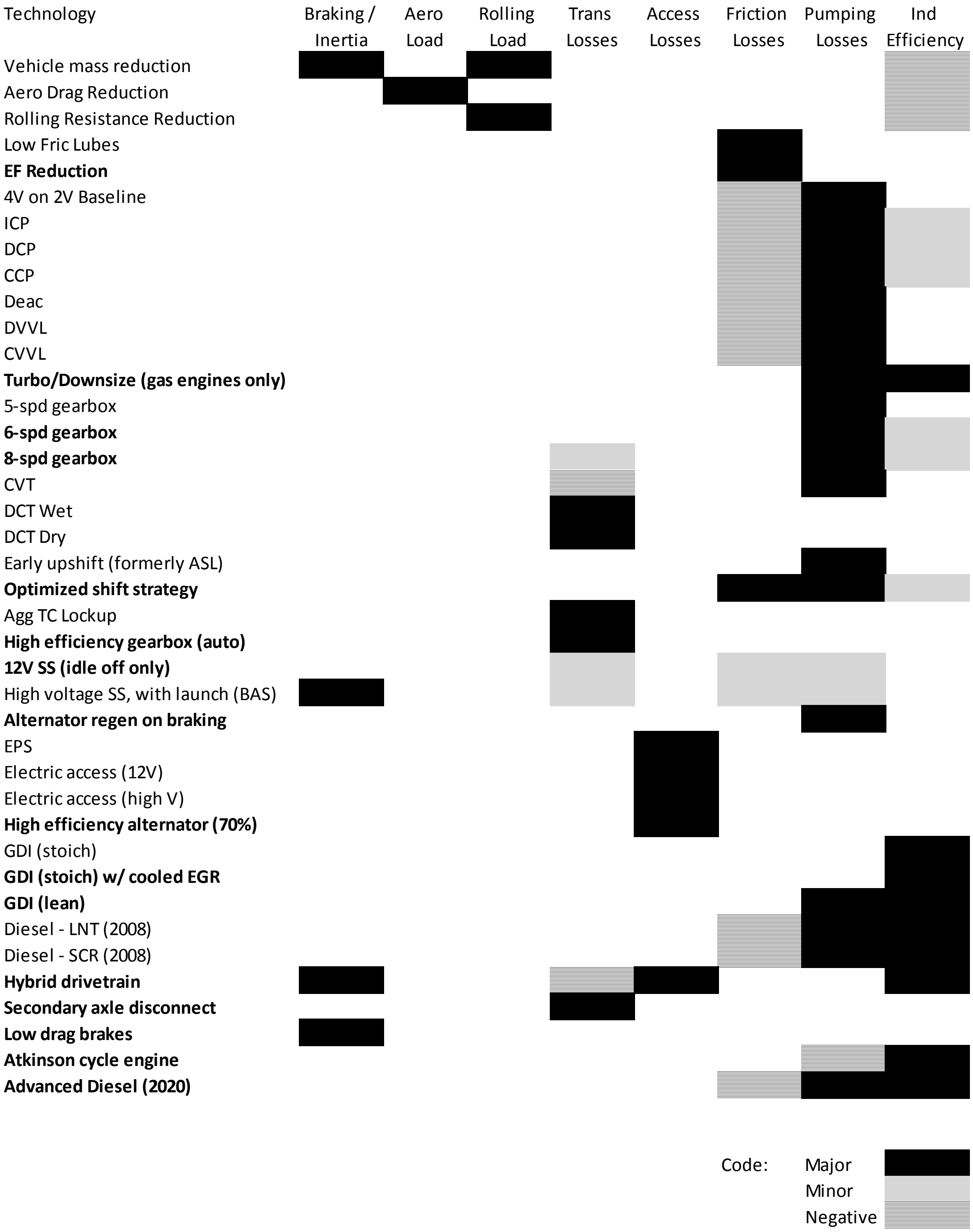
[N] When the alternator regeneration technology is included, it changes the efficiency of the engine by moving the average speed and load to a more efficient operating region. It was included in the definition of the 2010 baseline vehicle models.

[O] 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.



Technology	Braking / Inertia	Aero Load	Rolling Load	Trans Losses	Access Losses	Friction Losses	Pumping Losses	Ind Efficiency
Vehicle mass reduction	■		■					▨
Aero Drag Reduction		■						▨
Rolling Resistance Reduction			■					▨
Low Fric Lubes						■		
EF Reduction						■		
4V on 2V Baseline						▨	■	
ICP						▨	■	░
DCP						▨	■	░
CCP						▨	■	░
Deac						▨	■	
DVVL						▨	■	
CVVL						▨	■	
Turbo/Downsize (gas engines only)							■	■
5-spd gearbox							■	
6-spd gearbox							■	░
8-spd gearbox				░			■	░
CVT				▨			■	
DCT Wet				■				
DCT Dry				■				
Early upshift (formerly ASL)							■	
Optimized shift strategy						■	■	░
Agg TC Lockup				■				
High efficiency gearbox (auto)				■				
12V SS (idle off only)				░		░	░	
High voltage SS, with launch (BAS)	■			░		░	░	
Alternator regen on braking							■	
EPS					■			
Electric access (12V)					■			
Electric access (high V)					■			
High efficiency alternator (70%)					■			
GDI (stoich)								■
GDI (stoich) w/ cooled EGR								■
GDI (lean)							■	■
Diesel - LNT (2008)						▨	■	■
Diesel - SCR (2008)						▨	■	■
Hybrid drivetrain	■			▨	■			■
Secondary axle disconnect				■				
Low drag brakes	■							
Atkinson cycle engine							▨	■
Advanced Diesel (2020)						▨	■	■

Code: Major ■
Minor ░
Negative ▨

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

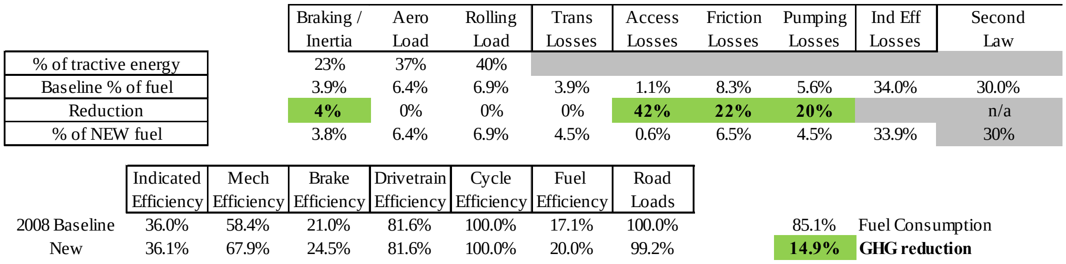
The following example package for a Large Car demonstrates how synergies build as content is added to a vehicle technology package.

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[P] 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%

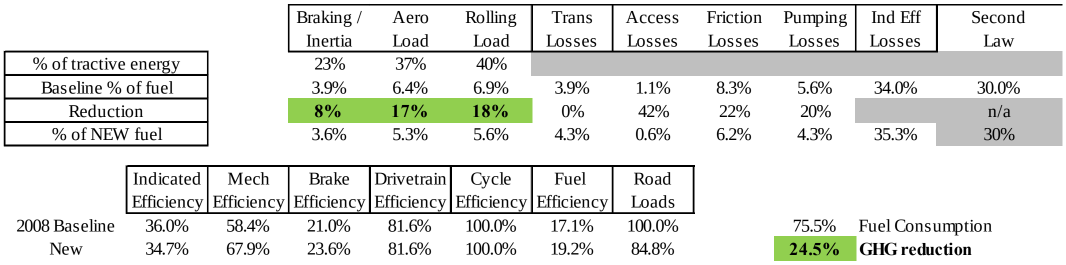
	Indicated Efficiency	Mech Efficiency	Brake Efficiency	Drivetrain Efficiency	Cycle Efficiency	Fuel Efficiency	Road Loads		
2008 Baseline	36.0%	58.4%	21.0%	81.6%	100.0%	17.1%	100.0%	85.1%	Fuel Consumption
New	36.1%	67.9%	24.5%	81.6%	100.0%	20.0%	99.2%	**14.9%**	**GHG reduction**

[P] 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



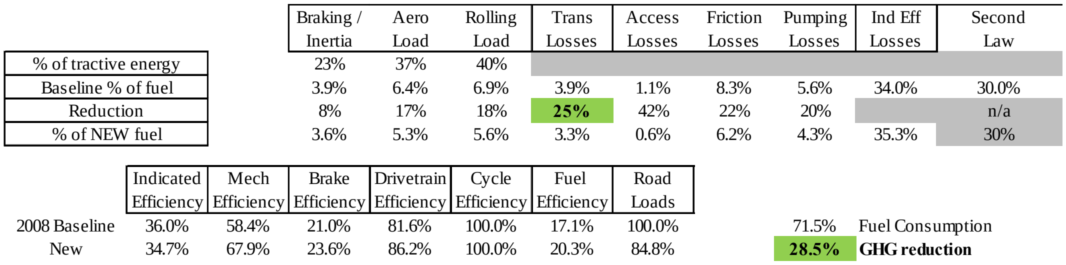
	Braking / Inertia	Aero Load	Rolling Load	Trans Losses	Access Losses	Friction Losses	Pumping Losses	Ind Eff Losses	Second Law
% of tractive energy	23%	37%	40%						
Baseline % of fuel	3.9%	6.4%	6.9%	3.9%	1.1%	8.3%	5.6%	34.0%	30.0%
Reduction	**8%**	**17%**	**18%**	0%	42%	22%	20%		n/a
% of NEW fuel	3.6%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

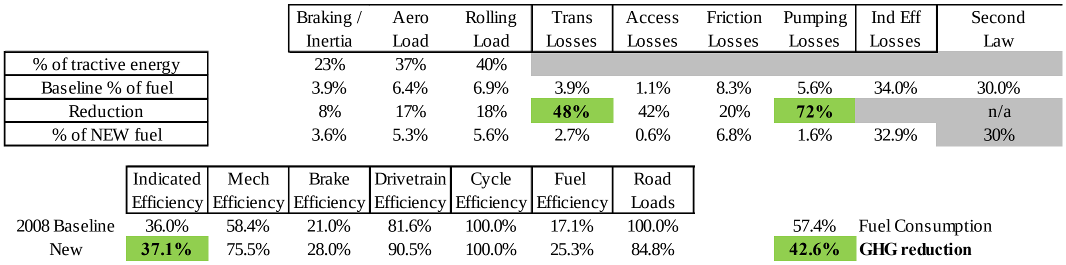
	Braking / Inertia	Aero Load	Rolling Load	Trans Losses	Access Losses	Friction Losses	Pumping Losses	Ind Eff Losses	Second Law
% of tractive energy	23%	37%	40%						
Baseline % of fuel	3.9%	6.4%	6.9%	3.9%	1.1%	8.3%	5.6%	34.0%	30.0%
Reduction	8%	17%	18%	25%	42%	20%	**67%**		n/a
% of NEW fuel	3.6%	5.3%	5.6%	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 proposed 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 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[Q]) compared to the lumped parameter estimates.

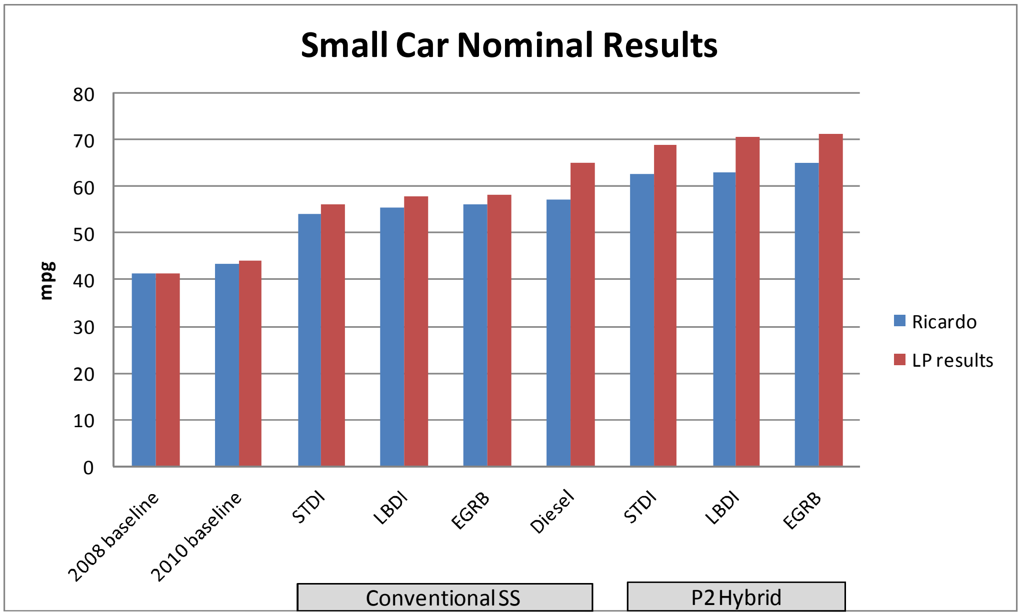


Figure 1.5-4 Comparison of LP to simulation results for Small Car class

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

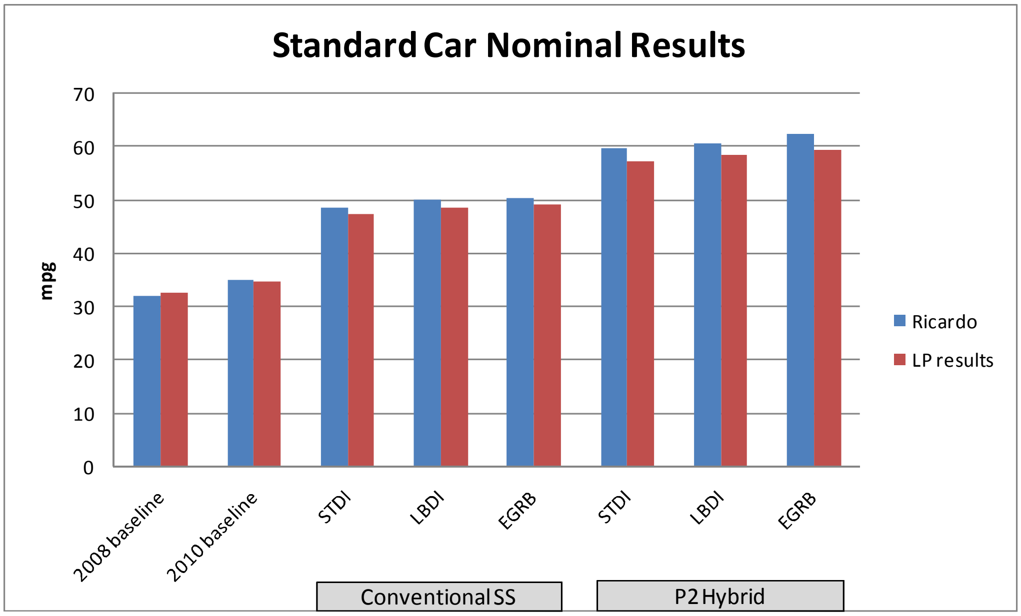


Figure 1.5-5 Comparison of LP to simulation results for Standard Car class

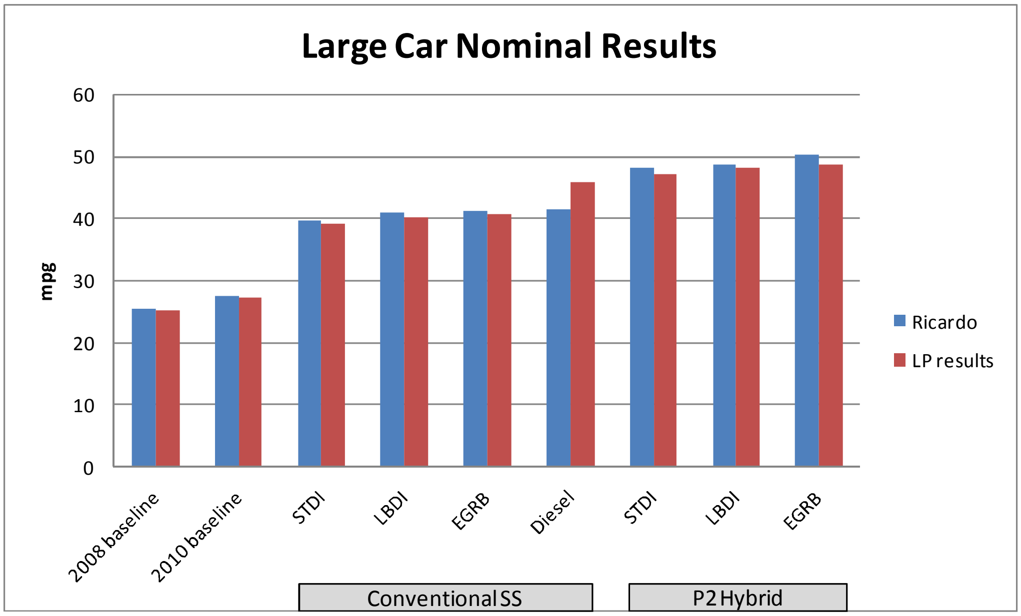


Figure 1.5-6 Comparison of LP to simulation results for Large Car class

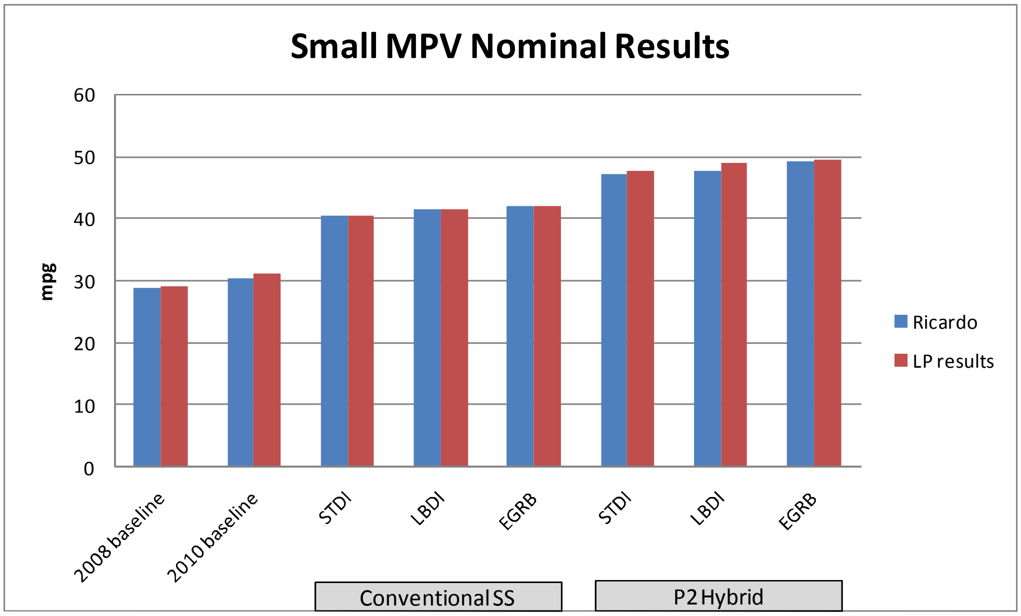


Figure 1.5-7 Comparison of LP to simulation results for Small MPV class

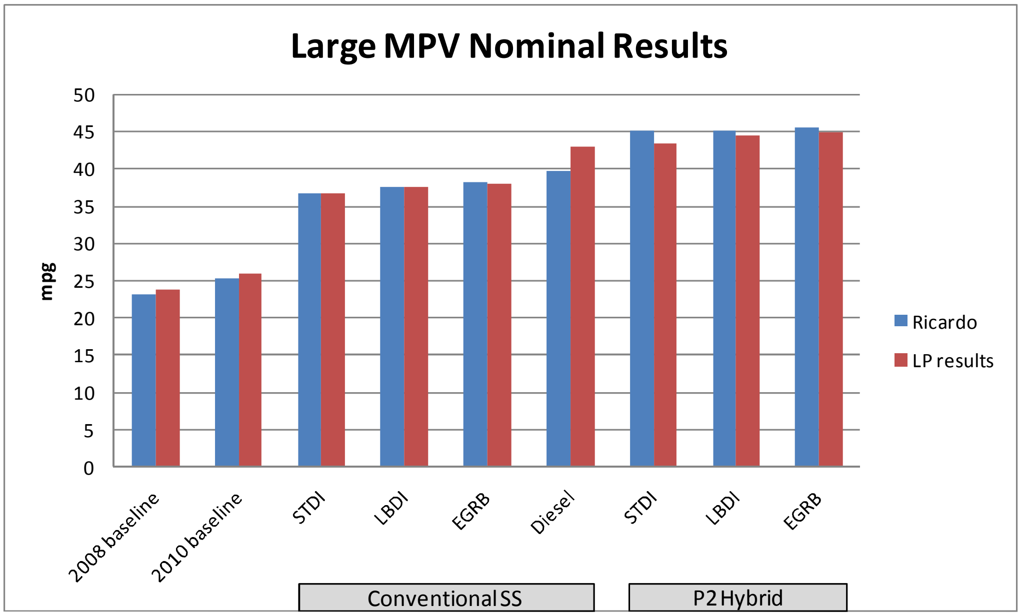


Figure 1.5-8 Comparison of LP to simulation results for Large MPV class

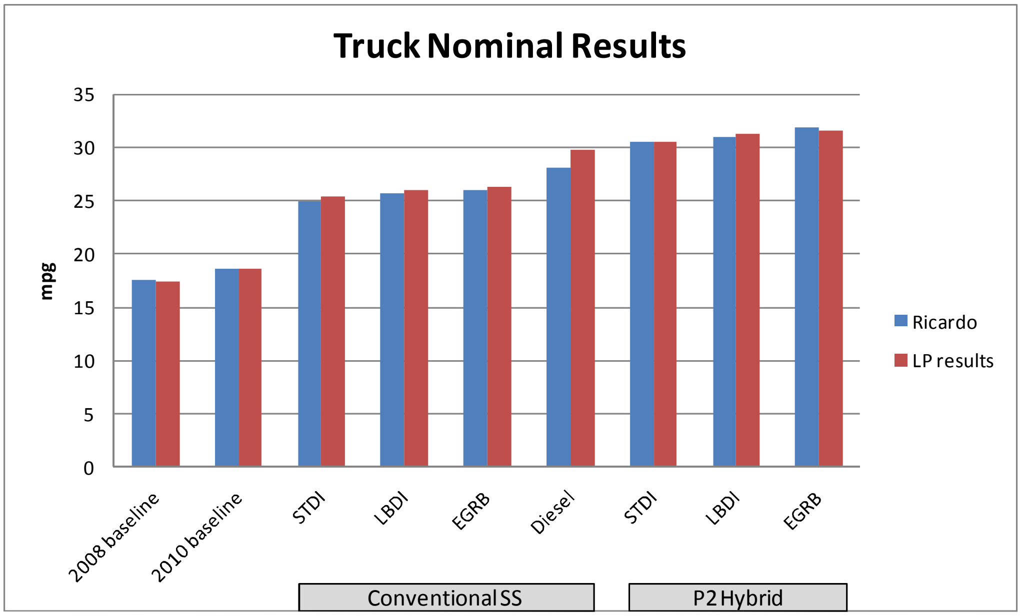


Figure 1.5-9 Comparison of LP to simulation results for Truck class

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.

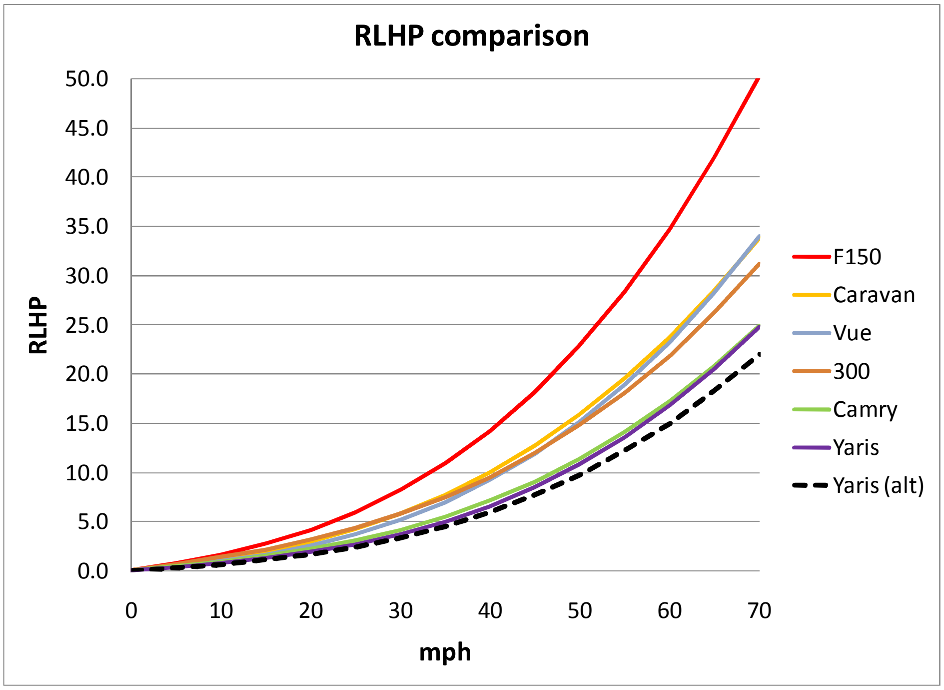


Figure 1.5-10 Road load power for modeled vehicles

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

[2] “OMEGA Master-sets and Ranked-sets of Packages,” Memorandum to Air Docket EPA-HQ-OAR-2010-0799 from Todd Sherwood, November 10, 2011.

[3] “OMEGA Master-sets and Ranked-sets of Packages,” Memorandum to Air Docket EPA-HQ-OAR-2010-0799 from Todd Sherwood, November 10, 2011.

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

[5] 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.

[6] Ref OMEGA description in RIA of 2012-2016 final rule

[7] U.S. EPA, “Project Report: 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, *Date TBD, Report# TBD*, Docket EPA-HQ-OAR-2010-0799.

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

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 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 it this is a very time-consuming and resource-intensive task). As a result, over the past year, EPA has begun to develop 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[9] and has also recently been published.[10] 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)(1).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 develop the light duty regulatory program but not for certification since it is not only feasible but common practice to certify light duty vehicles based on chassis-based vehicle testing. For light-duty vehicles, EPA has been developing this simulation tool for non-hybrid, hybrid, and electric vehicles, which is capable of simulating a wide range of conventional and advanced engines, transmissions, and vehicle technologies over various driving cycles. 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 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, It is also capable of simulating non-hybrid vehicles with a Dual-Clutch Transmission (DCT), under warmed-up conditions only. Additional simulation capabilities such as automatic transmissions, cold-start conditions, engine start-stops, and hybrid/electric vehicles are being developed by EPA for the final rule. In this proposal, we are using the current simulation tool in a more limited manner: to determine the maximum credit potential for A/C efficiency and to determine the default credit value for the pre-defined active aerodynamic and electrical load off-cycle technologies. See section 2.3 below.

The simulation tool 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 this tool in MATLAB/Simulink environment with a completely open source code. For the 2017 to 2025 GHG proposal, EPA used the simulation tool 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 the light-duty (LD) vehicle simulation model, 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

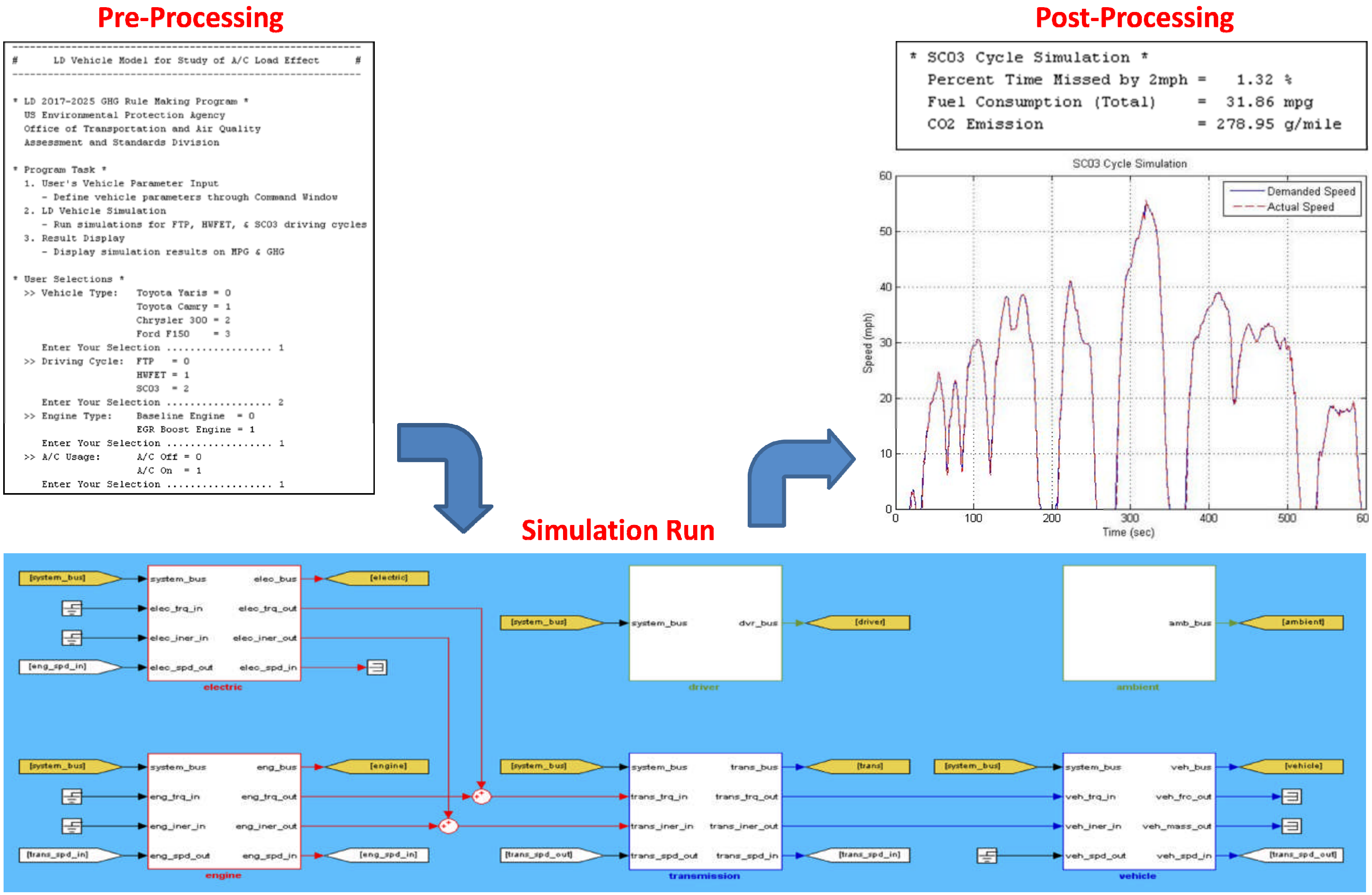
System	Component Models
Ambient	n/a
Driver	n/a
Electric	Accessory (electrical)
Engine	Accessory (mechanical), Cylinder
Transmission	Clutch, Gear
Vehicle	Final Drive, Differential, Axle, Tire, Chassis

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 prompts the user to enter desired inputs such as vehicle type, engine technology type, driving cycle, etc. Then, it initializes all necessary vehicle model parameters including engine maps, transmission gear ratios, and vehicle road load parameters. After the initialization, the script runs the Simulink vehicle model over the desired driving cycles. Upon completing the simulation, 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 version of the vehicle simulation tool is still in an early development stage and provides only a handful of simulation capabilities in terms of vehicle types, engine and transmission technologies, and driving cycles, it is undergoing constant upgrades and improvements to include more technology choices and simulation flexibilities. In fact, the first official version of the tool will have a Graphical User Interface (GUI) which will allow the user to choose from different technologies and other simulation options while making the use of the tool much easier and straightforward. The Section 2.4.2 will discuss and address these additional choices and simulation capabilities that are being planned for the improved version of the tool.

[9] "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.

[10] 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.



Pre-Processing

```
-------------------------------------------------------------------
#      LD Vehicle Model for Study of A/C Load Effect              #
-------------------------------------------------------------------

* LD 2017-2025 GHG Rule Making Program *
  US Environmental Protection Agency
  Office of Transportation and Air Quality
  Assessment and Standards Division

* Program Task *
  1. User's Vehicle Parameter Input
     - Define vehicle parameters through Command Window
  2. LD Vehicle Simulation
     - Run simulations for FTP, HWFET, & SC03 driving cycles
  3. Result Display
     - Display simulation results on MPG & GHG

* User Selections *
  >> Vehicle Type:   Toyota Yaris = 0
                     Toyota Camry = 1
                     Chrysler 300 = 2
                     Ford F150    = 3
     Enter Your Selection ................... 1
  >> Driving Cycle:  FTP   = 0
                     HWFET = 1
                     SC03  = 2
     Enter Your Selection ................... 2
  >> Engine Type:    Baseline Engine  = 0
                     EGR Boost Engine = 1
     Enter Your Selection ................... 1
  >> A/C Usage:      A/C Off = 0
                     A/C On  = 1
     Enter Your Selection ................... 1
```

Post-Processing

```
* SC03 Cycle Simulation *
  Percent Time Missed by 2mph =    1.32 %
  Fuel Consumption (Total)    =   31.86 mpg
  CO2 Emission                =  278.95 g/mile
```

Simulation Run

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 can be 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 the LD vehicle simulation tool, 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 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 the Proposed Rule

As mentioned previously, EPA used the vehicle simulation tool for the proposed 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 -- one 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. 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.[11,12] 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.[13,14,15] 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.

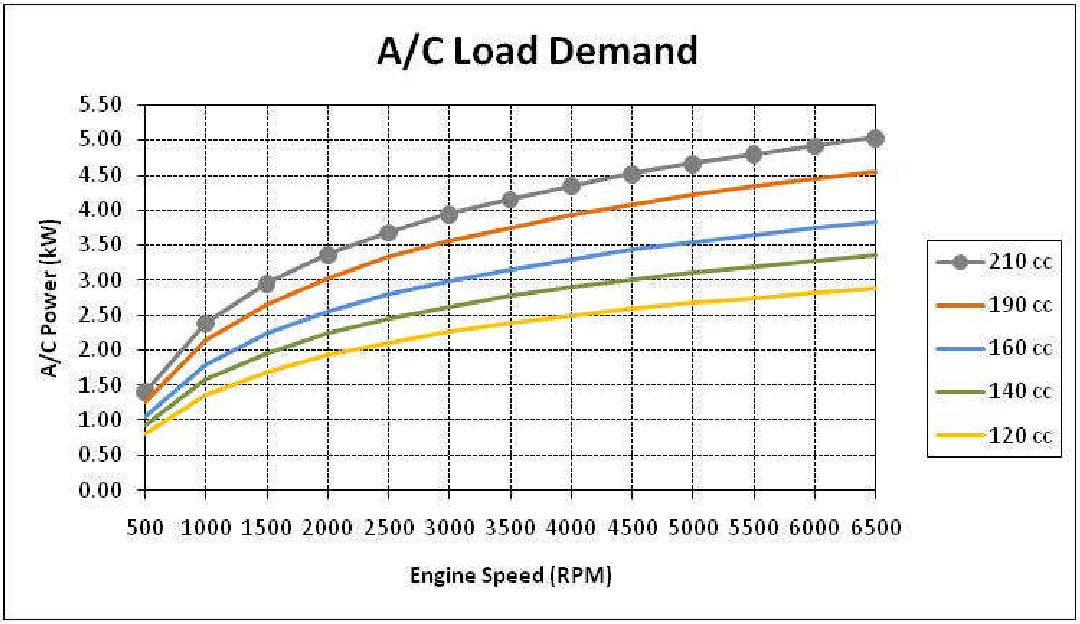


Figure 2.3-1 Representative A/C Compressor Load Curves

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 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.[16] 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 end 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[14] and NESCCAF[15] 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 very 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.[R]

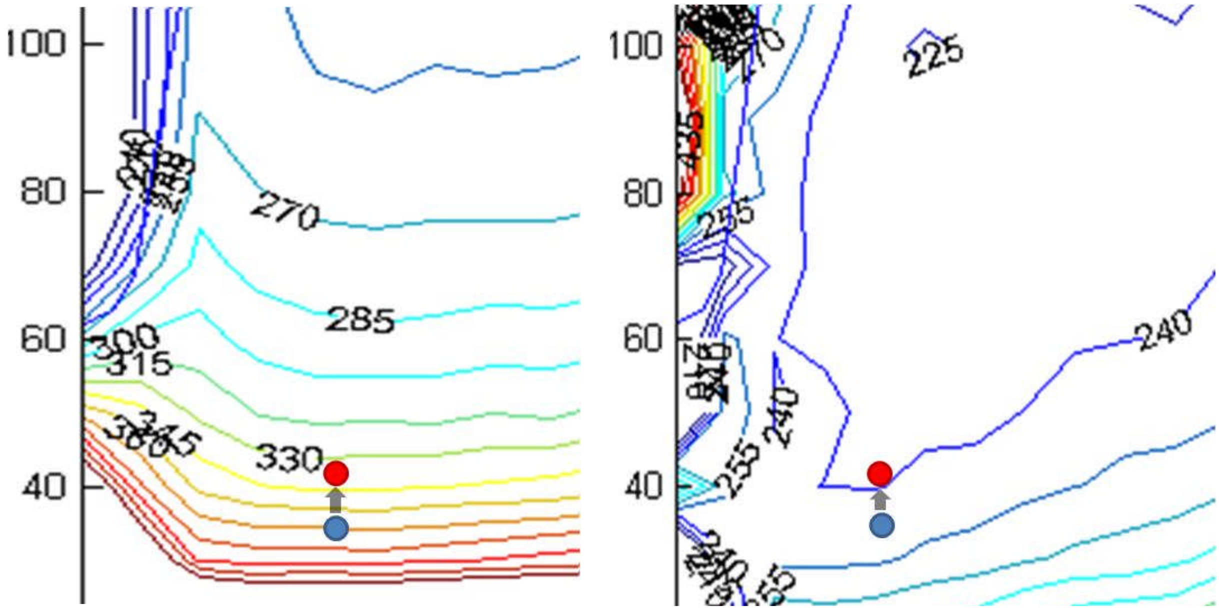


Figure 2.3-2 Average Engine Operating Conditions with A/C Off and A/C On over Fueling Maps for Baseline and EGR Boost Engines

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

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[R] 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.

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.

EPA is proposing to limit 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 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.

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

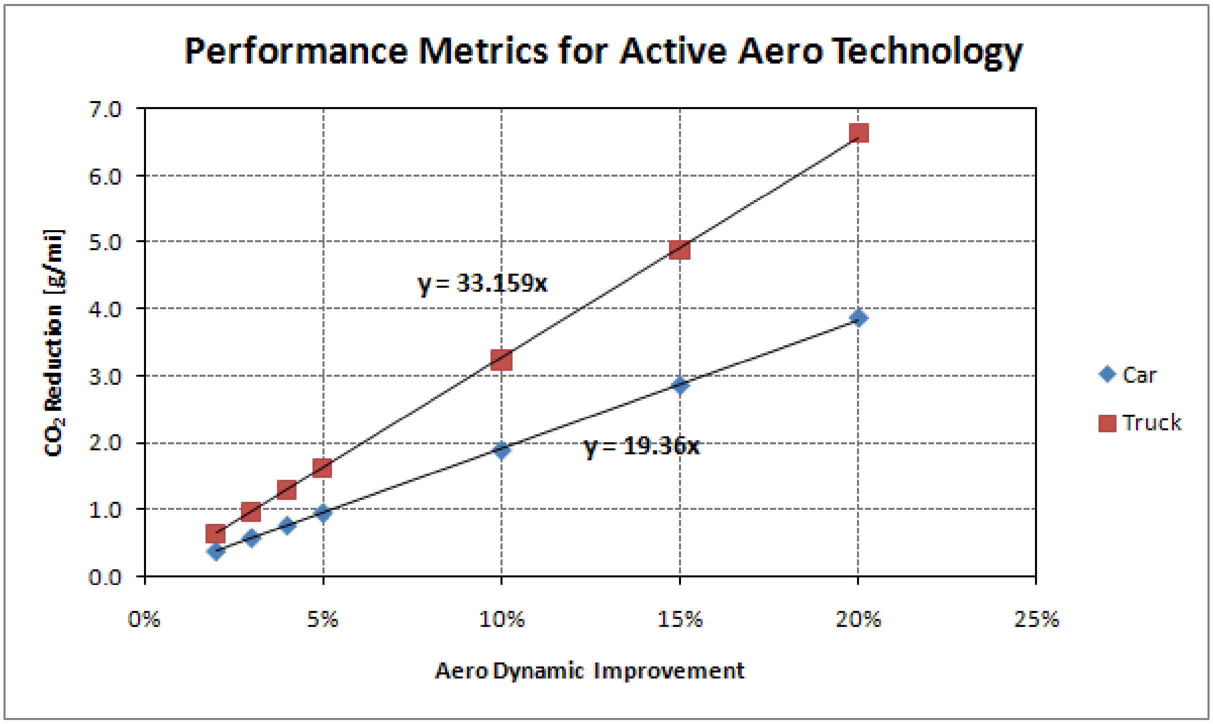

Figure 2.3-3 Simulated GHG Reduction Benefits of Active Aerodynamic Improvements

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 proposing to provide a credit for active aerodynamic technologies assuming that any of these technologies will achieve an aerodynamic drag of at least 3% improvement. The proposed default value for the credit will be 0.6 g/mile for cars and 1.0 g/mile for trucks, in accordance with the simulation results in

Table 2.3-3. It is conceivable that some systems can achieve better performance. Manufacturers may apply for greater credit for better performing systems through the normal application process described in Section III.C.5.b of the preamble to the proposed rule..

2.4 On-Going and Future Work

2.4.1 Simulation Tool Validation

Since the EPA's full vehicle simulation tool is still in the development phase, it has not been fully validated against actual 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 which had been calibrated and tuned with Ricardo's simulation results for a 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 the EPA's full vehicle simulation tool 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 before the final rule.

2.4.2 Simulation Tool Upgrade

As mentioned previously, the EPA's full light-duty vehicle simulation tool is still in the development phase. 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 assistance in further analysis for the final rule.

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 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 will 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 add hybrid electric vehicle (HEV) simulation capabilities. The HEV simulation tool is being currently developed within the EPA for power-split and P2 configurations. 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.

References

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3 Results of Proposed and Alternative Standards

3.1 Introduction

This chapter provides the methodology from and results of the technical assessment of the future vehicle scenarios presented in this proposal. 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.

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 16-18 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.[S]

EPA has described OMEGA's specific methodologies and algorithms previously in the model documentation,[17] the model is publically available on the EPA website,[18] and it has recently been peer reviewed.[19]

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 target has been met, OMEGA reports out the cost and societal benefits of doing so. OMEGA is capable of modeling two GHGs; carbon dioxide (CO_2) from fuel use and HFC refrigerant emissions from the air conditioning

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[S] 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 model. A/C improvements are relatively 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.

(A/C) system. 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 spreadsheet output files also 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.[T] While 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.[U]

OMEGA can be used to model either a single vehicle model or any number vehicle models. Vehicles can be those of specific manufacturers as in this analysis or generic fleet-average vehicles as in the 2010 Technical Assessment Report supporting the MY 2017-2025 NOI. Because OMEGA is an accounting model, the vehicles can be described using only a relatively few number of terms. The most important of these terms are the vehicle's baseline 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. Information required 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.[V] 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 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 "cap"). The effectiveness, cost, application limits of each technology package can also vary over time.[W] A list of technologies or packages is provided for each vehicle type, providing the connection to the specific vehicles being modeled and a description of these packages can be found in Chapter 1 of this draft RIA (DRIA)

[T] Vehicle simulation models may be used in creating the inputs to OMEGA as discussed in Draft Joint TSD Chapter 3 as well as Chapter 1 of the Draft RIA.

[U] While OMEGA does not model changes in vehicle sales, Draft RIA Chapter 8 discusses this topic.

[V] A vehicle's footprint is the product of its track width and wheelbase, usually specified in terms of square feet.

[W] "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.

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 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 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 constraints, as discussed in Draft Joint TSD 3) to vehicles until the sales-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 also 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 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.

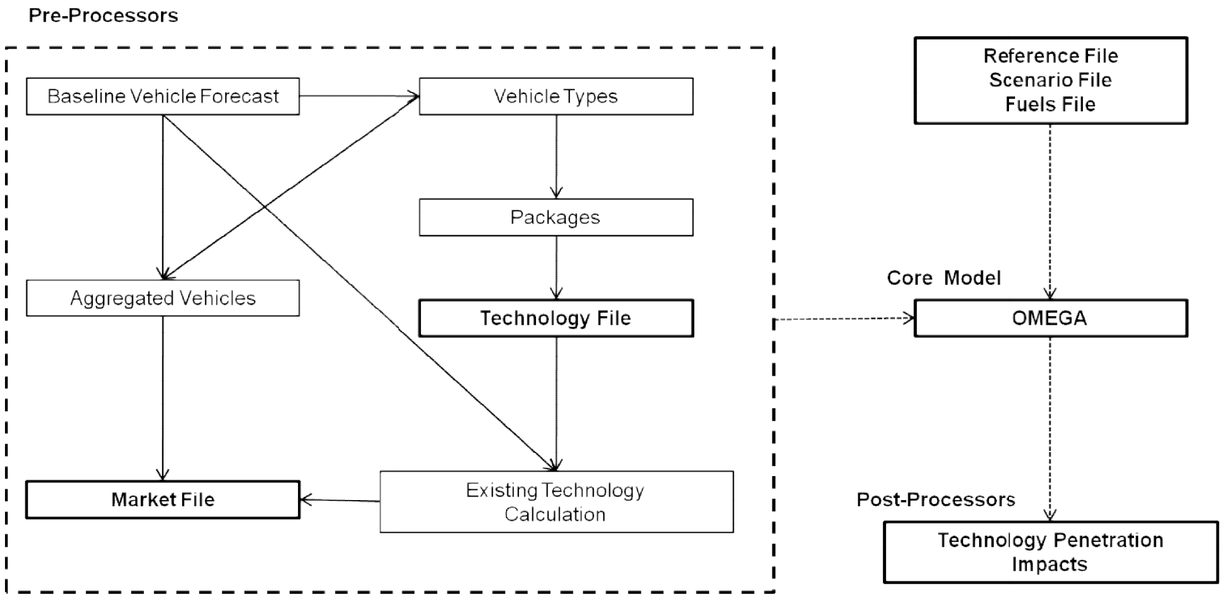
Once technology has been added so that every manufacturer meets the specified targets (or exhausts all of the available technologies), the model produces a variety of output files. These files include specific information about the technology added to each vehicle and the resulting costs and emissions. 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,[X] creating and ranking technology packages,[Y] and calculating the degree to which technology is present on baseline vehicles. The OMEGA core model collates this information and produces estimates of increases in vehicle cost and CO_2 reduction. Based on the OMEGA core model output, the technology penetration of the new vehicle mix and the scenario impacts (fuel savings, emission impacts, and other monetized benefits) are calculated by post-processors. The pre- and post-processors are Microsoft Excel spreadsheets and visual basic programs, 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

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[X] Joint Draft TSD Chapter 1
[Y] DRIA Chapter 1

which set of technologies can be applied to that vehicle. Chapter 1 of the Joint TSD contains a description of how the vehicle reference fleets 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 2008 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 Draft 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, primarily their cost, effectiveness, and electricity consumption. This information was described in Chapter 1 of this Draft RIA and Chapter 3 of the Draft 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 DRIA.

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 Draft Joint TSD.

The fourth type of data describes the CO_2 emission standards being modeled. These include the MY 2016 standards and the proposed standards. As described in more detail in Chapter 5 of the Draft Joint TSD and briefly in section 3.8.5 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 3.8.5, below.

The input files used in this analysis, as well as the current version of the OMEGA core 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 Draft Joint.TSD and in this RIA.

3.4 Model Inputs

3.4.1 Market Data

3.4.1.1 Vehicle platforms

As discussed in Draft Joint TSD Chapter 3 and in Chapter 1 of the DRIA, 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 3.4-2) 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 Type #	Name	Cam	Engine
1	Subcompact Car	DOHC	I4
2	Compact Car I4	DOHC	I4
3	Midsize Car/Small MPV (unibody)	DOHC	I4
4	Compact Car/Small MPV (unibody)	DOHC	V6
5	Midsize/Large Car	DOHC	V6
6	Midsize Car/Large Car	DOHC	V8
7	Mid-sized MPV (unibody)/Small Truck	DOHC	I4
8	Midsize MPV (unibody)/Small Truck	SOHC	V6
9	Large MPV (unibody)	SOHC	V8
10	Large MPV (unibody)	SOHC	V8
11	Large Truck (+ Van)	SOHC	V6
12	Large Truck + Large MPV	OHV	V6
13	Large Truck (+ Van)	OHV	V8
14	Large Truck (+Van)	SOHC3V	V8
15	Large Car	OHV	V8
16	Large MPV (unibody)	DOHC	V6
17	Large MPV (unibody)	DOHC	V8
18	Large Truck (+ Van)	DOHC	V6
19	Large Truck (+ Van)	DOHC	V8

Table 3.4-2 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 for the market data input file utilized by OMEGA, which characterizes the vehicle fleet, our modeling accounts for the fact that many 2008 MY vehicles are already equipped with one or more of the technologies discussed in Draft Joint TSD 3. Because of the choice to apply technologies in packages, and because 2008 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 2008 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 2008 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 of each technology package's incremental effectiveness and incremental cost is affected by the technology already present on the baseline vehicle. In this step , we calculate the degree to which a technology package's effectiveness is already present on the baseline vehicle, and produces a value for each package termed the technology effectiveness basis, or TEB. 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 TEB for each applicable technology package is determined as follows:

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

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 MY 2008 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.[Z]

[Z] The OMEGA TEB/CEB calculator used in the analysis of the proposal did not properly calculate CEBs for vehicles where a more efficient and less expensive engine was placed in a vehicle. We estimate that this issue

3.4.1.3 Accounting for Net Mass Reduction and Safety related Mass reduction

For this analysis, EPA modified its application of mass reduction to be similar to that used by NHTSA in the CAFE model analysis. In this methodology, and in contrast to the approach taken in the MY 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 includes no net additional fatalities to the fleet. Manufacturers may not necessarily apply mass reduction in this manner, but EPA demonstrates that a technically feasible and economically practicable 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 2011 Kahane report and the related adjustments for improvements in federal motor vehicle safety standards (FMVSS) as discussed in Section II.G of the Preamble to the proposed rule, and are subject to the same caveats.[AA] Changes to these coefficients would change the projected amount of mass reduction projected for the fleet.

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 coefficients used in the analysis, reducing weight from trucks above 4,594 pounds and from minivans, reduces fatalities. By contrast, this analysis implies 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**

).

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	1.44%	12.38	0.884	1.58E-12
PC above 3106	0.47%	10.33	0.884	4.29E-13
LT below 4594	0.52%	14.77	0.884	6.79E-13
LT above 4594	-0.39%	14.43	0.884	-4.97E-13
Minivan	-0.46%	8.30	0.884	-3.38E-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

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causes an overestimate of compliance costs by approximately $25 across the fleet in MY 2025, and will update the model appropriately in the final rulemaking.

[AA] Please note that the OMEGA safety assessment was performed with a draft version of the FMVSS adjustment , that raises the impact of the coefficients by approximately 1% relative to the analysis conducted by NHTSA, which uses an FMVSS adjustment of 0.874

The mass reduction scoping tool contains the entire fleet discussed in TSD 1, along with their curb weight, and their passenger car, light truck, minivan classification according to the criteria in the 2011 Kahane report. Using this tool, EPA determined that a simulation of fatality neutrality could result by assuming that no passenger car was light-weighted below 3,000 pounds, and no light trucks were reduced below 4,594 pounds. These values were determined iteratively, with the end product a fatality neutral analysis. Vehicles above these weight could have their weight reduced through mass reduction technology in the OMEGA model. The per vehicle 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. This was not done in the MYs 2012-2016 analysis or in the technical assessment report. A table of these weight impacts is presented in Draft Joint TSD Chapter 3. EPA did not include a weight penalty for dieselization, but will consider including such impacts in the final rulemaking. The per-vehicle limit on weight reduction determined above is for net mass reduction, not for 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 2008 fleet.

To implement this schema, each vehicle in the 2008 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 have an associated list of technology packages, costs and effectivenesses.[BB] 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.[CC] The processes to build and rank technology packages for the technology file are described in detail in Chapter 1 of the DRIA.

For this analysis, a separate technology file was developed for each 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 Draft Joint TSD Chapter 3, and also differ due to the different limits on maximum penetrations of technologies.

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.

Equation 3.4-3 – Calculation of New CO_2

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

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

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[BB] 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.

[CC] 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 Draft Joint TSD.

the baseline. Cost can be calculated for the application of the 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.

In light of the complex set of technology caps used in this analysis, EPA modified the methodology used to generate the OMEGA technology input file relative to previous analyses. As background, for both the MY 2012-2016 rulemaking analysis and the Technical Assessment Report supporting the 2017-2025 NOI, the technology caps generally fell into a few broad numeric categories. As an example, in the analysis supporting the 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 draft TSD, there are both more technologies and more technology cap levels considered in this proposal. Thus, it was more difficult to construct packages with uniform sets of caps. As a means of doing so in this 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 technology 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.

For reference case runs, EPA used three sets of TEB/CEB files in order to model the input caps.

- Set A is a normally Ranked Master-set (30%)
- Set B removes 8sp trans, IACC2, Aero2 from Set A (55%)

- Set C removes CCP, DCP, Deac, DVVL, CCC, GDI, TDS18, TDS24, 6sp trans, EPS, Stop-start, SAX, Aero1, DSL-Adv from Set B (15%)

For proposal and alternative runs in MY 2021, EPA used four sets of TEB/CEB files in order to model the input caps.

- Set A is a normally Ranked Master-set (60%)
- Set B removes HEG & EFR2 from Set A (15%)
- Set C removes LRRT2 from Set B (5%)
- Set D removes 8sp trans, Aero2, IACC2 from Set C (20%)

In creating the OMEGA input market file and technology file, these sets were then weighted together according to the fractions listed next to each set above. As an example, eight speed transmissions are capped at 80% in 2021 (see TSD 3). When weighted together, set D, which removes eight speed transmissions only gets 20% of the weighting in the cost, effectiveness and electric conversion fraction. Using this method, in the OMEGA input file, the cost, effectiveness and electricity consumption of each package was calculated to reflect the weighted cost and effectiveness of each package after accounting for the weighting of the sets.[DD] The technology penetrations are also calculated using the weighting of each set. Using the combination of the set weighting, and the technology cap feature in the technology input file, EPA reflects the analytic constraints. For the final rulemaking, EPA intends to simplify this process. When a technology package is applied to fewer than 100% of the sales of a vehicle model due to the market penetration cap, OMEGA tracks the sales volume of vehicles with each technology package applied.

OMEGA also tracks electrical consumption 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

[DD] Please note that incremental effectiveness values were not simply weighted together, as the resulting rates would not be correct. Therefore, EPA calculated the accurate CO_2 and backcalculated the appropriate incremental effectiveness values.

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 =

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

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

3.5 The Scenario File

3.5.1 Reference Scenario

In order to determine the technology costs associated with this NPRM, EPA performed three separate modeling exercises. The first was to determine the costs associated with meeting the MY 2016 CO_2 regulations. EPA considers the MY 2016 CO_2 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 NPRM alone, EPA seeks to subtract out any costs associated with meeting any existing standards related to GHG emissions.

EPA assumes that in the absence of the proposed GHG and CAFE standards, the reference case fleet in MY 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 MY 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.

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 MY 2017-2025. One important element supporting the proposed approach is that AEO2011 projects relatively stable gasoline prices over the next 15 years. The average actual gasoline price in the U.S. for the first nine months of 2011 of $3.57 per gallon ($3.38 in 2009 dollars)[EE]. However, the AEO2011 reference case projects a 2011 price of $2.80 per gallon (in 2009 dollars), well below actual prices. AEO2011 projects prices to be $3.25 in 2017, rising slightly to $3.54 per gallon in 2025 (which is less than a 4 cent/year increase on average). 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.

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 seminal reference on new light-duty vehicle CO_2 emissions and fuel economy.[FF] 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,[GG] 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) and have 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.

[17] 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)

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

[19] EPA-420-R-09-016, September 2009.

[EE] The Energy Information Administration estimated the average regular unleaded gasoline price in the U.S. for the first nine months of 2011 was $3.57 per gallon.

[FF] Light-Duty Automotive Technology, Carbon Dioxide Emissions, and Fuel Economy Trends: 1975 through 2010, November 2010, available at www.epa.gov/otaq/fetrends.htm.

[GG] There are no EPA LD GHG emissions regulations prior to MY 2012.

Table 3.5-1

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 3.5-2

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

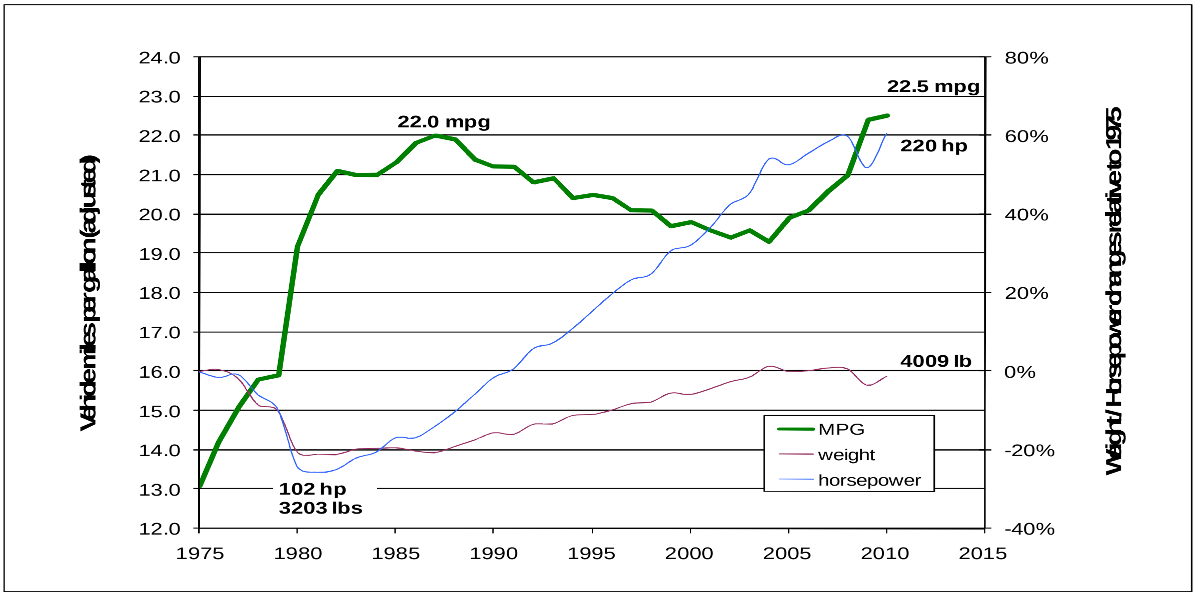
Year	Standard	GM	Ford	Chrysler	Sales-Weighted average	Delta	Vehicle Weight		Toyota	Honda	Nissan	Sales-Weighted average	Delta	Vehicle Weight		Vehicle Weight delta
1986	20.0	20.2	20.3	20.7	20.3	0.3	3917		26.1		24.7	25.5	5.5	3240		677
1987	20.5	20.5	20.5	21.3	20.7	0.2	3876		25.9		23.5	24.9	4.4	3259		617
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 MY 2012-2016 standards are footprint-based, every major manufacturer is expected to be constrained by the new standards in 2016 and manufacturers of small vehicles will not routinely over-comply as they had with the past universal standards.[HH] Thus, the historical evidence and the footprint-based design of the 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. There are additional factors that reinforce the historical evidence. 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.[20]

Figure 3.5-2 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.[II] All projections of actual GHG emissions and fuel economy performance in 2016 or any other future year are projections, of course, and it is plausible that actual GHG emissions and fuel economy performance in 2017-2025, absent more stringent standards, could be lower than projected if there are shifts from car market share to truck market share, or to higher footprint levels.

Figure 3.5-2 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)



[HH] With the notable exception of manufacturers who only market electric vehicles or other limited product lines.

[II] 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.

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 caps. 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 alternative refrigerant cost 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 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 decline 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 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 (Table 3.5-3). In the OMEGA projections, the vast majority of companies do not use EVs or PHEVs to comply with the MY 2016 standards. Five smaller companies under the technology restrictions set forth in this analysis, cannot comply with the MY 2016 standards.[JJ] This finding is consistent with the MY 2012-2016 rule analysis, and are Daimler, Geely-Volvo, Volkswagen, Porsche and Tata (which is comprised of Jaguar and Land Rover vehicles in the U.S. fleet). [21]

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 make 8%-10% of their fleet EVs and PHEVs by MY 2016. As an alternative to this choice, these

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[JJ] 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. 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 cut point include Lotus, Aston Martin, and McLaren.

companies could exceed the 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 MY 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 proposed later MY standards.

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.[KK] Again, this analytic choice increases the incremental costs of the MY 2017-MY 2025 program for these companies.

Table 3.5-3 – MY 2016 EV+PHEV Penetrations

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)
Daimler	17	-	$1,506	8%
Geely-Volvo	18	-	$1,869	9%
Porsche	46	23	$2,570	11%
Tata	20	-	$1,826	10%
Volkswagen	10	-	$645	5%

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.[LL] The Temporary Leadtime Allowance Alternative Standards (TLAAS), as analyzed in RIA chapter 5 of the

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[KK] In the OMEGA analysis, only BMW's MY 2016 compliance costs increase (by ~$350) because EV and PHEV technology was made unavailable.

[LL] The credit available for producing FFVs will have expired, although the real world usage credits will be available.

MY 2012-2016 rule, is projected have an impact of approximately 0.1 g/mile in MY 2016, and expire afterwards. Therefore, no incentive credits are projected to be available to the reference case. Off-cycle credits, which are designed to be environmentally neutral, would only lower costs. These credits are not modeled here due to the difficult in predicting manufacturers use of these credits under the MY 2016 program.

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 proposal 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 MY 2012-2016 and proposed MY 2017-2025 GHG rules.

3.5.2 Control Scenarios

Similar to the reference scenario, OMEGA runs were conducted in 2021 and 2025 for the proposal and 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 Draft Joint TSD Chapter 2. As in MYs 2012-2016, the curves from that joint fitting process 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 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 for cars and 24.4 for light trucks..

EPA's NPRM 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 is related to the standard level proposed. For purposes of this cost modeling, we assume that this cap is never reached. This does not imply that EPA has proposed a cap based on this criteria. The proposed PH/EV multipliers were not modeled in this analysis, but may be considered in the final rule analysis. A discussion of the potential impacts of these credits can be found in preamble section III.B and DRIA 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.[MM]

[MM] The costs for PHEVs and EVs in this rule reflect those costs discussed in Draft 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 proposed credit for HEV and performance based pickups was also not modeled in this proposal analysis of costs. Off-cycle credits, which are not modeled here, could only reduce costs. A discussion of the potential impacts on a g/mile and total tons basis can be found in DRIA chapter 4.

Like the reference case, car truck trading was allowed without limit. Depending on comment and other new input, these proposed flexibilities may be modeled differently for the final rule.

3.6 Fuels and reference data

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

VMT used in the payback analysis, which is used for calculating TARFs, was determined using the EPA benefits post-processor. As the general VMT formula used in this proposal is dependent on a vehicle's fuel cost per mile (see Draft Joint TSD Chapter 4), this was determined in an iterative process.

3.7 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 proposal, and all alternatives allow for averaging across a manufacturer's cars and trucks, 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 proposed regulations which govern credit trading between these two vehicle classes.[NN]

The model then works with one manufacturer at a time to add technologies until that manufacturer meets its applicable proposed 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 purchasers 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

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[NN] The analysis for the control cases in this proposal was run with slightly different lifetime VMT estimates than those proposed in the regulation. The impact is on the cost estimates is small and varies by manufacturer.

five years.[OO] 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).[PP] Any residual value of the additional technology which might remain when the vehicle is sold is not considered for this analysis. 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). 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 3.7-1 – 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.[22] Please note that the TARF equation does not consider attributes other than cost effectiveness 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 before the plug-in hybrid. The current TARF does not reflect potential consumer concerns with the range limits of the electric vehicle, although it could be modified to do so. 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

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

[PP] 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.

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 component of the manufacturer-based net cost-effectiveness equation is not a measure of the social cost of this proposed 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. [QQ]

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 draft RIA contains further detail on the values of manufacturer-based net cost-effectiveness for the various technology packages.

3.8 Analysis Results

3.8.1 Targets and Achieved Values

3.8.1.1 Reference Case

[QQ] 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 proposal, this factor was not included in our determination of manufacturer-based net cost-effectiveness in the analyses.

Table 3.8-1 Reference Case Targets and Projected Shortfall in MY 2021

Manufacturer	Car Target	Truck Target	Fleet Target (VMT and Sales Weighted)	Fleet Target (Sales weighted)	Car Achieved	Truck Achieved	Shortfall
Aston Martin	222	-	222	222	342	-	119
BMW	228	285	245	243	234	284	3
Chrysler/Fiat	230	295	261	259	224	300	-
Daimler	239	301	256	254	251	329	17
Ferrari	235	-	235	235	386	-	152
Ford	230	306	259	256	232	304	-
Geely	232	280	248	247	246	302	17
General Motors	229	308	271	268	227	310	-
Honda	222	283	243	241	214	297	-
Hyundai	223	280	236	235	224	277	-
Kia	225	291	241	239	222	299	-
Lotus	206	-	206	206	241	-	35
Mazda	223	276	233	232	228	253	-
Mitsubishi	219	270	238	237	222	265	-
Nissan	227	294	249	247	222	303	-
Porsche	206	287	227	225	251	333	46
Spyker	222	280	231	230	249	325	30
Subaru	216	267	229	228	229	230	0
Suzuki	208	272	221	219	209	268	-
Tata	250	273	262	261	244	322	24
Tesla	206	-	206	206	-	-	-
Toyota	221	293	251	249	209	309	-
Volkswagen	219	296	236	234	222	326	9
Fleet	225	297	253	250	222	304	1

Table 3.8-2 Reference Case Targets and Projected Shortfall in MY 2025

Manufacturer	Car Target	Truck Target	Fleet Target (VMT and Sales Weighted)	Fleet Target (Sales weighted)	Car Achieved	Truck Achieved	Shortfall
Aston Martin	222	-	222	222	342	-	119
BMW	228	286	245	243	234	287	4
Chrysler/Fiat	229	294	259	257	225	299	-
Daimler	239	302	255	253	253	329	17
Ferrari	235	-	235	235	386	-	152
Ford	230	304	255	253	232	301	-
Geely	232	280	248	246	245	302	16
General Motors	229	307	269	266	226	307	-
Honda	222	282	242	240	214	299	-
Hyundai	223	280	236	234	224	277	-
Kia	224	292	240	239	221	303	-
Lotus	206	-	206	206	241	-	35
Mazda	223	277	233	232	228	255	-
Mitsubishi	219	270	238	236	222	265	-
Nissan	227	292	248	246	222	302	-
Porsche	206	287	226	224	251	333	46
Spyker	222	280	230	229	249	325	30
Subaru	216	267	229	227	228	231	0
Suzuki	208	272	220	219	209	268	-
Tata	250	273	261	260	244	322	22
Tesla	206	-	206	206	-	-	-
Toyota	221	292	249	247	209	309	-
Volkswagen	219	296	236	234	222	326	9
Fleet	225	295	251	248	222	303	1

3.8.1.1 Proposal and Alternatives

Table 3.8-3 Proposal Targets and Projected Shortfall in MY 2021

Manufacturer	Car Target	Truck Target	Fleet Target (VMT and Sales Weighted)	Fleet Target (Sales weighted)	Car Achieved	Truck Achieved	Shortfall
Aston Martin	171	-	171	171	193	-	22
BMW	175	236	193	191	181	222	-
Chrysler/Fiat	176	246	211	208	182	239	-
Daimler	184	252	203	201	180	263	-
Ferrari	181	-	181	181	220	-	39
Ford	177	261	209	205	188	243	-
Geely	178	230	196	194	176	234	-
General Motors	176	261	222	218	188	250	-
Honda	170	233	192	190	174	225	-
Hyundai	171	230	185	183	177	210	-
Kia	172	242	190	188	180	218	-
Lotus	157	-	157	157	157	-	-
Mazda	171	226	182	181	178	197	-
Mitsubishi	168	220	188	186	178	204	-
Nissan	174	247	199	197	175	243	-
Porsche	157	237	179	176	149	260	-
Spyker	170	230	180	179	164	258	-
Subaru	165	217	179	177	180	177	-
Suzuki	158	222	171	170	162	207	-
Tata	193	223	209	208	169	243	-
Tesla	157	-	157	157	-	-	-
Toyota	169	245	202	199	175	238	-
Volkswagen	167	247	186	184	163	258	-
Fleet	173	249	203	199[RR]	178	239	-

[RR] While OMEGA does not model changes in vehicle sales, Draft RIA Chapter 8 discusses this topic.

Table 3.8-4 Proposal Targets and Projected Shortfall in MY 2025

Manufacturer	Car Target	Truck Target	Fleet Target (VMT and Sales Weighted)	Fleet Target (Sales weighted)	Car Achieved	Truck Achieved	Shortfall
Aston Martin	142	-	142	142	142	-	-
BMW	146	194	160	159	145	196	-
Chrysler/Fiat	146	201	172	170	148	199	-
Daimler	153	208	167	166	146	230	-
Ferrari	150	-	150	150	159	-	9
Ford	147	213	170	167	153	200	-
Geely	148	189	162	160	141	204	-
General Motors	146	213	181	178	146	212	-
Honda	142	191	158	156	143	186	-
Hyundai	142	188	153	151	145	178	-
Kia	143	199	157	155	146	189	-
Lotus	131	-	131	131	131	-	-
Mazda	142	186	150	149	145	172	-
Mitsubishi	139	180	154	153	144	171	-
Nissan	145	202	164	162	143	204	-
Porsche	131	195	146	144	119	231	-
Spyker	141	188	149	148	133	231	-
Subaru	137	177	147	146	147	149	-
Suzuki	132	181	141	140	132	179	-
Tata	161	182	172	171	134	208	-
Tesla	131	-	131	131	-	-	-
Toyota	141	200	165	163	140	201	-
Volkswagen	139	203	154	152	133	225	-
Fleet	144	203	166	163	144	202	-

Table 3.8-5 Alternative 1- (Trucks +20) Targets and Projected Shortfall in MY 2021

Manufacturer	Car Target	Truck Target	Fleet Target (VMT and Sales Weighted)	Fleet Target (Sales weighted)	Car Achieved	Truck Achieved	Shortfall
Aston Martin	171	-	171	171	193	0	22
BMW	175	256	199	197	186	230	-
Chrysler/Fiat	176	267	221	217	195	248	-
Daimler	184	273	209	206	188	263	-
Ferrari	181	-	181	181	220	0	39
Ford	177	284	217	213	196	253	-
Geely	178	250	203	201	186	235	-
General Motors	176	283	234	229	200	262	-
Honda	170	253	199	196	182	229	-
Hyundai	171	250	189	187	180	216	-
Kia	172	263	195	193	185	224	-
Lotus	157	-	157	157	157	0	-
Mazda	171	245	186	184	181	204	-
Mitsubishi	168	238	195	192	184	212	-
Nissan	174	267	206	203	185	245	-
Porsche	157	258	184	181	154	264	-
Spyker	170	249	183	181	168	259	-
Subaru	165	235	184	182	184	182	-
Suzuki	158	241	175	173	167	207	-
Tata	193	242	219	217	190	244	-
Tesla	157	-	157	157	0	0	-
Toyota	169	266	211	207	180	251	-
Volkswagen	167	268	191	188	170	258	-
Fleet	173	270	211	207	186	248	-

Table 3.8-6 Alternative 2- (Trucks -20) Targets and Projected Shortfall in MY 2021

Manufacturer	Car Target	Truck Target	Fleet Target (VMT and Sales Weighted)	Fleet Target (Sales weighted)	Car Achieved	Truck Achieved	Shortfall
Aston Martin	171	0	171	171	193	0	22
BMW	175	217	188	186	173	222	-
Chrysler/Fiat	176	227	201	199	176	227	-
Daimler	184	232	198	196	172	263	-
Ferrari	181	0	181	181	220	0	39
Ford	177	241	201	199	181	234	-
Geely	178	212	190	189	167	234	-
General Motors	176	241	211	208	175	242	-
Honda	170	215	186	184	169	216	-
Hyundai	171	212	181	179	171	210	-
Kia	172	223	185	184	174	217	-
Lotus	157	0	157	157	157	0	-
Mazda	171	208	178	177	174	195	-
Mitsubishi	168	202	181	180	170	198	-
Nissan	174	228	193	191	167	240	-
Porsche	157	219	174	172	143	259	-
Spyker	170	212	177	176	161	258	-
Subaru	165	199	174	173	173	177	-
Suzuki	158	204	168	167	159	204	-
Tata	193	205	199	199	162	231	-
Tesla	157	0	157	157	0	0	-
Toyota	169	226	194	192	167	228	-
Volkswagen	167	228	181	180	158	257	-
Fleet	173	230	195	193	171	232	-

Table 3.8-7 Alternative 3- (Cars +20) Targets and Projected Shortfall in MY 2021

Manufacturer	Car Target	Truck Target	Fleet Target (VMT and Sales Weighted)	Fleet Target (Sales weighted)	Car Achieved	Truck Achieved	Shortfall
Aston Martin	190	0	190	190	193	0	2
BMW	196	236	208	206	197	233	-
Chrysler/Fiat	197	247	221	219	195	249	-
Daimler	205	253	218	217	198	267	-
Ferrari	202	0	202	202	220	0	18
Ford	197	262	222	219	199	259	-
Geely	199	231	210	209	191	244	-
General Motors	196	262	231	229	199	259	-
Honda	190	233	205	203	187	239	-
Hyundai	191	231	200	199	191	231	-
Kia	192	243	205	204	195	235	-
Lotus	176	0	176	176	176	0	-
Mazda	191	226	198	197	195	210	-
Mitsubishi	187	220	200	199	189	215	-
Nissan	194	248	213	211	188	259	-
Porsche	176	238	192	190	166	264	-
Spyker	190	230	196	196	184	260	-
Subaru	184	217	193	192	191	196	-
Suzuki	177	222	186	185	177	217	-
Tata	215	223	219	219	190	244	-
Tesla	176	0	176	176	0	0	-
Toyota	189	246	214	211	184	252	-
Volkswagen	187	248	201	199	184	258	-
Fleet	193	250	215	213	191	251	-

Table 3.8-8 Alternative 4- (Cars -20) Targets and Projected Shortfall in MY 2021

Manufacturer	Car Target	Truck Target	Fleet Target (VMT and Sales Weighted)	Fleet Target (Sales weighted)	Car Achieved	Truck Achieved	Shortfall
Aston Martin	151	0	151	151	0	193	42
BMW	155	236	179	177	222	178	-
Chrysler/Fiat	156	247	201	197	227	201	-
Daimler	163	253	188	185	262	188	-
Ferrari	160	0	160	160	0	220	60
Ford	157	262	196	192	228	196	-
Geely	158	231	183	180	234	183	-
General Motors	156	262	213	208	243	212	-
Honda	150	233	179	176	212	179	-
Hyundai	151	231	170	167	201	170	-
Kia	152	243	175	173	213	175	-
Lotus	139	0	139	139	0	139	-
Mazda	151	226	166	164	190	166	-
Mitsubishi	148	220	176	173	197	175	-
Nissan	154	248	186	183	232	186	-
Porsche	139	238	165	162	257	172	7
Spyker	150	230	164	162	258	164	-
Subaru	146	217	165	163	167	165	-
Suzuki	140	222	157	155	201	157	-
Tata	171	223	199	197	231	199	-
Tesla	139	0	139	139	0	0	-
Toyota	150	246	191	187	225	191	-
Volkswagen	148	248	171	168	254	171	-
Fleet	153	250	191	187	229	190	-

Table 3.8-9 Alternative 1- (Trucks +20) Targets and Projected Shortfall in MY 2025

Manufacturer	Car Target	Truck Target	Fleet Target (VMT and Sales Weighted)	Fleet Target (Sales weighted)	Car Achieved	Truck Achieved	Shortfall
Aston Martin	142	0	142	142	0	142	-
BMW	146	213	166	164	202	165	-
Chrysler/Fiat	146	221	182	178	207	182	-
Daimler	153	228	173	170	230	173	-
Ferrari	150	0	150	150	0	159	9
Ford	147	234	177	174	204	177	-
Geely	148	207	168	166	204	167	-
General Motors	146	234	192	188	219	192	-
Honda	142	210	164	162	194	163	-
Hyundai	142	207	157	155	184	157	-
Kia	143	218	161	159	194	161	-
Lotus	131	0	131	131	0	131	-
Mazda	142	204	154	152	172	154	-
Mitsubishi	139	198	161	159	176	161	-
Nissan	145	221	170	168	213	170	-
Porsche	131	214	151	149	231	151	-
Spyker	141	207	151	150	232	151	-
Subaru	137	195	152	150	157	152	-
Suzuki	132	200	145	143	183	144	-
Tata	161	200	181	179	215	181	-
Tesla	131	0	131	131	0	0	-
Toyota	141	220	173	170	206	173	-
Volkswagen	139	223	158	156	225	158	-
Fleet	144	223	173	170	208	173	-

Table 3.8-10 Alternative 2- (Trucks -20) Targets and Projected Shortfall in MY 2025

Manufacturer	Car Target	Truck Target	Fleet Target (VMT and Sales Weighted)	Fleet Target (Sales weighted)	Car Achieved	Truck Achieved	Shortfall
Aston Martin	142	0	142	142	142	0	-
BMW	146	174	154	153	136	196	-
Chrysler/Fiat	146	182	163	161	136	191	-
Daimler	153	187	162	161	138	230	-
Ferrari	150	0	150	150	159	0	9
Ford	147	192	163	161	146	194	-
Geely	148	170	156	155	130	204	-
General Motors	146	192	170	168	138	200	-
Honda	142	172	152	150	137	180	-
Hyundai	142	170	148	148	140	178	-
Kia	143	179	152	151	142	183	-
Lotus	131	0	131	131	131	0	-
Mazda	142	167	147	146	141	170	-
Mitsubishi	139	162	148	147	134	171	-
Nissan	145	182	157	156	134	203	-
Porsche	131	175	142	140	113	231	-
Spyker	141	170	146	145	130	231	-
Subaru	137	159	143	142	141	149	-
Suzuki	132	163	138	137	128	179	-
Tata	161	164	162	162	126	198	-
Tesla	131	0	131	131	0	0	-
Toyota	141	181	157	155	130	196	-
Volkswagen	139	183	149	148	127	225	-
Fleet	144	183	158	157	136	195	-

Table 3.8-11 Alternative 3- (Cars +20) Targets and Projected Shortfall in MY 2025

Manufacturer	Car Target	Truck Target	Fleet Target (VMT and Sales Weighted)	Fleet Target (Sales weighted)	Car Achieved	Truck Achieved	Shortfall
Aston Martin	162	0	162	162	162	0	-
BMW	166	194	174	173	162	202	-
Chrysler/Fiat	166	201	183	181	159	208	-
Daimler	174	208	183	182	165	233	-
Ferrari	171	0	171	171	171	0	-
Ford	168	213	183	182	165	217	-
Geely	169	189	175	175	158	210	-
General Motors	167	213	191	189	161	218	-
Honda	161	191	171	170	157	196	-
Hyundai	162	188	168	167	160	193	-
Kia	163	199	172	171	164	195	-
Lotus	149	0	149	149	149	0	-
Mazda	162	186	166	166	162	183	-
Mitsubishi	159	180	167	166	158	182	-
Nissan	165	202	177	176	155	221	-
Porsche	149	195	160	159	137	231	-
Spyker	161	188	165	165	153	232	-
Subaru	156	177	162	161	163	157	-
Suzuki	150	181	156	155	150	183	-
Tata	183	182	182	182	149	215	-
Tesla	149	0	149	149	0	0	-
Toyota	160	200	177	175	155	207	-
Volkswagen	159	203	169	167	152	225	-
Fleet	164	203	178	177	159	211	-

Table 3.8-12 Alternative 4- (Cars -20) Targets and Projected Shortfall in MY 2025

Manufacturer	Car Target	Truck Target	Fleet Target (VMT and Sales Weighted)	Fleet Target (Sales weighted)	Car Achieved	Truck Achieved	Shortfall
Aston Martin	122	0	122	122	137	0	15
BMW	126	194	146	144	123	196	-
Chrysler/Fiat	126	201	162	158	135	191	-
Daimler	132	208	152	149	125	229	-
Ferrari	130	0	130	130	159	0	30
Ford	127	213	157	153	137	191	-
Geely	128	189	148	146	120	204	-
General Motors	126	213	171	167	139	200	-
Honda	122	191	145	142	130	173	-
Hyundai	122	188	137	135	126	175	-
Kia	123	199	142	139	129	182	-
Lotus	112	0	112	112	112	0	-
Mazda	122	186	134	133	128	158	-
Mitsubishi	120	180	142	140	127	165	-
Nissan	125	202	150	147	128	195	-
Porsche	112	195	133	130	101	229	-
Spyker	122	188	132	130	114	230	-
Subaru	118	177	133	131	132	138	-
Suzuki	113	181	127	125	116	168	-
Tata	139	182	161	159	122	198	-
Tesla	112	0	112	112	0	0	-
Toyota	121	200	153	150	127	190	-
Volkswagen	120	203	138	136	114	224	-
Fleet	124	203	153	150	129	192	-

3.8.1 Penetration of Selected Technologies

OMEGA model projected penetrations of selected technologies by manufacturer, model year, and car/truck class are presented on the following pages. These tables show results of both the reference case, the proposed standards as well as the four alternatives. 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. 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 cut point include Lotus, Aston Martin, and McLaren.

Most obviously, while no manufacturer is actually restricted by the technology caps modeled in this analysis, a smaller manufacturer with only a few vehicle platforms may pursue a single technology path.

The technology penetrations presented here are absolute, and include baseline technologies. The analyses shown here represent a single path towards compliance, of which there are many. The breadth of technology options in the Technical Assessment Report analysis reflected these opportunities.

Table 3.8-13 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

[20] 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.

[21] See 75 FR at 25457.

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

3.8.2 Projected Technology Penetrations in Reference Case

Table 3.8-14 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
Aston Martin	-10%	-9%	1%	42%	15%	0%	0%	0%	59%	25%	16%	0%	15%	15%	0%	0%	57%	0%	30%	0%	72%	13%
BMW	-9%	-8%	1%	47%	15%	0%	12%	0%	48%	26%	13%	0%	15%	15%	0%	0%	57%	0%	30%	0%	77%	13%
Chrysler/Fiat	-7%	-7%	0%	62%	13%	0%	4%	1%	53%	28%	3%	0%	1%	0%	0%	0%	0%	0%	10%	0%	75%	0%
Daimler	-9%	-8%	1%	43%	15%	0%	4%	11%	51%	28%	7%	0%	15%	15%	0%	0%	57%	0%	30%	0%	71%	14%
Ferrari	-8%	-8%	1%	42%	15%	0%	14%	0%	52%	28%	5%	0%	15%	15%	0%	0%	57%	0%	30%	0%	72%	13%
Ford	-8%	-8%	0%	50%	10%	0%	23%	8%	36%	20%	7%	0%	7%	2%	0%	0%	0%	0%	20%	0%	59%	0%
Geely	-9%	-8%	1%	52%	15%	0%	22%	4%	46%	25%	3%	0%	15%	15%	0%	0%	57%	0%	30%	0%	72%	13%
General Motors	-7%	-7%	0%	42%	7%	0%	19%	9%	36%	19%	6%	0%	2%	0%	0%	0%	0%	0%	16%	0%	50%	0%
Honda	-2%	-2%	0%	0%	0%	0%	13%	0%	50%	22%	12%	0%	0%	3%	0%	0%	0%	0%	5%	0%	0%	0%
Hyundai	-3%	-3%	0%	14%	0%	0%	15%	7%	39%	21%	7%	0%	0%	0%	0%	0%	0%	0%	5%	0%	14%	0%
Kia	-2%	-2%	0%	0%	0%	0%	9%	2%	46%	25%	9%	0%	0%	0%	0%	0%	0%	0%	6%	0%	0%	0%
Lotus	-1%	0%	1%	54%	15%	0%	0%	0%	10%	5%	85%	0%	15%	15%	0%	0%	57%	0%	30%	0%	72%	13%
Mazda	-4%	-4%	0%	16%	10%	0%	16%	4%	37%	20%	17%	0%	3%	0%	0%	0%	0%	0%	26%	0%	26%	0%
Mitsubishi	-6%	-6%	0%	68%	15%	0%	5%	0%	50%	27%	9%	0%	15%	2%	0%	0%	0%	0%	26%	0%	85%	0%
Nissan	-5%	-5%	0%	23%	4%	0%	5%	1%	50%	27%	5%	0%	0%	1%	0%	0%	0%	0%	21%	0%	27%	0%
Porsche	-4%	-4%	1%	45%	15%	0%	5%	0%	25%	14%	56%	0%	15%	15%	0%	0%	57%	0%	30%	0%	75%	13%
Spyker	-10%	-9%	1%	57%	15%	0%	13%	0%	48%	26%	13%	0%	15%	15%	0%	0%	57%	0%	30%	0%	72%	13%
Subaru	-6%	-6%	0%	39%	2%	0%	2%	0%	40%	22%	27%	0%	2%	0%	0%	0%	0%	0%	20%	0%	39%	0%
Suzuki	0%	0%	0%	68%	15%	0%	1%	0%	49%	27%	11%	0%	15%	2%	0%	0%	0%	0%	25%	0%	85%	0%
Tata	-10%	-9%	1%	42%	15%	0%	15%	0%	55%	30%	0%	0%	15%	15%	0%	0%	57%	0%	30%	0%	72%	13%
Tesla	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%	0%
Toyota	-2%	-2%	0%	0%	0%	0%	7%	2%	42%	22%	7%	0%	0%	15%	0%	0%	0%	0%	6%	0%	8%	0%
Volkswagen	-8%	-7%	1%	48%	15%	0%	10%	0%	50%	26%	14%	0%	15%	15%	0%	0%	57%	0%	30%	0%	86%	13%
Fleet	-5%	-5%	0%	27%	6%	0%	12%	4%	43%	23%	8%	0%	4%	6%	0%	0%	8%	0%	15%	0%	37%	2%

Table 3.8-15 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
Aston Martin	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
BMW	-9%	-9%	1%	60%	15%	0%	70%	30%	0%	0%	0%	0%	15%	15%	0%	0%	57%	0%	30%	0%	75%	0
Chrysler/Fiat	-7%	-7%	0%	25%	7%	0%	56%	26%	6%	3%	3%	0%	7%	0%	0%	0%	0%	0%	27%	0%	32%	0
Daimler	-10%	-9%	1%	64%	13%	0%	55%	45%	0%	0%	0%	0%	13%	15%	0%	0%	57%	0%	30%	0%	64%	0
Ferrari	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%	56%	15%	0%	42%	21%	14%	8%	3%	0%	15%	2%	0%	0%	0%	0%	24%	0%	71%	-
Geely	-10%	-9%	1%	57%	15%	0%	70%	30%	0%	0%	0%	0%	15%	15%	0%	0%	57%	0%	30%	0%	72%	0
General Motors	-8%	-8%	0%	33%	9%	0%	57%	28%	4%	2%	0%	0%	9%	0%	0%	0%	0%	0%	27%	0%	42%	-
Honda	-4%	-4%	0%	19%	0%	0%	49%	19%	21%	11%	0%	0%	0%	0%	0%	0%	0%	0%	14%	0%	19%	-
Hyundai	-5%	-5%	0%	85%	0%	0%	61%	27%	5%	3%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	85%	-
Kia	-4%	-4%	0%	39%	0%	0%	66%	30%	0%	0%	1%	0%	0%	0%	0%	0%	0%	0%	16%	0%	39%	-
Lotus	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Mazda	-10%	-10%	0%	73%	15%	0%	49%	19%	19%	10%	2%	0%	10%	0%	0%	0%	0%	0%	17%	0%	88%	-
Mitsubishi	-10%	-10%	0%	68%	15%	0%	39%	19%	19%	11%	0%	0%	15%	2%	0%	0%	0%	0%	30%	0%	85%	-
Nissan	-5%	-5%	0%	57%	15%	0%	54%	23%	12%	7%	2%	0%	10%	0%	0%	0%	0%	0%	22%	0%	72%	-
Porsche	-10%	-9%	1%	59%	15%	0%	69%	30%	0%	0%	1%	0%	15%	15%	0%	0%	57%	0%	30%	0%	87%	0
Spyker	-3%	-2%	1%	57%	15%	0%	55%	30%	0%	0%	0%	0%	15%	15%	0%	0%	57%	0%	30%	0%	72%	0
Subaru	-10%	-10%	0%	70%	15%	0%	18%	7%	37%	20%	8%	0%	5%	0%	0%	0%	0%	0%	8%	0%	85%	-
Suzuki	-8%	-8%	0%	67%	15%	0%	58%	24%	11%	6%	0%	0%	15%	3%	0%	0%	0%	0%	30%	0%	85%	-
Tata	-7%	-6%	1%	55%	15%	0%	51%	20%	19%	10%	0%	0%	15%	15%	0%	0%	57%	0%	30%	0%	72%	0
Tesla	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%	56%	24%	7%	4%	3%	0%	0%	5%	0%	0%	0%	0%	21%	0%	19%	-
Volkswagen	-10%	-9%	1%	57%	15%	0%	70%	30%	0%	0%	0%	0%	15%	15%	0%	0%	57%	0%	30%	0%	87%	0
Fleet	-6%	-6%	0%	37%	8%	0%	54%	25%	9%	5%	2%	0%	7%	3%	0%	0%	5%	0%	23%	0%	46%	0

Table 3.8-16 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
Aston Martin	-10%	-9%	1%	42%	15%	0%	0%	0%	59%	25%	16%	0%	15%	15%	0%	0%	57%	0%	30%	0%	72%	13%
BMW	-9%	-8%	1%	51%	15%	0%	28%	8%	36%	19%	9%	0%	15%	15%	0%	0%	57%	0%	30%	0%	77%	13%
Chrysler/Fiat	-7%	-7%	0%	45%	11%	0%	27%	12%	31%	17%	3%	0%	4%	0%	0%	0%	0%	0%	18%	0%	56%	0%
Daimler	-9%	-8%	1%	48%	14%	0%	16%	19%	39%	21%	5%	0%	14%	15%	0%	0%	57%	0%	30%	0%	69%	16%
Ferrari	-8%	-8%	1%	42%	15%	0%	14%	0%	52%	28%	5%	0%	15%	15%	0%	0%	57%	0%	30%	0%	72%	13%
Ford	-7%	-7%	0%	52%	12%	0%	30%	12%	29%	16%	6%	0%	10%	2%	0%	0%	0%	0%	21%	0%	63%	0%
Geely	-9%	-8%	1%	54%	15%	0%	37%	12%	32%	17%	2%	0%	15%	15%	0%	0%	57%	0%	30%	0%	72%	13%
General Motors	-7%	-7%	0%	37%	8%	0%	38%	18%	20%	11%	3%	0%	6%	0%	0%	0%	0%	0%	21%	0%	46%	0%
Honda	-3%	-3%	0%	6%	0%	0%	24%	6%	41%	19%	8%	0%	0%	2%	0%	0%	0%	0%	8%	0%	6%	0%
Hyundai	-3%	-3%	0%	28%	0%	0%	24%	11%	32%	17%	6%	0%	0%	0%	0%	0%	0%	0%	4%	0%	28%	0%
Kia	-3%	-3%	0%	9%	0%	0%	22%	9%	35%	19%	7%	0%	0%	0%	0%	0%	0%	0%	8%	0%	9%	0%
Lotus	-1%	0%	1%	54%	15%	0%	0%	0%	10%	5%	85%	0%	15%	15%	0%	0%	57%	0%	30%	0%	72%	13%
Mazda	-5%	-5%	0%	26%	11%	0%	22%	7%	34%	19%	14%	0%	4%	0%	0%	0%	0%	0%	24%	0%	37%	0%
Mitsubishi	-8%	-7%	0%	68%	15%	0%	17%	7%	39%	22%	6%	0%	15%	2%	0%	0%	0%	0%	27%	0%	85%	0%
Nissan	-5%	-5%	0%	33%	8%	0%	20%	8%	39%	21%	4%	0%	3%	1%	0%	0%	0%	0%	21%	0%	41%	0%
Porsche	-6%	-5%	1%	48%	15%	0%	20%	7%	19%	10%	43%	0%	15%	15%	0%	0%	57%	0%	30%	0%	78%	13%
Spyker	-9%	-8%	1%	57%	15%	0%	19%	4%	41%	23%	11%	0%	15%	15%	0%	0%	57%	0%	30%	0%	72%	13%
Subaru	-7%	-7%	0%	46%	5%	0%	6%	2%	39%	22%	22%	0%	3%	0%	0%	0%	0%	0%	17%	0%	50%	0%
Suzuki	-2%	-1%	0%	67%	15%	0%	11%	4%	42%	23%	9%	0%	15%	3%	0%	0%	0%	0%	26%	0%	85%	0%
Tata	-8%	-8%	1%	48%	15%	0%	33%	10%	37%	20%	0%	0%	15%	15%	0%	0%	57%	0%	30%	0%	72%	13%
Tesla	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%	0%
Toyota	-2%	-2%	0%	5%	0%	0%	26%	10%	28%	15%	5%	0%	0%	12%	0%	0%	0%	0%	12%	0%	12%	0%
Volkswagen	-8%	-7%	1%	50%	15%	0%	22%	6%	40%	21%	11%	0%	15%	15%	0%	0%	57%	0%	30%	0%	86%	13%
Fleet	-5%	-5%	0%	30%	7%	0%	27%	11%	31%	16%	6%	0%	5%	5%	0%	0%	7%	0%	18%	0%	40%	2%

Table 3.8-17 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
Aston Martin	-10%	-9%	1%	42%	15%	0%	0%	0%	59%	25%	16%	0%	15%	15%	0%	0%	57%	0%	30%	0%	72%	13%
BMW	-9%	-8%	1%	47%	15%	0%	12%	0%	48%	26%	13%	0%	15%	15%	0%	0%	57%	0%	30%	0%	77%	13%
Chrysler/Fiat	-7%	-7%	0%	48%	13%	0%	3%	1%	53%	29%	3%	0%	1%	0%	0%	0%	0%	0%	15%	0%	61%	0%
Daimler	-9%	-8%	1%	43%	15%	0%	4%	11%	52%	28%	6%	0%	15%	15%	0%	0%	57%	0%	30%	0%	71%	14%
Ferrari	-8%	-8%	1%	42%	15%	0%	14%	0%	52%	28%	5%	0%	15%	15%	0%	0%	57%	0%	30%	0%	72%	13%
Ford	-8%	-8%	0%	51%	10%	0%	24%	8%	35%	19%	7%	0%	8%	1%	0%	0%	0%	0%	19%	0%	61%	0%
Geely	-9%	-8%	1%	52%	15%	0%	22%	4%	46%	25%	3%	0%	15%	15%	0%	0%	57%	0%	30%	0%	72%	13%
General Motors	-7%	-7%	0%	43%	7%	0%	18%	8%	37%	20%	6%	0%	2%	0%	0%	0%	0%	0%	15%	0%	51%	0%
Honda	-2%	-2%	0%	0%	0%	0%	13%	0%	50%	22%	12%	0%	0%	3%	0%	0%	0%	0%	5%	0%	0%	0%
Hyundai	-2%	-2%	0%	13%	0%	0%	14%	7%	39%	21%	7%	0%	0%	0%	0%	0%	0%	0%	5%	0%	13%	0%
Kia	-2%	-2%	0%	0%	0%	0%	9%	2%	46%	25%	9%	0%	0%	0%	0%	0%	0%	0%	6%	0%	0%	0%
Lotus	-1%	0%	1%	54%	15%	0%	0%	0%	10%	5%	85%	0%	15%	15%	0%	0%	57%	0%	30%	0%	72%	13%
Mazda	-4%	-4%	0%	15%	10%	0%	16%	4%	38%	20%	18%	0%	3%	0%	0%	0%	0%	0%	26%	0%	26%	0%
Mitsubishi	-6%	-6%	0%	68%	15%	0%	4%	0%	50%	27%	9%	0%	15%	2%	0%	0%	0%	0%	26%	0%	85%	0%
Nissan	-5%	-5%	0%	23%	4%	0%	5%	1%	50%	27%	5%	0%	0%	1%	0%	0%	0%	0%	20%	0%	27%	0%
Porsche	-4%	-4%	1%	45%	15%	0%	5%	0%	25%	14%	56%	0%	15%	15%	0%	0%	57%	0%	30%	0%	75%	13%
Spyker	-10%	-9%	1%	57%	15%	0%	13%	0%	48%	26%	13%	0%	15%	15%	0%	0%	57%	0%	30%	0%	72%	13%
Subaru	-6%	-6%	0%	47%	2%	0%	2%	0%	40%	22%	27%	0%	2%	0%	0%	0%	0%	0%	17%	0%	47%	0%
Suzuki	0%	0%	0%	68%	15%	0%	1%	0%	49%	27%	11%	0%	15%	2%	0%	0%	0%	0%	25%	0%	85%	0%
Tata	-10%	-9%	1%	42%	15%	0%	15%	0%	55%	30%	0%	0%	15%	15%	0%	0%	57%	0%	30%	0%	72%	13%
Tesla	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%	0%
Toyota	-2%	-2%	0%	0%	0%	0%	7%	1%	52%	12%	7%	0%	0%	16%	0%	0%	0%	0%	6%	0%	8%	0%
Volkswagen	-8%	-7%	1%	48%	15%	0%	9%	0%	50%	26%	14%	0%	15%	15%	0%	0%	57%	0%	30%	0%	86%	13%
Fleet	-5%	-5%	0%	27%	6%	0%	12%	4%	45%	21%	8%	0%	4%	6%	0%	0%	8%	0%	15%	0%	36%	2%

Table 3.8-18 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
Aston Martin	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
BMW	-9%	-8%	1%	60%	15%	0%	70%	30%	0%	0%	0%	0%	15%	15%	0%	0%	57%	0%	30%	0%	76%	13%
Chrysler/Fiat	-7%	-7%	0%	26%	8%	0%	56%	26%	6%	3%	3%	0%	8%	0%	0%	0%	0%	0%	27%	0%	34%	0%
Daimler	-10%	-9%	1%	64%	13%	0%	55%	45%	0%	0%	0%	0%	13%	15%	0%	0%	57%	0%	30%	0%	64%	24%
Ferrari	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%	57%	15%	0%	41%	20%	15%	8%	3%	0%	15%	3%	0%	0%	0%	0%	24%	0%	71%	0%
Geely	-10%	-9%	1%	57%	15%	0%	70%	30%	0%	0%	0%	0%	15%	15%	0%	0%	57%	0%	30%	0%	72%	13%
General Motors	-8%	-8%	0%	36%	10%	0%	58%	28%	4%	2%	0%	0%	10%	0%	0%	0%	0%	0%	26%	0%	46%	0%
Honda	-4%	-4%	0%	15%	0%	0%	49%	18%	21%	11%	0%	0%	0%	0%	0%	0%	0%	0%	16%	0%	15%	0%
Hyundai	-5%	-5%	0%	85%	0%	0%	60%	27%	5%	3%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	85%	0%
Kia	-5%	-5%	0%	28%	0%	0%	66%	30%	0%	0%	1%	0%	0%	0%	0%	0%	0%	0%	20%	0%	28%	0%
Lotus	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Mazda	-10%	-10%	0%	72%	15%	0%	50%	20%	17%	9%	2%	0%	11%	0%	0%	0%	0%	0%	17%	0%	87%	0%
Mitsubishi	-10%	-10%	0%	68%	15%	0%	39%	19%	19%	11%	0%	0%	15%	2%	0%	0%	0%	0%	30%	0%	85%	0%
Nissan	-5%	-5%	0%	57%	12%	0%	54%	23%	12%	7%	2%	0%	11%	0%	0%	0%	0%	0%	23%	0%	70%	0%
Porsche	-10%	-9%	1%	59%	15%	0%	69%	30%	0%	0%	1%	0%	15%	15%	0%	0%	57%	0%	30%	0%	87%	13%
Spyker	-3%	-2%	1%	57%	15%	0%	55%	30%	0%	0%	0%	0%	15%	15%	0%	0%	57%	0%	30%	0%	72%	13%
Subaru	-10%	-10%	0%	70%	15%	0%	18%	7%	37%	20%	8%	0%	5%	0%	0%	0%	0%	0%	8%	0%	85%	0%
Suzuki	-8%	-8%	0%	67%	15%	0%	58%	24%	11%	6%	0%	0%	15%	3%	0%	0%	0%	0%	30%	0%	85%	0%
Tata	-7%	-6%	1%	55%	15%	0%	51%	20%	19%	10%	0%	0%	15%	15%	0%	0%	57%	0%	30%	0%	72%	13%
Tesla	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%	9%	0%	0%	55%	23%	7%	4%	3%	0%	0%	6%	0%	0%	0%	0%	22%	0%	16%	0%
Volkswagen	-10%	-9%	1%	57%	15%	0%	70%	30%	0%	0%	0%	0%	15%	15%	0%	0%	57%	0%	30%	0%	87%	13%
Fleet	-6%	-6%	0%	36%	8%	0%	54%	25%	9%	5%	2%	0%	7%	3%	0%	0%	5%	0%	23%	0%	46%	1%

Table 3.8-19 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
Aston Martin	-10%	-9%	1%	42%	15%	0%	0%	0%	59%	25%	16%	0%	15%	15%	0%	0%	57%	0%	30%	0%	72%	13%
BMW	-9%	-8%	1%	51%	15%	0%	28%	8%	36%	19%	9%	0%	15%	15%	0%	0%	57%	0%	30%	0%	77%	13%
Chrysler/Fiat	-7%	-7%	0%	38%	11%	0%	26%	12%	33%	18%	3%	0%	4%	0%	0%	0%	0%	0%	20%	0%	49%	0%
Daimler	-9%	-8%	1%	48%	14%	0%	15%	18%	40%	22%	5%	0%	14%	15%	0%	0%	57%	0%	30%	0%	70%	16%
Ferrari	-8%	-8%	1%	42%	15%	0%	14%	0%	52%	28%	5%	0%	15%	15%	0%	0%	57%	0%	30%	0%	72%	13%
Ford	-7%	-7%	0%	53%	12%	0%	29%	12%	29%	16%	6%	0%	10%	2%	0%	0%	0%	0%	21%	0%	64%	0%
Geely	-9%	-8%	1%	53%	15%	0%	36%	12%	33%	18%	2%	0%	15%	15%	0%	0%	57%	0%	30%	0%	72%	13%
General Motors	-7%	-7%	0%	40%	9%	0%	37%	18%	21%	11%	3%	0%	6%	0%	0%	0%	0%	0%	21%	0%	49%	0%
Honda	-3%	-3%	0%	4%	0%	0%	23%	5%	42%	19%	8%	0%	0%	2%	0%	0%	0%	0%	8%	0%	4%	0%
Hyundai	-3%	-3%	0%	27%	0%	0%	24%	11%	32%	18%	6%	0%	0%	0%	0%	0%	0%	0%	4%	0%	27%	0%
Kia	-3%	-3%	0%	6%	0%	0%	21%	8%	36%	20%	7%	0%	0%	0%	0%	0%	0%	0%	9%	0%	6%	0%
Lotus	-1%	0%	1%	54%	15%	0%	0%	0%	10%	5%	85%	0%	15%	15%	0%	0%	57%	0%	30%	0%	72%	13%
Mazda	-5%	-5%	0%	25%	11%	0%	22%	7%	34%	19%	15%	0%	4%	0%	0%	0%	0%	0%	25%	0%	36%	0%
Mitsubishi	-7%	-7%	0%	68%	15%	0%	16%	6%	40%	22%	6%	0%	15%	2%	0%	0%	0%	0%	27%	0%	85%	0%
Nissan	-5%	-5%	0%	33%	7%	0%	20%	8%	39%	21%	4%	0%	3%	1%	0%	0%	0%	0%	21%	0%	40%	0%
Porsche	-6%	-5%	1%	48%	15%	0%	19%	6%	20%	11%	44%	0%	15%	15%	0%	0%	57%	0%	30%	0%	78%	13%
Spyker	-9%	-8%	1%	57%	15%	0%	18%	4%	42%	23%	11%	0%	15%	15%	0%	0%	57%	0%	30%	0%	72%	13%
Subaru	-7%	-7%	0%	52%	5%	0%	6%	2%	39%	21%	23%	0%	3%	0%	0%	0%	0%	0%	15%	0%	55%	0%
Suzuki	-1%	-1%	0%	67%	15%	0%	11%	4%	42%	23%	9%	0%	15%	3%	0%	0%	0%	0%	26%	0%	85%	0%
Tata	-9%	-8%	1%	48%	15%	0%	32%	9%	38%	21%	0%	0%	15%	15%	0%	0%	57%	0%	30%	0%	72%	13%
Tesla	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%	0%
Toyota	-2%	-2%	0%	3%	0%	0%	25%	9%	36%	9%	5%	0%	0%	12%	0%	0%	0%	0%	12%	0%	11%	0%
Volkswagen	-8%	-7%	1%	50%	15%	0%	21%	6%	40%	21%	11%	0%	15%	15%	0%	0%	57%	0%	30%	0%	86%	13%
Fleet	-5%	-5%	0%	30%	6%	0%	26%	11%	33%	15%	6%	0%	5%	5%	0%	0%	7%	0%	18%	0%	39%	2%

3.8.3 Projected Technology Penetrations in Proposal case

Table 3.8-20 Proposal 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
Aston Martin	-16%	-7%	9%	0%	0%	15%	0%	0%	15%	61%	7%	50%	15%	30%	16%	15%	15%	75%	80%	50%	60%	24%
BMW	-12%	-8%	4%	40%	26%	2%	0%	0%	18%	70%	10%	59%	28%	30%	2%	0%	0%	75%	80%	59%	98%	0%
Chrysler/Fiat	-8%	-8%	0%	89%	7%	1%	1%	2%	19%	76%	3%	60%	3%	0%	0%	0%	0%	75%	80%	60%	97%	0%
Daimler	-13%	-8%	5%	37%	21%	4%	0%	0%	17%	69%	5%	55%	25%	30%	8%	0%	0%	75%	80%	55%	91%	1%
Ferrari	-13%	-7%	6%	0%	0%	15%	0%	0%	16%	65%	2%	50%	15%	30%	16%	15%	15%	75%	80%	50%	60%	24%
Ford	-8%	-8%	0%	76%	15%	1%	5%	21%	13%	52%	7%	59%	16%	2%	0%	0%	0%	74%	79%	59%	92%	0%
Geely	-13%	-9%	4%	43%	15%	8%	3%	11%	15%	61%	2%	55%	22%	30%	8%	0%	0%	75%	80%	55%	92%	0%
General Motors	-7%	-7%	0%	48%	9%	1%	6%	23%	13%	52%	6%	60%	5%	0%	0%	0%	0%	75%	80%	60%	59%	0%
Honda	-4%	-4%	0%	15%	0%	0%	0%	0%	17%	68%	12%	58%	0%	3%	0%	0%	0%	73%	77%	58%	15%	0%
Hyundai	-5%	-5%	0%	38%	0%	0%	4%	18%	14%	56%	7%	60%	0%	0%	0%	0%	0%	75%	80%	60%	38%	0%
Kia	-3%	-3%	0%	20%	0%	0%	2%	7%	17%	66%	9%	60%	0%	0%	0%	0%	0%	31%	33%	60%	20%	0%
Lotus	-3%	0%	3%	16%	30%	0%	0%	0%	9%	35%	46%	54%	30%	30%	11%	13%	0%	75%	80%	54%	89%	0%
Mazda	-5%	-5%	0%	80%	20%	0%	3%	12%	14%	54%	17%	60%	7%	0%	0%	0%	0%	75%	80%	60%	100%	0%
Mitsubishi	-9%	-8%	0%	64%	30%	0%	0%	0%	18%	74%	8%	60%	30%	6%	0%	0%	0%	75%	80%	60%	100%	0%
Nissan	-5%	-5%	0%	65%	9%	0%	1%	3%	18%	73%	5%	59%	10%	1%	0%	0%	0%	74%	79%	59%	75%	0%
Porsche	-8%	-3%	5%	14%	25%	3%	0%	0%	12%	47%	27%	52%	27%	30%	14%	15%	4%	75%	80%	52%	86%	0%
Spyker	-15%	-9%	7%	27%	25%	3%	0%	0%	16%	64%	8%	53%	27%	30%	12%	4%	0%	75%	80%	53%	88%	0%
Subaru	-8%	-8%	0%	68%	30%	0%	0%	0%	15%	59%	26%	60%	30%	2%	0%	0%	0%	75%	80%	60%	100%	0%
Suzuki	-1%	0%	1%	46%	30%	0%	0%	0%	18%	73%	9%	60%	30%	24%	0%	0%	0%	75%	80%	60%	100%	0%
Tata	-15%	-10%	6%	42%	7%	11%	0%	0%	18%	72%	0%	54%	19%	30%	10%	0%	0%	75%	80%	54%	90%	0%
Tesla	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%	0%
Toyota	-3%	-3%	0%	23%	0%	0%	1%	3%	15%	60%	7%	51%	0%	15%	0%	0%	0%	17%	18%	51%	24%	0%
Volkswagen	-10%	-7%	3%	34%	29%	1%	0%	0%	17%	67%	10%	57%	29%	30%	6%	1%	0%	75%	80%	57%	94%	0%
Fleet	-6%	-6%	1%	45%	10%	1%	2%	9%	15%	61%	8%	57%	9%	8%	1%	0%	0%	62%	67%	57%	60%	0%

Table 3.8-21 Proposal 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
Aston Martin	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
BMW	-14%	-12%	2%	73%	24%	3%	20%	80%	0%	0%	0%	60%	27%	30%	0%	0%	0%	75%	80%	60%	100%	0%
Chrysler/Fiat	-7%	-7%	0%	35%	25%	3%	17%	69%	2%	9%	3%	60%	27%	0%	0%	0%	0%	75%	80%	60%	62%	0%
Daimler	-15%	-13%	2%	80%	14%	6%	20%	80%	0%	0%	0%	60%	20%	30%	0%	0%	0%	75%	80%	60%	89%	11%
Ferrari	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%	75%	17%	6%	14%	55%	5%	21%	3%	59%	23%	2%	0%	0%	0%	73%	78%	59%	98%	0%
Geely	-15%	-13%	2%	72%	27%	2%	20%	80%	0%	0%	0%	60%	28%	30%	0%	0%	35%	75%	80%	60%	100%	0%
General Motors	-8%	-8%	0%	33%	19%	5%	19%	75%	1%	5%	0%	60%	24%	0%	0%	0%	0%	75%	80%	60%	57%	0%
Honda	-8%	-8%	0%	72%	0%	0%	12%	50%	8%	30%	0%	60%	0%	0%	0%	0%	0%	75%	80%	60%	72%	0%
Hyundai	-10%	-10%	0%	70%	30%	0%	18%	72%	2%	8%	0%	60%	30%	0%	0%	0%	0%	75%	80%	60%	100%	0%
Kia	-9%	-9%	0%	99%	0%	0%	20%	79%	0%	0%	1%	60%	0%	0%	0%	0%	0%	75%	80%	60%	99%	0%
Lotus	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Mazda	-14%	-14%	0%	70%	30%	0%	13%	51%	7%	27%	2%	60%	30%	0%	0%	0%	0%	75%	80%	60%	100%	0%
Mitsubishi	-15%	-14%	1%	66%	30%	0%	13%	52%	7%	28%	0%	60%	30%	4%	0%	0%	0%	75%	80%	60%	100%	0%
Nissan	-5%	-5%	0%	73%	24%	3%	15%	61%	5%	18%	2%	60%	27%	0%	0%	0%	0%	75%	80%	60%	100%	0%
Porsche	-15%	-13%	2%	55%	24%	8%	20%	79%	0%	0%	1%	60%	32%	30%	0%	0%	55%	75%	80%	60%	87%	13%
Spyker	-4%	-2%	2%	76%	19%	6%	20%	80%	0%	0%	0%	60%	24%	30%	0%	0%	70%	75%	80%	60%	100%	0%
Subaru	-15%	-15%	0%	70%	30%	0%	5%	20%	13%	54%	8%	60%	30%	0%	0%	0%	0%	75%	80%	60%	100%	0%
Suzuki	-12%	-12%	0%	64%	30%	0%	16%	63%	4%	16%	0%	60%	30%	6%	0%	0%	0%	75%	80%	60%	100%	0%
Tata	-11%	-9%	2%	66%	10%	10%	13%	53%	6%	24%	0%	58%	20%	30%	4%	0%	9%	75%	80%	58%	96%	0%
Tesla	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%	66%	0%	3%	16%	63%	3%	11%	3%	57%	3%	5%	0%	0%	0%	71%	76%	57%	69%	0%
Volkswagen	-14%	-12%	2%	73%	23%	3%	20%	80%	0%	0%	0%	60%	27%	30%	0%	0%	0%	75%	80%	60%	100%	0%
Fleet	-8%	-8%	0%	59%	14%	4%	16%	65%	3%	13%	2%	59%	17%	4%	0%	0%	1%	74%	79%	59%	76%	0%

Table 3.8-22 Proposal 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
Aston Martin	-16%	-7%	9%	0%	0%	15%	0%	0%	15%	61%	7%	50%	15%	30%	16%	15%	15%	75%	80%	50%	60%	24%
BMW	-13%	-9%	4%	49%	25%	2%	5%	21%	13%	52%	8%	59%	28%	30%	1%	0%	0%	75%	80%	59%	99%	0%
Chrysler/Fiat	-7%	-7%	0%	64%	15%	2%	8%	32%	11%	45%	3%	60%	14%	0%	0%	0%	0%	75%	80%	60%	81%	0%
Daimler	-14%	-10%	4%	48%	20%	4%	5%	20%	13%	52%	4%	57%	24%	30%	6%	0%	0%	75%	80%	57%	91%	3%
Ferrari	-13%	-7%	6%	0%	0%	15%	0%	0%	16%	65%	2%	50%	15%	30%	16%	15%	15%	75%	80%	50%	60%	24%
Ford	-8%	-8%	0%	75%	16%	3%	8%	32%	10%	42%	6%	59%	18%	2%	0%	0%	0%	74%	79%	59%	94%	0%
Geely	-13%	-10%	3%	52%	18%	6%	8%	32%	10%	42%	1%	57%	24%	30%	6%	0%	11%	75%	80%	57%	94%	0%
General Motors	-8%	-8%	0%	41%	14%	3%	12%	49%	7%	29%	3%	60%	14%	0%	0%	0%	0%	75%	80%	60%	58%	0%
Honda	-5%	-5%	0%	33%	0%	0%	4%	15%	14%	56%	8%	59%	0%	2%	0%	0%	0%	73%	78%	59%	33%	0%
Hyundai	-6%	-6%	0%	45%	6%	0%	7%	29%	12%	46%	6%	60%	6%	0%	0%	0%	0%	75%	80%	60%	51%	0%
Kia	-4%	-4%	0%	37%	0%	0%	6%	23%	13%	51%	7%	60%	0%	0%	0%	0%	0%	41%	44%	60%	37%	0%
Lotus	-3%	0%	3%	16%	30%	0%	0%	0%	9%	35%	46%	54%	30%	30%	11%	13%	0%	75%	80%	54%	89%	0%
Mazda	-6%	-6%	0%	78%	22%	0%	5%	19%	12%	50%	14%	60%	11%	0%	0%	0%	0%	75%	80%	60%	100%	0%
Mitsubishi	-11%	-10%	1%	64%	30%	0%	5%	18%	14%	58%	5%	60%	30%	6%	0%	0%	0%	75%	80%	60%	100%	0%
Nissan	-5%	-5%	0%	68%	14%	1%	5%	21%	14%	56%	4%	60%	15%	1%	0%	0%	0%	75%	80%	60%	83%	0%
Porsche	-10%	-5%	4%	24%	25%	4%	5%	19%	9%	36%	21%	54%	29%	30%	11%	11%	16%	75%	80%	54%	86%	3%
Spyker	-14%	-8%	6%	34%	24%	3%	3%	11%	14%	55%	7%	54%	27%	30%	10%	3%	10%	75%	80%	54%	90%	0%
Subaru	-10%	-9%	0%	69%	30%	0%	1%	5%	14%	58%	22%	60%	30%	1%	0%	0%	0%	75%	80%	60%	100%	0%
Suzuki	-3%	-2%	1%	49%	30%	0%	3%	11%	16%	63%	7%	60%	30%	21%	0%	0%	0%	75%	80%	60%	100%	0%
Tata	-13%	-9%	4%	54%	9%	11%	7%	26%	12%	48%	0%	56%	19%	30%	7%	0%	4%	75%	80%	56%	93%	0%
Tesla	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%	0%
Toyota	-3%	-3%	0%	40%	0%	1%	7%	26%	10%	41%	5%	53%	1%	12%	0%	0%	0%	38%	40%	53%	41%	0%
Volkswagen	-11%	-8%	3%	42%	27%	1%	4%	16%	13%	54%	8%	57%	29%	30%	5%	0%	0%	75%	80%	57%	95%	0%
Fleet	-7%	-6%	0%	50%	11%	2%	7%	28%	11%	44%	6%	58%	12%	7%	1%	0%	0%	66%	71%	58%	65%	0%

Table 3.8-23 Proposal 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
Aston Martin	-20%	-6%	14%	0%	0%	9%	0%	0%	0%	75%	2%	77%	9%	50%	23%	18%	0%	100%	100%	77%	77%	0%
BMW	-15%	-9%	5%	0%	56%	5%	0%	0%	0%	81%	9%	90%	61%	28%	10%	0%	0%	100%	100%	90%	90%	0%
Chrysler/Fiat	-12%	-9%	2%	8%	70%	2%	0%	2%	0%	95%	2%	99%	72%	19%	1%	0%	0%	100%	100%	99%	99%	0%
Daimler	-17%	-10%	7%	1%	43%	9%	0%	0%	0%	80%	5%	85%	52%	32%	15%	0%	0%	100%	100%	85%	84%	1%
Ferrari	-15%	-6%	9%	0%	0%	5%	0%	0%	0%	77%	0%	77%	5%	50%	23%	22%	5%	100%	100%	77%	77%	0%
Ford	-13%	-11%	2%	15%	64%	4%	0%	27%	0%	62%	6%	95%	68%	13%	4%	0%	0%	99%	99%	95%	95%	0%
Geely	-16%	-9%	7%	3%	31%	16%	0%	13%	0%	71%	1%	85%	47%	41%	15%	0%	0%	100%	100%	85%	85%	0%
General Motors	-12%	-11%	2%	11%	68%	2%	0%	28%	0%	65%	4%	97%	70%	15%	3%	0%	0%	100%	100%	97%	97%	0%
Honda	-5%	-5%	0%	24%	73%	0%	0%	0%	0%	85%	12%	97%	73%	3%	0%	0%	0%	97%	97%	97%	97%	0%
Hyundai	-8%	-8%	0%	25%	75%	0%	0%	22%	0%	71%	7%	100%	75%	0%	0%	0%	0%	100%	100%	100%	100%	0%
Kia	-5%	-5%	0%	43%	57%	0%	0%	7%	0%	84%	9%	100%	33%	0%	0%	0%	0%	100%	100%	100%	100%	0%
Lotus	-4%	0%	4%	0%	44%	0%	0%	0%	0%	36%	44%	80%	44%	25%	20%	11%	0%	100%	100%	80%	80%	0%
Mazda	-8%	-6%	2%	4%	73%	0%	0%	14%	0%	71%	12%	98%	73%	21%	2%	0%	0%	100%	100%	98%	98%	0%
Mitsubishi	-11%	-9%	2%	4%	69%	0%	0%	0%	0%	88%	6%	94%	69%	21%	6%	0%	0%	100%	100%	94%	94%	0%
Nissan	-8%	-7%	1%	8%	73%	0%	0%	4%	0%	90%	4%	98%	73%	18%	1%	0%	0%	99%	99%	98%	98%	0%
Porsche	-9%	-3%	6%	0%	35%	1%	0%	0%	0%	53%	24%	78%	36%	29%	22%	13%	0%	100%	100%	78%	78%	0%
Spyker	-19%	-11%	8%	0%	47%	1%	0%	0%	0%	76%	6%	82%	48%	29%	18%	5%	0%	100%	100%	82%	82%	0%
Subaru	-10%	-9%	2%	5%	70%	0%	0%	0%	0%	73%	22%	95%	70%	20%	5%	0%	0%	100%	100%	95%	95%	0%
Suzuki	-1%	0%	1%	0%	66%	0%	0%	0%	0%	83%	8%	91%	66%	25%	9%	0%	0%	100%	100%	91%	91%	0%
Tata	-20%	-11%	9%	0%	14%	26%	0%	0%	0%	85%	0%	85%	41%	44%	15%	0%	0%	100%	100%	85%	85%	0%
Tesla	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%	0%
Toyota	-6%	-5%	0%	20%	61%	1%	0%	3%	0%	75%	7%	84%	62%	17%	0%	0%	0%	84%	84%	84%	84%	0%
Volkswagen	-11%	-8%	4%	0%	60%	1%	0%	0%	0%	78%	10%	88%	60%	26%	12%	1%	0%	100%	100%	88%	88%	0%
Fleet	-9%	-8%	2%	14%	65%	2%	0%	11%	0%	75%	7%	93%	66%	15%	4%	0%	0%	96%	96%	93%	93%	0%

Table 3.8-24 Proposal 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
Aston Martin	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
BMW	-18%	-11%	7%	30%	61%	10%	0%	100%	0%	0%	0%	100%	70%	50%	0%	0%	0%	100%	100%	100%	100%	0%
Chrysler/Fiat	-13%	-12%	1%	26%	61%	8%	0%	86%	0%	10%	2%	99%	70%	10%	1%	0%	0%	100%	100%	99%	99%	0%
Daimler	-20%	-12%	8%	46%	35%	19%	0%	100%	0%	0%	0%	100%	54%	50%	0%	0%	0%	100%	100%	100%	92%	8%
Ferrari	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Ford	-12%	-9%	3%	27%	40%	20%	0%	67%	0%	27%	2%	96%	60%	31%	3%	1%	0%	98%	98%	96%	96%	0%
Geely	-20%	-12%	8%	28%	66%	6%	0%	100%	0%	0%	0%	100%	72%	50%	0%	0%	0%	100%	100%	100%	100%	0%
General Motors	-12%	-12%	0%	31%	51%	15%	0%	93%	0%	6%	0%	99%	66%	3%	1%	0%	0%	100%	100%	99%	99%	0%
Honda	-15%	-15%	0%	23%	75%	0%	0%	62%	0%	38%	0%	100%	75%	2%	0%	0%	0%	100%	100%	100%	100%	0%
Hyundai	-20%	-19%	1%	23%	74%	0%	0%	90%	0%	9%	0%	99%	74%	2%	1%	0%	0%	100%	100%	99%	99%	0%
Kia	-14%	-14%	0%	25%	75%	0%	0%	99%	0%	0%	1%	100%	75%	0%	0%	0%	0%	100%	100%	100%	100%	0%
Lotus	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%	1%	17%	74%	0%	0%	66%	0%	32%	1%	100%	74%	8%	0%	0%	0%	100%	100%	100%	100%	0%
Mitsubishi	-20%	-18%	2%	16%	71%	0%	0%	65%	0%	31%	0%	96%	71%	9%	4%	0%	0%	100%	100%	96%	96%	0%
Nissan	-9%	-6%	3%	24%	59%	9%	0%	77%	0%	20%	1%	98%	68%	24%	2%	0%	0%	100%	100%	98%	98%	0%
Porsche	-20%	-12%	8%	39%	34%	28%	0%	99%	0%	0%	1%	100%	61%	50%	0%	0%	6%	100%	100%	100%	100%	0%
Spyker	-5%	-2%	3%	35%	46%	19%	0%	100%	0%	0%	0%	100%	65%	50%	0%	0%	19%	100%	100%	100%	100%	0%
Subaru	-20%	-17%	3%	6%	74%	0%	0%	25%	0%	69%	6%	99%	74%	19%	1%	0%	0%	100%	100%	99%	99%	0%
Suzuki	-16%	-16%	0%	20%	72%	0%	0%	79%	0%	17%	0%	97%	72%	5%	3%	0%	0%	100%	100%	97%	97%	0%
Tata	-14%	-7%	6%	33%	18%	33%	0%	66%	0%	26%	0%	92%	50%	41%	8%	0%	0%	100%	100%	92%	92%	0%
Tesla	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Toyota	-10%	-10%	0%	27%	59%	8%	0%	78%	0%	14%	2%	94%	67%	7%	0%	0%	0%	94%	94%	94%	94%	0%
Volkswagen	-19%	-11%	7%	31%	58%	11%	0%	100%	0%	0%	0%	100%	69%	50%	0%	0%	0%	100%	100%	100%	100%	0%
Fleet	-13%	-11%	1%	27%	57%	11%	0%	81%	0%	15%	1%	98%	67%	13%	1%	0%	0%	99%	99%	98%	97%	0%

Table 3.8-25 Proposal 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
Aston Martin	-20%	-6%	14%	0%	0%	9%	0%	0%	0%	75%	2%	77%	9%	50%	23%	18%	0%	100%	100%	77%	77%	0%
BMW	-15%	-10%	6%	8%	58%	6%	0%	26%	0%	59%	7%	92%	64%	34%	8%	0%	0%	100%	100%	92%	92%	0%
Chrysler/Fiat	-12%	-11%	2%	16%	66%	5%	0%	38%	0%	58%	2%	99%	71%	15%	1%	0%	0%	100%	100%	99%	99%	0%
Daimler	-18%	-11%	7%	11%	41%	11%	0%	23%	0%	62%	4%	88%	53%	36%	12%	0%	0%	100%	100%	88%	86%	2%
Ferrari	-15%	-6%	9%	0%	0%	5%	0%	0%	0%	77%	0%	77%	5%	50%	23%	22%	5%	100%	100%	77%	77%	0%
Ford	-13%	-11%	2%	18%	56%	9%	0%	39%	0%	51%	4%	95%	65%	19%	4%	0%	0%	99%	99%	95%	95%	0%
Geely	-17%	-10%	7%	11%	42%	13%	0%	39%	0%	50%	1%	89%	54%	44%	11%	0%	0%	100%	100%	89%	89%	0%
General Motors	-12%	-11%	1%	21%	60%	8%	0%	59%	0%	37%	2%	98%	68%	10%	2%	0%	0%	100%	100%	98%	98%	0%
Honda	-8%	-8%	0%	24%	73%	0%	0%	18%	0%	71%	8%	98%	73%	3%	0%	0%	0%	98%	98%	98%	98%	0%
Hyundai	-10%	-10%	0%	25%	75%	0%	0%	35%	0%	58%	6%	100%	75%	0%	0%	0%	0%	100%	100%	100%	100%	0%
Kia	-7%	-7%	0%	39%	61%	0%	0%	27%	0%	66%	7%	100%	42%	0%	0%	0%	0%	100%	100%	100%	100%	0%
Lotus	-4%	0%	4%	0%	44%	0%	0%	0%	0%	36%	44%	80%	44%	25%	20%	11%	0%	100%	100%	80%	80%	0%
Mazda	-10%	-8%	2%	6%	73%	0%	0%	23%	0%	65%	11%	98%	73%	19%	2%	0%	0%	100%	100%	98%	98%	0%
Mitsubishi	-14%	-12%	2%	8%	70%	0%	0%	21%	0%	69%	4%	95%	70%	17%	5%	0%	0%	100%	100%	95%	95%	0%
Nissan	-8%	-7%	1%	13%	69%	3%	0%	25%	0%	69%	3%	98%	72%	20%	2%	0%	0%	100%	100%	98%	98%	0%
Porsche	-11%	-5%	7%	8%	35%	7%	0%	21%	0%	42%	19%	83%	41%	34%	17%	10%	1%	100%	100%	83%	83%	0%
Spyker	-17%	-10%	7%	5%	47%	3%	0%	13%	0%	66%	6%	84%	50%	32%	16%	5%	2%	100%	100%	84%	84%	0%
Subaru	-13%	-10%	2%	6%	71%	0%	0%	6%	0%	72%	19%	96%	71%	19%	4%	0%	0%	100%	100%	96%	96%	0%
Suzuki	-4%	-3%	1%	3%	67%	0%	0%	14%	0%	72%	6%	92%	67%	22%	8%	0%	0%	100%	100%	92%	92%	0%
Tata	-17%	-9%	8%	15%	16%	29%	0%	31%	0%	58%	0%	88%	45%	43%	12%	0%	0%	100%	100%	88%	88%	0%
Tesla	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%	0%
Toyota	-7%	-7%	0%	23%	60%	4%	0%	30%	0%	53%	5%	88%	64%	13%	0%	0%	0%	88%	88%	88%	88%	0%
Volkswagen	-13%	-8%	5%	6%	60%	3%	0%	20%	0%	63%	8%	90%	62%	31%	10%	1%	0%	100%	100%	90%	90%	0%
Fleet	-11%	-9%	2%	19%	62%	5%	0%	34%	0%	55%	5%	94%	66%	15%	3%	0%	0%	97%	97%	94%	94%	0%

3.8.4 Projected Technology Penetrations in Alternative Cases

Table 3.8-26 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
Aston Martin	-16%	-7%	9%	0%	0%	15%	0%	0%	15%	61%	7%	50%	15%	30%	16%	15%	15%	75%	80%	50%	60%	24%
BMW	-12%	-9%	3%	49%	26%	2%	0%	0%	17%	69%	12%	59%	28%	22%	1%	0%	0%	75%	80%	59%	99%	0%
Chrysler/Fiat	-7%	-7%	0%	33%	0%	1%	1%	2%	19%	76%	3%	60%	1%	0%	0%	0%	0%	75%	80%	60%	33%	0%
Daimler	-13%	-9%	4%	42%	21%	4%	0%	0%	17%	70%	8%	57%	25%	28%	4%	0%	0%	75%	80%	57%	95%	1%
Ferrari	-13%	-7%	6%	0%	0%	15%	0%	0%	16%	65%	2%	50%	15%	30%	16%	15%	15%	75%	80%	50%	60%	24%
Ford	-8%	-8%	0%	44%	7%	1%	5%	21%	13%	52%	7%	59%	8%	2%	0%	0%	0%	74%	79%	59%	52%	0%
Geely	-13%	-9%	3%	47%	15%	8%	3%	11%	16%	63%	2%	57%	22%	26%	5%	0%	0%	75%	80%	57%	95%	0%
General Motors	-7%	-7%	0%	13%	0%	0%	6%	23%	13%	52%	6%	60%	0%	0%	0%	0%	0%	75%	80%	60%	12%	0%
Honda	-2%	-2%	0%	15%	0%	0%	0%	0%	17%	68%	12%	58%	0%	3%	0%	0%	0%	25%	27%	58%	15%	0%
Hyundai	-4%	-4%	0%	33%	0%	0%	4%	18%	14%	56%	7%	60%	0%	0%	0%	0%	0%	75%	80%	60%	33%	0%
Kia	-2%	-2%	0%	20%	0%	0%	2%	7%	17%	66%	9%	60%	0%	0%	0%	0%	0%	6%	7%	60%	20%	0%
Lotus	-3%	0%	3%	16%	30%	0%	0%	0%	9%	35%	46%	54%	30%	30%	11%	13%	0%	75%	80%	54%	89%	0%
Mazda	-4%	-4%	0%	68%	19%	0%	3%	12%	14%	54%	17%	60%	6%	0%	0%	0%	0%	75%	80%	60%	86%	0%
Mitsubishi	-7%	-7%	0%	75%	25%	0%	0%	0%	18%	73%	9%	60%	25%	0%	0%	0%	0%	75%	80%	60%	100%	0%
Nissan	-5%	-5%	0%	32%	0%	0%	1%	3%	18%	73%	5%	59%	0%	1%	0%	0%	0%	74%	79%	59%	32%	0%
Porsche	-8%	-3%	5%	16%	25%	3%	0%	0%	12%	47%	29%	53%	27%	30%	12%	15%	0%	75%	80%	53%	88%	0%
Spyker	-15%	-9%	6%	29%	25%	3%	0%	0%	16%	65%	8%	53%	27%	30%	11%	3%	0%	75%	80%	53%	89%	0%
Subaru	-7%	-7%	0%	95%	5%	0%	0%	0%	15%	59%	27%	60%	5%	0%	0%	0%	0%	75%	80%	60%	100%	0%
Suzuki	-1%	0%	1%	57%	30%	0%	0%	0%	18%	72%	10%	60%	30%	13%	0%	0%	0%	75%	80%	60%	100%	0%
Tata	-15%	-11%	4%	57%	7%	11%	0%	0%	20%	79%	0%	59%	19%	23%	2%	0%	0%	75%	80%	59%	98%	0%
Tesla	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%	0%
Toyota	-2%	-2%	0%	23%	0%	0%	1%	3%	60%	15%	7%	51%	0%	15%	0%	0%	0%	2%	2%	51%	24%	0%
Volkswagen	-10%	-7%	3%	38%	29%	1%	0%	0%	17%	69%	11%	58%	29%	30%	3%	1%	0%	75%	80%	58%	97%	0%
Fleet	-6%	-5%	1%	31%	5%	1%	2%	9%	23%	53%	8%	57%	6%	7%	1%	0%	0%	53%	57%	57%	41%	0%

Table 3.8-27 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
Aston Martin	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
BMW	-14%	-13%	0%	73%	24%	3%	20%	80%	0%	0%	1%	60%	27%	6%	0%	0%	0%	75%	80%	60%	100%	0%
Chrysler/Fiat	-7%	-7%	0%	28%	3%	3%	17%	69%	2%	9%	3%	60%	6%	0%	0%	0%	0%	75%	80%	60%	34%	0%
Daimler	-15%	-13%	2%	80%	14%	6%	20%	80%	0%	0%	0%	60%	20%	30%	0%	0%	0%	75%	80%	60%	89%	11%
Ferrari	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%	40%	16%	6%	14%	55%	5%	21%	3%	59%	22%	2%	0%	0%	0%	73%	78%	59%	62%	0%
Geely	-15%	-13%	2%	72%	27%	2%	20%	80%	0%	0%	0%	60%	28%	30%	0%	0%	0%	75%	80%	60%	100%	0%
General Motors	-8%	-8%	0%	40%	0%	0%	19%	75%	1%	5%	0%	60%	0%	0%	0%	0%	0%	75%	80%	60%	40%	0%
Honda	-6%	-6%	0%	66%	0%	0%	12%	50%	8%	30%	0%	60%	0%	0%	0%	0%	0%	75%	80%	60%	66%	0%
Hyundai	-10%	-10%	0%	100%	0%	0%	18%	72%	2%	8%	0%	60%	0%	0%	0%	0%	0%	75%	80%	60%	100%	0%
Kia	-5%	-5%	0%	99%	0%	0%	20%	79%	0%	0%	1%	60%	0%	0%	0%	0%	0%	75%	80%	60%	99%	0%
Lotus	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Mazda	-10%	-10%	0%	79%	21%	0%	13%	51%	7%	27%	2%	60%	21%	0%	0%	0%	0%	75%	80%	60%	100%	0%
Mitsubishi	-11%	-11%	0%	70%	30%	0%	13%	52%	7%	28%	0%	60%	30%	0%	0%	0%	0%	75%	80%	60%	100%	0%
Nissan	-5%	-5%	0%	82%	15%	3%	15%	61%	5%	18%	2%	60%	18%	0%	0%	0%	0%	75%	80%	60%	100%	0%
Porsche	-15%	-13%	2%	78%	13%	8%	20%	79%	0%	0%	1%	60%	22%	30%	0%	0%	25%	75%	80%	60%	100%	0%
Spyker	-4%	-2%	2%	76%	19%	6%	20%	80%	0%	0%	0%	60%	24%	30%	0%	0%	46%	75%	80%	60%	100%	0%
Subaru	-11%	-11%	0%	70%	30%	0%	5%	20%	13%	54%	8%	60%	30%	0%	0%	0%	0%	75%	80%	60%	100%	0%
Suzuki	-12%	-12%	0%	64%	30%	0%	16%	63%	4%	16%	0%	60%	30%	6%	0%	0%	0%	75%	80%	60%	100%	0%
Tata	-11%	-9%	2%	66%	10%	10%	13%	53%	6%	24%	0%	58%	20%	30%	4%	0%	0%	75%	80%	58%	96%	0%
Tesla	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%	66%	0%	0%	16%	63%	6%	7%	3%	57%	0%	5%	0%	0%	0%	13%	14%	57%	66%	0%
Volkswagen	-14%	-12%	2%	73%	23%	3%	20%	80%	0%	0%	0%	60%	27%	30%	0%	0%	0%	75%	80%	60%	100%	0%
Fleet	-7%	-7%	0%	57%	6%	2%	16%	65%	4%	12%	2%	59%	7%	4%	0%	0%	0%	62%	66%	59%	64%	0%

Table 3.8-28 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
Aston Martin	-16%	-7%	9%	0%	0%	15%	0%	0%	15%	61%	7%	50%	15%	30%	16%	15%	15%	75%	80%	50%	60%	24%
BMW	-12%	-10%	2%	55%	25%	2%	5%	21%	13%	51%	9%	59%	28%	18%	1%	0%	0%	75%	80%	59%	99%	0%
Chrysler/Fiat	-7%	-7%	0%	31%	1%	1%	8%	32%	11%	45%	3%	60%	3%	0%	0%	0%	0%	75%	80%	60%	34%	0%
Daimler	-13%	-10%	4%	52%	20%	4%	5%	20%	13%	53%	6%	58%	24%	28%	3%	0%	0%	75%	80%	58%	93%	3%
Ferrari	-13%	-7%	6%	0%	0%	15%	0%	0%	16%	65%	2%	50%	15%	30%	16%	15%	15%	75%	80%	50%	60%	24%
Ford	-7%	-7%	0%	43%	10%	3%	8%	32%	10%	42%	6%	59%	13%	2%	0%	0%	0%	74%	79%	59%	55%	0%
Geely	-13%	-10%	3%	55%	18%	6%	8%	32%	11%	44%	1%	58%	24%	27%	3%	0%	0%	75%	80%	58%	97%	0%
General Motors	-7%	-7%	0%	26%	0%	0%	12%	49%	7%	29%	3%	60%	0%	0%	0%	0%	0%	75%	80%	60%	26%	0%
Honda	-4%	-4%	0%	31%	0%	0%	4%	15%	14%	56%	8%	59%	0%	2%	0%	0%	0%	40%	43%	59%	31%	0%
Hyundai	-5%	-5%	0%	47%	0%	0%	7%	29%	12%	46%	6%	60%	0%	0%	0%	0%	0%	75%	80%	60%	47%	0%
Kia	-3%	-3%	0%	37%	0%	0%	6%	23%	13%	51%	7%	60%	0%	0%	0%	0%	0%	22%	23%	60%	37%	0%
Lotus	-3%	0%	3%	16%	30%	0%	0%	0%	9%	35%	46%	54%	30%	30%	11%	13%	0%	75%	80%	54%	89%	0%
Mazda	-5%	-5%	0%	70%	19%	0%	5%	19%	12%	50%	14%	60%	8%	0%	0%	0%	0%	75%	80%	60%	89%	0%
Mitsubishi	-8%	-8%	0%	73%	27%	0%	5%	18%	14%	57%	6%	60%	27%	0%	0%	0%	0%	75%	80%	60%	100%	0%
Nissan	-5%	-5%	0%	47%	5%	1%	5%	21%	14%	56%	4%	60%	6%	1%	0%	0%	0%	75%	80%	60%	53%	0%
Porsche	-9%	-5%	4%	31%	22%	4%	5%	19%	9%	36%	22%	55%	26%	30%	9%	11%	6%	75%	80%	55%	91%	0%
Spyker	-14%	-8%	6%	36%	24%	3%	3%	11%	14%	55%	7%	54%	27%	30%	9%	2%	7%	75%	80%	54%	91%	0%
Subaru	-8%	-8%	0%	89%	11%	0%	1%	5%	14%	57%	22%	60%	11%	0%	0%	0%	0%	75%	80%	60%	100%	0%
Suzuki	-3%	-2%	1%	58%	30%	0%	3%	11%	16%	62%	8%	60%	30%	12%	0%	0%	0%	75%	80%	60%	100%	0%
Tata	-13%	-10%	3%	61%	9%	11%	7%	26%	13%	52%	0%	58%	19%	26%	3%	0%	0%	75%	80%	58%	97%	0%
Tesla	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%	0%
Toyota	-2%	-2%	0%	40%	0%	0%	7%	26%	39%	12%	5%	53%	0%	12%	0%	0%	0%	6%	7%	53%	40%	0%
Volkswagen	-11%	-8%	3%	45%	27%	1%	4%	16%	14%	55%	9%	59%	29%	30%	2%	0%	0%	75%	80%	59%	98%	0%
Fleet	-6%	-6%	0%	40%	5%	1%	7%	28%	17%	39%	6%	58%	6%	6%	0%	0%	0%	56%	60%	58%	49%	0%

Table 3.8-29 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
Aston Martin	-16%	-7%	9%	0%	0%	15%	0%	0%	15%	61%	7%	50%	15%	30%	16%	15%	15%	75%	80%	50%	60%	24%
BMW	-12%	-8%	5%	37%	26%	2%	0%	0%	17%	68%	10%	57%	28%	30%	6%	0%	0%	75%	80%	57%	94%	0%
Chrysler/Fiat	-10%	-9%	0%	67%	28%	1%	1%	2%	19%	76%	2%	60%	29%	1%	0%	0%	0%	75%	80%	60%	98%	0%
Daimler	-13%	-8%	5%	33%	21%	4%	0%	0%	17%	69%	5%	55%	25%	30%	8%	4%	0%	75%	80%	55%	91%	1%
Ferrari	-13%	-7%	6%	0%	0%	15%	0%	0%	16%	65%	2%	50%	15%	30%	16%	15%	15%	75%	80%	50%	60%	24%
Ford	-10%	-10%	0%	68%	27%	1%	5%	21%	13%	53%	7%	59%	28%	4%	0%	0%	0%	74%	79%	59%	98%	0%
Geely	-13%	-8%	5%	37%	15%	8%	3%	11%	15%	60%	2%	54%	22%	30%	9%	6%	0%	75%	80%	54%	91%	0%
General Motors	-10%	-10%	0%	68%	28%	1%	6%	23%	13%	52%	5%	60%	29%	1%	0%	0%	0%	75%	80%	60%	98%	0%
Honda	-4%	-4%	0%	48%	0%	0%	0%	0%	17%	68%	12%	58%	0%	3%	0%	0%	0%	73%	77%	58%	48%	0%
Hyundai	-5%	-5%	0%	53%	7%	0%	4%	18%	14%	56%	7%	60%	7%	0%	0%	0%	0%	75%	80%	60%	60%	0%
Kia	-4%	-4%	0%	20%	0%	0%	2%	7%	17%	66%	9%	60%	0%	0%	0%	0%	0%	75%	80%	60%	20%	0%
Lotus	-3%	0%	3%	16%	30%	0%	0%	0%	9%	35%	46%	54%	30%	30%	11%	13%	0%	75%	80%	54%	89%	0%
Mazda	-6%	-6%	0%	69%	30%	0%	3%	12%	14%	55%	16%	60%	30%	1%	0%	0%	0%	75%	80%	60%	100%	0%
Mitsubishi	-9%	-7%	2%	45%	30%	0%	0%	0%	19%	75%	6%	60%	30%	25%	0%	0%	0%	75%	80%	60%	100%	0%
Nissan	-6%	-6%	0%	69%	30%	0%	1%	3%	18%	73%	5%	59%	30%	1%	0%	0%	0%	74%	79%	59%	99%	0%
Porsche	-8%	-3%	5%	11%	25%	3%	0%	0%	12%	46%	26%	50%	27%	30%	16%	15%	14%	75%	80%	50%	84%	0%
Spyker	-16%	-8%	7%	24%	25%	3%	0%	0%	16%	65%	7%	53%	27%	30%	12%	7%	0%	75%	80%	53%	88%	0%
Subaru	-8%	-7%	2%	53%	30%	0%	0%	0%	15%	61%	23%	60%	30%	17%	0%	0%	0%	75%	80%	60%	100%	0%
Suzuki	-1%	0%	1%	40%	30%	0%	0%	0%	18%	73%	8%	60%	30%	30%	0%	0%	0%	75%	80%	60%	100%	0%
Tata	-15%	-9%	6%	38%	7%	11%	0%	0%	18%	71%	0%	53%	19%	30%	11%	3%	0%	75%	80%	53%	89%	0%
Tesla	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%	0%
Toyota	-4%	-4%	0%	23%	0%	0%	1%	3%	15%	60%	7%	51%	0%	15%	0%	0%	0%	63%	68%	51%	24%	0%
Volkswagen	-10%	-7%	4%	32%	29%	1%	0%	0%	16%	66%	10%	55%	29%	30%	8%	1%	0%	75%	80%	55%	92%	0%
Fleet	-7%	-7%	1%	50%	17%	1%	2%	9%	15%	61%	8%	57%	18%	9%	1%	0%	0%	72%	77%	57%	73%	0%

Table 3.8-30 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
Aston Martin	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
BMW	-14%	-12%	2%	73%	24%	3%	20%	80%	0%	0%	0%	60%	27%	30%	0%	0%	0%	75%	80%	60%	100%	0%
Chrysler/Fiat	-9%	-9%	0%	71%	25%	3%	17%	69%	2%	9%	3%	60%	27%	2%	0%	0%	0%	75%	80%	60%	100%	0%
Daimler	-15%	-13%	2%	80%	14%	6%	20%	80%	0%	0%	0%	60%	20%	30%	0%	0%	0%	75%	80%	60%	89%	11%
Ferrari	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%	66%	17%	6%	14%	55%	5%	22%	2%	59%	23%	16%	0%	0%	0%	74%	79%	59%	98%	0%
Geely	-15%	-13%	2%	72%	27%	2%	20%	80%	0%	0%	0%	60%	28%	30%	0%	0%	35%	75%	80%	60%	100%	0%
General Motors	-10%	-10%	0%	51%	20%	5%	19%	75%	1%	5%	0%	60%	25%	2%	0%	0%	0%	75%	80%	60%	77%	0%
Honda	-8%	-8%	0%	78%	22%	0%	12%	50%	8%	30%	0%	60%	22%	0%	0%	0%	0%	75%	80%	60%	100%	0%
Hyundai	-10%	-10%	0%	70%	30%	0%	18%	72%	2%	8%	0%	60%	30%	0%	0%	0%	0%	75%	80%	60%	100%	0%
Kia	-9%	-9%	0%	91%	9%	0%	20%	79%	0%	0%	1%	60%	9%	0%	0%	0%	0%	75%	80%	60%	100%	0%
Lotus	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Mazda	-15%	-15%	0%	69%	30%	0%	13%	51%	7%	27%	2%	60%	30%	1%	0%	0%	0%	75%	80%	60%	100%	0%
Mitsubishi	-15%	-13%	2%	58%	30%	0%	13%	52%	7%	27%	0%	59%	30%	11%	1%	0%	0%	75%	80%	59%	99%	0%
Nissan	-6%	-6%	0%	73%	24%	3%	15%	61%	5%	18%	1%	60%	27%	0%	0%	0%	0%	75%	80%	60%	100%	0%
Porsche	-15%	-13%	2%	48%	27%	8%	20%	79%	0%	0%	1%	60%	36%	30%	0%	0%	53%	75%	80%	60%	83%	17%
Spyker	-4%	-2%	2%	76%	19%	6%	20%	80%	0%	0%	0%	60%	24%	30%	0%	0%	70%	75%	80%	60%	100%	0%
Subaru	-15%	-15%	0%	70%	30%	0%	5%	20%	13%	54%	8%	60%	30%	0%	0%	0%	0%	75%	80%	60%	100%	0%
Suzuki	-12%	-12%	0%	63%	30%	0%	16%	63%	4%	16%	0%	59%	30%	6%	1%	0%	0%	75%	80%	59%	99%	0%
Tata	-11%	-9%	3%	59%	10%	10%	13%	53%	6%	23%	0%	57%	20%	30%	6%	5%	9%	75%	80%	57%	94%	0%
Tesla	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%	73%	13%	3%	16%	63%	3%	11%	3%	57%	15%	5%	0%	0%	0%	71%	76%	57%	88%	0%
Volkswagen	-14%	-12%	2%	73%	23%	3%	20%	80%	0%	0%	0%	60%	27%	30%	0%	0%	31%	75%	80%	60%	100%	0%
Fleet	-9%	-9%	0%	66%	19%	4%	16%	65%	3%	13%	1%	59%	23%	7%	0%	0%	1%	74%	79%	59%	91%	0%

Table 3.8-31 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
Aston Martin	-16%	-7%	9%	0%	0%	15%	0%	0%	15%	61%	7%	50%	15%	30%	16%	15%	15%	75%	80%	50%	60%	24%
BMW	-13%	-9%	4%	46%	25%	2%	5%	21%	12%	50%	7%	58%	28%	30%	4%	0%	0%	75%	80%	58%	96%	0%
Chrysler/Fiat	-9%	-9%	0%	69%	27%	2%	8%	32%	11%	45%	3%	60%	28%	2%	0%	0%	0%	75%	80%	60%	99%	0%
Daimler	-14%	-9%	5%	45%	20%	4%	5%	20%	13%	52%	4%	56%	24%	30%	6%	3%	0%	75%	80%	56%	90%	3%
Ferrari	-13%	-7%	6%	0%	0%	15%	0%	0%	16%	65%	2%	50%	15%	30%	16%	15%	15%	75%	80%	50%	60%	24%
Ford	-10%	-9%	1%	67%	23%	3%	8%	32%	11%	42%	5%	59%	26%	8%	0%	0%	0%	74%	79%	59%	98%	0%
Geely	-14%	-10%	4%	48%	18%	6%	8%	32%	10%	41%	1%	56%	24%	30%	6%	4%	11%	75%	80%	56%	94%	0%
General Motors	-10%	-10%	0%	59%	24%	3%	12%	49%	7%	29%	3%	60%	27%	2%	0%	0%	0%	75%	80%	60%	88%	0%
Honda	-5%	-5%	0%	58%	7%	0%	4%	15%	14%	56%	8%	59%	7%	2%	0%	0%	0%	73%	78%	59%	64%	0%
Hyundai	-6%	-6%	0%	57%	12%	0%	7%	29%	12%	46%	6%	60%	12%	0%	0%	0%	0%	75%	80%	60%	68%	0%
Kia	-5%	-5%	0%	35%	2%	0%	6%	23%	13%	51%	7%	60%	2%	0%	0%	0%	0%	75%	80%	60%	38%	0%
Lotus	-3%	0%	3%	16%	30%	0%	0%	0%	9%	35%	46%	54%	30%	30%	11%	13%	0%	75%	80%	54%	89%	0%
Mazda	-7%	-7%	0%	69%	30%	0%	5%	19%	13%	50%	13%	60%	30%	1%	0%	0%	0%	75%	80%	60%	100%	0%
Mitsubishi	-11%	-9%	2%	50%	30%	0%	5%	18%	15%	58%	4%	60%	30%	20%	0%	0%	0%	75%	80%	60%	100%	0%
Nissan	-6%	-6%	0%	70%	28%	1%	5%	21%	14%	56%	4%	60%	29%	1%	0%	0%	0%	75%	80%	60%	99%	0%
Porsche	-10%	-5%	5%	20%	25%	4%	5%	19%	9%	35%	20%	52%	29%	30%	13%	11%	23%	75%	80%	52%	84%	4%
Spyker	-14%	-8%	6%	31%	24%	3%	3%	11%	14%	55%	6%	54%	27%	30%	10%	6%	10%	75%	80%	54%	90%	0%
Subaru	-10%	-9%	1%	57%	30%	0%	1%	5%	15%	60%	20%	60%	30%	13%	0%	0%	0%	75%	80%	60%	100%	0%
Suzuki	-3%	-2%	1%	44%	30%	0%	3%	11%	16%	63%	7%	60%	30%	26%	0%	0%	0%	75%	80%	60%	100%	0%
Tata	-13%	-9%	4%	48%	9%	11%	7%	26%	12%	47%	0%	55%	19%	30%	8%	4%	4%	75%	80%	55%	92%	0%
Tesla	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%	0%
Toyota	-5%	-5%	0%	42%	5%	1%	7%	26%	10%	41%	5%	53%	6%	12%	0%	0%	0%	66%	71%	53%	49%	0%
Volkswagen	-11%	-8%	3%	41%	27%	1%	4%	16%	13%	52%	8%	56%	29%	30%	6%	0%	6%	75%	80%	56%	94%	0%
Fleet	-8%	-7%	1%	55%	18%	2%	7%	28%	11%	44%	5%	58%	20%	8%	1%	0%	1%	73%	78%	58%	79%	0%

Table 3.8-32 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
Aston Martin	-16%	-7%	9%	0%	0%	15%	0%	0%	15%	61%	7%	50%	15%	30%	16%	15%	15%	75%	80%	50%	60%	24%
BMW	-12%	-11%	1%	67%	26%	2%	0%	0%	17%	68%	14%	60%	28%	4%	1%	0%	0%	75%	80%	60%	99%	0%
Chrysler/Fiat	-7%	-7%	0%	33%	0%	1%	1%	2%	19%	76%	3%	60%	1%	0%	0%	0%	0%	75%	80%	60%	33%	0%
Daimler	-13%	-10%	2%	57%	21%	4%	0%	0%	18%	71%	8%	58%	25%	14%	3%	0%	0%	75%	80%	58%	96%	1%
Ferrari	-13%	-7%	6%	0%	0%	15%	0%	0%	16%	65%	2%	50%	15%	30%	16%	15%	15%	75%	80%	50%	60%	24%
Ford	-8%	-8%	0%	51%	0%	0%	5%	21%	13%	52%	7%	59%	0%	2%	0%	0%	0%	74%	79%	59%	50%	0%
Geely	-13%	-9%	3%	49%	15%	8%	3%	11%	16%	65%	2%	58%	22%	26%	3%	0%	0%	75%	80%	58%	97%	0%
General Motors	-7%	-7%	0%	12%	0%	0%	6%	23%	13%	52%	6%	60%	0%	0%	0%	0%	0%	75%	80%	60%	13%	0%
Honda	-2%	-2%	0%	15%	0%	0%	0%	0%	38%	47%	12%	58%	0%	3%	0%	0%	0%	0%	0%	58%	15%	0%
Hyundai	-3%	-3%	0%	33%	0%	0%	4%	18%	20%	50%	7%	60%	0%	0%	0%	0%	0%	0%	0%	60%	33%	0%
Kia	-2%	-2%	0%	12%	0%	0%	2%	7%	83%	0%	9%	60%	0%	0%	0%	0%	0%	0%	0%	60%	12%	0%
Lotus	-2%	0%	2%	27%	30%	0%	0%	0%	7%	26%	57%	54%	30%	30%	11%	3%	0%	75%	80%	54%	89%	0%
Mazda	-4%	-4%	0%	19%	1%	0%	3%	12%	14%	54%	17%	60%	1%	0%	0%	0%	0%	75%	80%	60%	21%	0%
Mitsubishi	-6%	-6%	0%	68%	15%	0%	0%	0%	18%	73%	9%	60%	0%	0%	0%	0%	0%	75%	80%	60%	83%	0%
Nissan	-5%	-5%	0%	32%	0%	0%	1%	3%	18%	73%	5%	59%	0%	1%	0%	0%	0%	45%	48%	59%	32%	0%
Porsche	-7%	-3%	4%	23%	25%	3%	0%	0%	11%	43%	34%	53%	27%	30%	12%	8%	0%	75%	80%	53%	88%	0%
Spyker	-15%	-10%	5%	36%	25%	3%	0%	0%	17%	67%	9%	56%	27%	30%	6%	0%	0%	75%	80%	56%	94%	0%
Subaru	-6%	-6%	0%	68%	3%	0%	0%	0%	15%	59%	27%	60%	3%	0%	0%	0%	0%	75%	80%	60%	71%	0%
Suzuki	0%	0%	0%	100%	0%	0%	0%	0%	18%	71%	12%	60%	0%	0%	0%	0%	0%	75%	80%	60%	100%	0%
Tata	-15%	-11%	4%	57%	7%	11%	0%	0%	20%	79%	0%	59%	19%	23%	2%	0%	0%	75%	80%	59%	98%	0%
Tesla	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%	0%
Toyota	-2%	-2%	0%	19%	0%	0%	1%	3%	73%	2%	7%	51%	0%	15%	0%	0%	0%	0%	0%	51%	24%	0%
Volkswagen	-9%	-7%	2%	58%	29%	1%	0%	0%	17%	68%	15%	60%	29%	12%	1%	0%	0%	75%	80%	60%	99%	0%
Fleet	-6%	-5%	0%	32%	4%	0%	2%	9%	31%	46%	8%	58%	4%	5%	1%	0%	0%	43%	46%	58%	38%	0%

Table 3.8-33 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
Aston Martin	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%	0%	73%	24%	3%	20%	80%	0%	0%	1%	60%	27%	0%	0%	0%	0%	75%	80%	60%	100%	0%
Chrysler/Fiat	-7%	-7%	0%	28%	3%	1%	17%	69%	2%	9%	3%	60%	4%	0%	0%	0%	0%	75%	80%	60%	33%	0%
Daimler	-15%	-14%	1%	80%	14%	6%	20%	80%	0%	0%	0%	60%	20%	16%	0%	0%	0%	75%	80%	60%	89%	11%
Ferrari	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%	44%	0%	4%	14%	55%	5%	21%	3%	59%	4%	2%	0%	0%	0%	73%	78%	59%	49%	0%
Geely	-15%	-15%	0%	72%	27%	2%	20%	80%	0%	0%	0%	60%	28%	3%	0%	0%	0%	75%	80%	60%	100%	0%
General Motors	-8%	-8%	0%	42%	0%	0%	19%	75%	1%	5%	0%	60%	0%	0%	0%	0%	0%	75%	80%	60%	42%	0%
Honda	-4%	-4%	0%	66%	0%	0%	12%	50%	8%	30%	0%	60%	0%	0%	0%	0%	0%	26%	28%	60%	66%	0%
Hyundai	-5%	-5%	0%	100%	0%	0%	18%	72%	2%	8%	0%	60%	0%	0%	0%	0%	0%	15%	16%	60%	100%	0%
Kia	-4%	-4%	0%	99%	0%	0%	20%	79%	0%	0%	1%	60%	0%	0%	0%	0%	0%	0%	0%	60%	99%	0%
Lotus	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Mazda	-10%	-10%	0%	53%	19%	0%	13%	51%	7%	27%	2%	60%	19%	0%	0%	0%	0%	75%	80%	60%	72%	0%
Mitsubishi	-10%	-10%	0%	81%	19%	0%	13%	52%	7%	28%	0%	60%	19%	0%	0%	0%	0%	75%	80%	60%	100%	0%
Nissan	-4%	-4%	0%	59%	0%	3%	15%	61%	5%	18%	2%	60%	3%	0%	0%	0%	0%	75%	80%	60%	62%	0%
Porsche	-15%	-13%	2%	78%	13%	8%	20%	79%	0%	0%	1%	60%	22%	30%	0%	0%	25%	75%	80%	60%	100%	0%
Spyker	-4%	-2%	2%	76%	19%	6%	20%	80%	0%	0%	0%	60%	24%	30%	0%	0%	0%	75%	80%	60%	100%	0%
Subaru	-10%	-10%	0%	23%	10%	0%	5%	20%	13%	54%	8%	60%	10%	0%	0%	0%	0%	75%	80%	60%	32%	0%
Suzuki	-8%	-8%	0%	70%	30%	0%	16%	63%	4%	16%	0%	60%	30%	0%	0%	0%	0%	75%	80%	60%	100%	0%
Tata	-11%	-9%	2%	66%	10%	10%	13%	53%	6%	24%	0%	58%	20%	30%	4%	0%	0%	75%	80%	58%	96%	0%
Tesla	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%	66%	0%	0%	16%	63%	11%	2%	3%	57%	0%	5%	0%	0%	0%	13%	14%	57%	66%	0%
Volkswagen	-14%	-12%	2%	73%	23%	3%	20%	80%	0%	0%	0%	60%	27%	30%	0%	0%	0%	75%	80%	60%	100%	0%
Fleet	-6%	-6%	0%	55%	2%	1%	16%	65%	5%	11%	2%	59%	4%	3%	0%	0%	0%	54%	58%	59%	59%	0%

Table 3.8-34 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
Aston Martin	-16%	-7%	9%	0%	0%	15%	0%	0%	15%	61%	7%	50%	15%	30%	16%	15%	15%	75%	80%	50%	60%	24%
BMW	-12%	-12%	0%	69%	25%	2%	5%	21%	13%	50%	10%	60%	28%	3%	0%	0%	0%	75%	80%	60%	100%	0%
Chrysler/Fiat	-7%	-7%	0%	31%	1%	1%	8%	32%	11%	45%	3%	60%	2%	0%	0%	0%	0%	75%	80%	60%	33%	0%
Daimler	-13%	-11%	2%	63%	20%	4%	5%	20%	13%	53%	6%	59%	24%	15%	2%	0%	0%	75%	80%	59%	94%	3%
Ferrari	-13%	-7%	6%	0%	0%	15%	0%	0%	16%	65%	2%	50%	15%	30%	16%	15%	15%	75%	80%	50%	60%	24%
Ford	-7%	-7%	0%	49%	0%	2%	8%	32%	10%	42%	6%	59%	2%	2%	0%	0%	0%	74%	79%	59%	50%	0%
Geely	-13%	-11%	2%	56%	18%	6%	8%	32%	11%	45%	2%	59%	24%	19%	2%	0%	0%	75%	80%	59%	98%	0%
General Motors	-8%	-8%	0%	27%	0%	0%	12%	49%	7%	29%	3%	60%	0%	0%	0%	0%	0%	75%	80%	60%	27%	0%
Honda	-3%	-3%	0%	31%	0%	0%	4%	15%	29%	42%	8%	59%	0%	2%	0%	0%	0%	8%	9%	59%	31%	0%
Hyundai	-3%	-3%	0%	47%	0%	0%	7%	29%	16%	42%	6%	60%	0%	0%	0%	0%	0%	3%	3%	60%	47%	0%
Kia	-3%	-3%	0%	31%	0%	0%	6%	23%	64%	0%	7%	60%	0%	0%	0%	0%	0%	0%	0%	60%	31%	0%
Lotus	-2%	0%	2%	27%	30%	0%	0%	0%	7%	26%	57%	54%	30%	30%	11%	3%	0%	75%	80%	54%	89%	0%
Mazda	-5%	-5%	0%	25%	5%	0%	5%	19%	12%	50%	14%	60%	5%	0%	0%	0%	0%	75%	80%	60%	30%	0%
Mitsubishi	-8%	-8%	0%	73%	17%	0%	5%	18%	14%	57%	6%	60%	7%	0%	0%	0%	0%	75%	80%	60%	89%	0%
Nissan	-5%	-5%	0%	40%	0%	1%	5%	21%	14%	56%	4%	60%	1%	1%	0%	0%	0%	54%	58%	60%	41%	0%
Porsche	-9%	-6%	3%	36%	22%	4%	5%	19%	8%	33%	26%	55%	26%	30%	9%	6%	6%	75%	80%	55%	91%	0%
Spyker	-13%	-9%	5%	42%	24%	3%	3%	11%	14%	58%	8%	57%	27%	30%	5%	0%	0%	75%	80%	57%	95%	0%
Subaru	-7%	-7%	0%	57%	5%	0%	1%	5%	14%	57%	22%	60%	5%	0%	0%	0%	0%	75%	80%	60%	62%	0%
Suzuki	-1%	-1%	0%	95%	5%	0%	3%	11%	15%	61%	10%	60%	5%	0%	0%	0%	0%	75%	80%	60%	100%	0%
Tata	-13%	-10%	3%	61%	9%	11%	7%	26%	13%	52%	0%	58%	19%	26%	3%	0%	0%	75%	80%	58%	97%	0%
Tesla	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%	0%
Toyota	-2%	-2%	0%	37%	0%	0%	7%	26%	49%	2%	5%	53%	0%	12%	0%	0%	0%	5%	6%	53%	40%	0%
Volkswagen	-10%	-8%	2%	61%	27%	1%	4%	16%	14%	54%	12%	60%	29%	16%	0%	0%	0%	75%	80%	60%	100%	0%
Fleet	-6%	-6%	0%	40%	3%	1%	7%	28%	22%	34%	6%	58%	4%	4%	0%	0%	0%	47%	50%	58%	46%	0%

Table 3.8-35 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
Aston Martin	-16%	-7%	9%	0%	0%	15%	0%	0%	15%	61%	7%	50%	15%	30%	16%	15%	15%	75%	80%	50%	60%	24%
BMW	-12%	-7%	5%	30%	26%	2%	0%	0%	16%	65%	9%	54%	28%	30%	10%	1%	0%	75%	80%	54%	90%	0%
Chrysler/Fiat	-10%	-9%	0%	67%	28%	1%	1%	2%	19%	76%	2%	60%	29%	1%	0%	0%	0%	75%	80%	60%	97%	0%
Daimler	-14%	-7%	6%	26%	21%	4%	0%	0%	17%	66%	5%	53%	25%	30%	12%	6%	0%	75%	80%	53%	87%	1%
Ferrari	-13%	-7%	6%	0%	0%	15%	0%	0%	16%	65%	2%	50%	15%	30%	16%	15%	15%	75%	80%	50%	60%	24%
Ford	-11%	-10%	1%	58%	27%	1%	5%	21%	13%	53%	6%	59%	28%	14%	0%	0%	0%	74%	79%	59%	98%	0%
Geely	-14%	-8%	6%	31%	15%	8%	3%	11%	15%	59%	1%	53%	22%	30%	11%	10%	0%	75%	80%	53%	89%	0%
General Motors	-10%	-10%	0%	68%	28%	1%	6%	23%	13%	52%	6%	60%	29%	0%	0%	0%	0%	75%	80%	60%	97%	0%
Honda	-4%	-4%	0%	70%	14%	0%	0%	0%	17%	68%	12%	58%	5%	3%	0%	0%	0%	73%	77%	58%	84%	0%
Hyundai	-6%	-6%	0%	67%	30%	0%	4%	18%	14%	57%	7%	60%	30%	3%	0%	0%	0%	75%	80%	60%	100%	0%
Kia	-4%	-4%	0%	69%	12%	0%	2%	7%	17%	66%	9%	60%	2%	0%	0%	0%	0%	75%	80%	60%	81%	0%
Lotus	-4%	0%	4%	0%	15%	15%	0%	0%	9%	36%	39%	50%	30%	30%	16%	15%	30%	75%	80%	50%	75%	9%
Mazda	-7%	-5%	2%	43%	30%	0%	3%	12%	14%	58%	11%	59%	30%	26%	1%	0%	0%	75%	80%	59%	98%	0%
Mitsubishi	-9%	-6%	3%	37%	30%	0%	0%	0%	18%	73%	6%	58%	30%	30%	3%	0%	0%	75%	80%	58%	97%	0%
Nissan	-7%	-6%	1%	56%	30%	0%	1%	3%	18%	73%	4%	60%	30%	14%	0%	0%	0%	75%	80%	60%	99%	0%
Porsche	-8%	-3%	5%	0%	12%	15%	0%	0%	12%	46%	26%	50%	27%	30%	16%	15%	27%	75%	80%	50%	72%	11%
Spyker	-16%	-7%	9%	14%	25%	3%	0%	0%	16%	64%	6%	52%	27%	30%	13%	15%	4%	75%	80%	52%	87%	0%
Subaru	-9%	-6%	2%	42%	30%	0%	0%	0%	16%	64%	18%	59%	30%	27%	1%	0%	0%	75%	80%	59%	99%	0%
Suzuki	-2%	0%	2%	33%	30%	0%	0%	0%	17%	69%	7%	56%	30%	30%	7%	0%	0%	75%	80%	56%	93%	0%
Tata	-15%	-9%	6%	37%	7%	11%	0%	0%	18%	71%	0%	53%	19%	30%	11%	3%	0%	75%	80%	53%	89%	0%
Tesla	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%	0%
Toyota	-4%	-4%	0%	28%	1%	0%	1%	3%	15%	60%	7%	51%	1%	15%	0%	0%	0%	63%	68%	51%	30%	0%
Volkswagen	-11%	-6%	4%	25%	29%	1%	0%	0%	16%	64%	9%	53%	29%	30%	11%	5%	1%	75%	80%	53%	89%	0%
Fleet	-8%	-7%	1%	51%	21%	1%	2%	9%	15%	61%	7%	57%	20%	12%	2%	1%	0%	72%	77%	57%	82%	0%

Table 3.8-36 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
Aston Martin	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
BMW	-14%	-12%	2%	73%	24%	3%	20%	80%	0%	0%	0%	60%	27%	30%	0%	0%	0%	75%	80%	60%	100%	0%
Chrysler/Fiat	-9%	-9%	0%	71%	25%	3%	17%	69%	2%	9%	3%	60%	27%	2%	0%	0%	0%	75%	80%	60%	100%	0%
Daimler	-15%	-13%	2%	80%	14%	6%	20%	80%	0%	0%	0%	60%	20%	30%	0%	0%	19%	75%	80%	60%	89%	11%
Ferrari	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Ford	-10%	-8%	2%	65%	17%	6%	14%	55%	5%	22%	2%	59%	23%	25%	1%	0%	0%	74%	79%	59%	98%	0%
Geely	-15%	-13%	2%	72%	27%	2%	20%	80%	0%	0%	0%	60%	28%	30%	0%	0%	35%	75%	80%	60%	100%	0%
General Motors	-10%	-10%	0%	47%	20%	5%	19%	75%	1%	5%	0%	60%	25%	2%	0%	0%	0%	75%	80%	60%	73%	0%
Honda	-9%	-9%	0%	70%	30%	0%	12%	50%	8%	30%	0%	60%	30%	0%	0%	0%	0%	75%	80%	60%	100%	0%
Hyundai	-15%	-15%	0%	67%	30%	0%	18%	72%	2%	8%	0%	60%	30%	3%	0%	0%	0%	75%	80%	60%	100%	0%
Kia	-9%	-9%	0%	70%	30%	0%	20%	79%	0%	0%	1%	60%	30%	0%	0%	0%	0%	75%	80%	60%	100%	0%
Lotus	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%	2%	59%	30%	0%	13%	51%	7%	27%	1%	60%	30%	11%	0%	0%	0%	75%	80%	60%	99%	0%
Mitsubishi	-15%	-13%	2%	57%	30%	0%	13%	52%	7%	27%	0%	59%	30%	11%	2%	0%	0%	75%	80%	59%	98%	0%
Nissan	-7%	-6%	1%	66%	24%	3%	15%	61%	4%	18%	1%	60%	27%	13%	0%	0%	0%	75%	80%	60%	100%	0%
Porsche	-15%	-13%	2%	30%	25%	15%	20%	79%	0%	0%	1%	60%	40%	30%	0%	0%	40%	75%	80%	60%	70%	30%
Spyker	-4%	-2%	2%	76%	19%	6%	20%	80%	0%	0%	0%	60%	24%	30%	0%	0%	70%	75%	80%	60%	100%	0%
Subaru	-15%	-12%	3%	47%	30%	0%	5%	20%	14%	56%	6%	60%	30%	23%	0%	0%	0%	75%	80%	60%	100%	0%
Suzuki	-12%	-12%	0%	61%	30%	0%	16%	63%	4%	15%	0%	59%	30%	6%	2%	0%	0%	75%	80%	59%	98%	0%
Tata	-11%	-9%	3%	59%	10%	10%	13%	53%	6%	23%	0%	57%	20%	30%	6%	5%	9%	75%	80%	57%	94%	0%
Tesla	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%	21%	3%	16%	63%	3%	11%	3%	57%	24%	5%	0%	0%	0%	71%	76%	57%	95%	0%
Volkswagen	-14%	-12%	2%	61%	29%	3%	20%	80%	0%	0%	0%	60%	32%	30%	0%	0%	63%	75%	80%	60%	93%	7%
Fleet	-9%	-9%	1%	62%	22%	4%	16%	65%	3%	13%	1%	59%	26%	9%	0%	0%	2%	74%	79%	59%	91%	0%

Table 3.8-37 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
Aston Martin	-16%	-7%	9%	0%	0%	15%	0%	0%	15%	61%	7%	50%	15%	30%	16%	15%	15%	75%	80%	50%	60%	24%
BMW	-13%	-8%	4%	42%	25%	2%	5%	21%	12%	48%	6%	55%	28%	30%	8%	1%	0%	75%	80%	55%	92%	0%
Chrysler/Fiat	-9%	-9%	0%	69%	27%	2%	8%	32%	11%	45%	3%	60%	28%	2%	0%	0%	0%	75%	80%	60%	98%	0%
Daimler	-14%	-9%	5%	40%	20%	4%	5%	20%	12%	50%	3%	54%	24%	30%	9%	5%	5%	75%	80%	54%	88%	3%
Ferrari	-13%	-7%	6%	0%	0%	15%	0%	0%	16%	65%	2%	50%	15%	30%	16%	15%	15%	75%	80%	50%	60%	24%
Ford	-10%	-9%	1%	60%	23%	3%	8%	32%	11%	42%	5%	59%	26%	18%	0%	0%	0%	74%	79%	59%	98%	0%
Geely	-14%	-9%	5%	43%	18%	6%	8%	32%	10%	41%	1%	55%	24%	30%	8%	7%	11%	75%	80%	55%	92%	0%
General Motors	-10%	-10%	0%	58%	24%	3%	12%	49%	7%	29%	3%	60%	27%	1%	0%	0%	0%	75%	80%	60%	85%	0%
Honda	-6%	-6%	0%	70%	19%	0%	4%	15%	14%	56%	8%	59%	12%	2%	0%	0%	0%	73%	78%	59%	89%	0%
Hyundai	-8%	-8%	0%	67%	30%	0%	7%	29%	12%	47%	5%	60%	30%	3%	0%	0%	0%	75%	80%	60%	100%	0%
Kia	-5%	-5%	0%	69%	16%	0%	6%	23%	13%	51%	7%	60%	9%	0%	0%	0%	0%	75%	80%	60%	85%	0%
Lotus	-4%	0%	4%	0%	15%	15%	0%	0%	9%	36%	39%	50%	30%	30%	16%	15%	30%	75%	80%	50%	75%	9%
Mazda	-8%	-6%	2%	46%	30%	0%	5%	19%	13%	52%	10%	59%	30%	23%	1%	0%	0%	75%	80%	59%	99%	0%
Mitsubishi	-11%	-9%	3%	44%	30%	0%	5%	18%	14%	57%	4%	59%	30%	23%	2%	0%	0%	75%	80%	59%	98%	0%
Nissan	-7%	-6%	1%	59%	28%	1%	5%	21%	14%	56%	3%	60%	29%	14%	0%	0%	0%	75%	80%	60%	99%	0%
Porsche	-10%	-5%	5%	7%	15%	15%	5%	19%	9%	35%	20%	52%	30%	30%	13%	11%	30%	75%	80%	52%	72%	16%
Spyker	-14%	-7%	8%	23%	24%	3%	3%	11%	14%	55%	5%	53%	27%	30%	12%	13%	13%	75%	80%	53%	88%	0%
Subaru	-10%	-8%	3%	43%	30%	0%	1%	5%	16%	62%	15%	59%	30%	26%	1%	0%	0%	75%	80%	59%	99%	0%
Suzuki	-3%	-2%	1%	38%	30%	0%	3%	11%	15%	59%	6%	56%	30%	26%	6%	0%	0%	75%	80%	56%	94%	0%
Tata	-13%	-9%	5%	48%	9%	11%	7%	26%	12%	47%	0%	55%	19%	30%	8%	4%	4%	75%	80%	55%	92%	0%
Tesla	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%	0%
Toyota	-5%	-5%	0%	45%	9%	1%	7%	26%	10%	41%	5%	53%	10%	12%	0%	0%	0%	66%	71%	53%	55%	0%
Volkswagen	-11%	-7%	4%	32%	29%	1%	4%	16%	13%	51%	7%	55%	30%	30%	9%	4%	14%	75%	80%	55%	90%	1%
Fleet	-8%	-7%	1%	55%	21%	2%	7%	28%	11%	44%	5%	58%	22%	11%	1%	0%	1%	73%	78%	58%	85%	0%

Table 3.8-38 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
Aston Martin	-20%	-6%	14%	0%	0%	9%	0%	0%	0%	75%	2%	77%	9%	50%	23%	18%	0%	100%	100%	77%	77%	0%
BMW	-14%	-10%	5%	3%	58%	5%	0%	0%	0%	81%	10%	91%	63%	25%	9%	0%	0%	100%	100%	91%	91%	0%
Chrysler/Fiat	-10%	-10%	0%	24%	71%	3%	0%	2%	0%	95%	2%	100%	74%	2%	0%	0%	0%	100%	100%	100%	99%	0%
Daimler	-17%	-11%	6%	1%	46%	9%	0%	0%	0%	83%	5%	88%	56%	32%	12%	0%	0%	100%	100%	88%	88%	1%
Ferrari	-15%	-6%	9%	0%	0%	5%	0%	0%	0%	77%	0%	77%	5%	50%	23%	22%	5%	100%	100%	77%	77%	0%
Ford	-12%	-12%	0%	25%	68%	4%	0%	27%	0%	65%	6%	98%	71%	3%	1%	0%	0%	99%	99%	98%	98%	0%
Geely	-16%	-10%	6%	3%	32%	18%	0%	13%	0%	74%	1%	88%	50%	35%	12%	0%	0%	100%	100%	88%	88%	0%
General Motors	-10%	-10%	0%	18%	70%	3%	0%	28%	0%	66%	6%	100%	73%	0%	0%	0%	0%	100%	100%	100%	91%	0%
Honda	-4%	-4%	0%	28%	60%	0%	0%	0%	0%	85%	12%	97%	36%	3%	0%	0%	0%	97%	97%	97%	89%	0%
Hyundai	-5%	-5%	0%	25%	75%	0%	0%	22%	0%	71%	7%	100%	75%	0%	0%	0%	0%	100%	100%	100%	100%	0%
Kia	-4%	-4%	0%	28%	45%	0%	0%	7%	0%	84%	9%	100%	21%	0%	0%	0%	0%	100%	100%	100%	73%	0%
Lotus	-4%	0%	4%	0%	44%	0%	0%	0%	0%	36%	44%	80%	44%	25%	20%	11%	0%	100%	100%	80%	80%	0%
Mazda	-8%	-7%	1%	13%	73%	0%	0%	14%	0%	71%	14%	98%	73%	13%	2%	0%	0%	100%	100%	98%	98%	0%
Mitsubishi	-11%	-9%	2%	5%	73%	0%	0%	0%	0%	91%	7%	98%	73%	20%	2%	0%	0%	100%	100%	98%	98%	0%
Nissan	-8%	-7%	0%	20%	73%	0%	0%	4%	0%	90%	4%	98%	73%	6%	1%	0%	0%	99%	99%	98%	98%	0%
Porsche	-9%	-3%	6%	0%	38%	1%	0%	0%	0%	54%	27%	81%	39%	29%	19%	13%	0%	100%	100%	81%	81%	0%
Spyker	-19%	-12%	7%	0%	49%	1%	0%	0%	0%	76%	7%	83%	50%	29%	17%	4%	0%	100%	100%	83%	83%	0%
Subaru	-10%	-9%	2%	10%	71%	0%	0%	0%	0%	72%	23%	96%	71%	15%	4%	0%	0%	100%	100%	96%	96%	0%
Suzuki	-1%	0%	1%	0%	67%	0%	0%	0%	0%	84%	8%	92%	67%	25%	8%	0%	0%	100%	100%	92%	92%	0%
Tata	-20%	-12%	8%	0%	16%	31%	0%	0%	0%	91%	0%	91%	47%	44%	9%	0%	0%	100%	100%	91%	91%	0%
Tesla	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%	0%
Toyota	-4%	-4%	0%	46%	20%	1%	0%	3%	0%	75%	7%	84%	15%	16%	0%	0%	0%	84%	84%	84%	68%	0%
Volkswagen	-11%	-8%	3%	0%	63%	1%	0%	0%	0%	81%	10%	91%	64%	26%	9%	1%	0%	100%	100%	91%	91%	0%
Fleet	-8%	-7%	1%	23%	57%	2%	0%	11%	0%	76%	8%	94%	54%	9%	2%	0%	0%	96%	96%	94%	88%	0%

Table 3.8-39 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
Aston Martin	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
BMW	-17%	-13%	4%	30%	61%	10%	0%	100%	0%	0%	0%	100%	70%	30%	0%	0%	0%	100%	100%	100%	100%	0%
Chrysler/Fiat	-12%	-12%	0%	24%	62%	8%	0%	86%	0%	11%	3%	99%	70%	0%	1%	0%	0%	100%	100%	99%	94%	0%
Daimler	-20%	-12%	8%	46%	35%	19%	0%	100%	0%	0%	0%	100%	54%	50%	0%	0%	0%	100%	100%	100%	92%	8%
Ferrari	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%	32%	41%	20%	0%	67%	0%	27%	2%	96%	61%	26%	2%	0%	0%	98%	98%	96%	96%	0%
Geely	-20%	-12%	8%	28%	66%	6%	0%	100%	0%	0%	0%	100%	72%	50%	0%	0%	0%	100%	100%	100%	100%	0%
General Motors	-12%	-12%	0%	15%	53%	15%	0%	93%	0%	7%	0%	100%	67%	2%	0%	0%	0%	100%	100%	100%	84%	0%
Honda	-10%	-10%	0%	25%	75%	0%	0%	62%	0%	38%	0%	100%	75%	0%	0%	0%	0%	100%	100%	100%	100%	0%
Hyundai	-17%	-17%	0%	25%	75%	0%	0%	90%	0%	10%	0%	100%	75%	0%	0%	0%	0%	100%	100%	100%	100%	0%
Kia	-10%	-10%	0%	25%	75%	0%	0%	99%	0%	0%	1%	100%	75%	0%	0%	0%	0%	100%	100%	100%	100%	0%
Lotus	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%	1%	17%	75%	0%	0%	66%	0%	32%	1%	100%	75%	8%	0%	0%	0%	100%	100%	100%	100%	0%
Mitsubishi	-20%	-18%	2%	16%	73%	0%	0%	65%	0%	34%	0%	98%	73%	9%	2%	0%	0%	100%	100%	98%	98%	0%
Nissan	-8%	-8%	0%	24%	60%	9%	0%	77%	0%	22%	1%	99%	70%	8%	1%	0%	0%	100%	100%	99%	99%	0%
Porsche	-20%	-12%	8%	39%	34%	28%	0%	99%	0%	0%	1%	100%	61%	50%	0%	0%	6%	100%	100%	100%	100%	0%
Spyker	-5%	-2%	3%	35%	46%	19%	0%	100%	0%	0%	0%	100%	65%	50%	0%	0%	0%	100%	100%	100%	100%	0%
Subaru	-20%	-20%	0%	25%	75%	0%	0%	25%	0%	67%	8%	100%	75%	0%	0%	0%	0%	100%	100%	100%	100%	0%
Suzuki	-16%	-16%	0%	20%	73%	0%	0%	79%	0%	19%	0%	98%	73%	5%	2%	0%	0%	100%	100%	98%	98%	0%
Tata	-13%	-7%	6%	33%	20%	33%	0%	66%	0%	29%	0%	95%	53%	41%	5%	0%	0%	100%	100%	95%	95%	0%
Tesla	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%	28%	59%	8%	0%	78%	0%	14%	3%	94%	67%	6%	0%	0%	0%	94%	94%	94%	94%	0%
Volkswagen	-19%	-11%	7%	31%	58%	11%	0%	100%	0%	0%	0%	100%	69%	50%	0%	0%	0%	100%	100%	100%	100%	0%
Fleet	-11%	-10%	1%	24%	57%	11%	0%	81%	0%	16%	1%	98%	68%	9%	0%	0%	0%	99%	99%	98%	94%	0%

Table 3.8-40 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
Aston Martin	-20%	-6%	14%	0%	0%	9%	0%	0%	0%	75%	2%	77%	9%	50%	23%	18%	0%	100%	100%	77%	77%	0%
BMW	-15%	-11%	5%	10%	59%	6%	0%	26%	0%	59%	8%	93%	65%	26%	7%	0%	0%	100%	100%	93%	93%	0%
Chrysler/Fiat	-11%	-11%	0%	24%	67%	5%	0%	38%	0%	59%	3%	100%	72%	1%	0%	0%	0%	100%	100%	100%	97%	0%
Daimler	-17%	-11%	7%	11%	44%	12%	0%	23%	0%	64%	4%	91%	55%	36%	9%	0%	0%	100%	100%	91%	89%	2%
Ferrari	-15%	-6%	9%	0%	0%	5%	0%	0%	0%	77%	0%	77%	5%	50%	23%	22%	5%	100%	100%	77%	77%	0%
Ford	-12%	-11%	1%	27%	59%	9%	0%	39%	0%	53%	5%	97%	68%	10%	1%	0%	0%	98%	98%	97%	97%	0%
Geely	-17%	-11%	6%	11%	43%	14%	0%	39%	0%	52%	1%	92%	57%	39%	8%	0%	0%	100%	100%	92%	92%	0%
General Motors	-11%	-11%	0%	17%	62%	9%	0%	59%	0%	38%	3%	100%	71%	1%	0%	0%	0%	100%	100%	100%	88%	0%
Honda	-6%	-6%	0%	27%	65%	0%	0%	18%	0%	71%	8%	98%	48%	2%	0%	0%	0%	98%	98%	98%	92%	0%
Hyundai	-8%	-8%	0%	25%	75%	0%	0%	35%	0%	59%	6%	100%	75%	0%	0%	0%	0%	100%	100%	100%	100%	0%
Kia	-6%	-6%	0%	28%	51%	0%	0%	27%	0%	66%	7%	100%	32%	0%	0%	0%	0%	100%	100%	100%	79%	0%
Lotus	-4%	0%	4%	0%	44%	0%	0%	0%	0%	36%	44%	80%	44%	25%	20%	11%	0%	100%	100%	80%	80%	0%
Mazda	-10%	-9%	1%	13%	73%	0%	0%	23%	0%	64%	11%	98%	73%	12%	2%	0%	0%	100%	100%	98%	98%	0%
Mitsubishi	-14%	-12%	2%	9%	73%	0%	0%	21%	0%	72%	5%	98%	73%	16%	2%	0%	0%	100%	100%	98%	98%	0%
Nissan	-8%	-7%	0%	21%	69%	3%	0%	25%	0%	70%	3%	98%	72%	7%	1%	0%	0%	99%	99%	98%	98%	0%
Porsche	-11%	-5%	6%	8%	37%	7%	0%	21%	0%	43%	21%	85%	44%	34%	15%	10%	1%	100%	100%	85%	85%	0%
Spyker	-17%	-11%	7%	5%	49%	3%	0%	13%	0%	66%	6%	85%	52%	32%	15%	3%	0%	100%	100%	85%	85%	0%
Subaru	-12%	-11%	1%	13%	72%	0%	0%	6%	0%	71%	20%	97%	72%	12%	3%	0%	0%	100%	100%	97%	97%	0%
Suzuki	-4%	-3%	1%	3%	68%	0%	0%	14%	0%	73%	7%	93%	68%	22%	7%	0%	0%	100%	100%	93%	93%	0%
Tata	-17%	-10%	7%	15%	18%	32%	0%	31%	0%	62%	0%	93%	50%	43%	7%	0%	0%	100%	100%	93%	93%	0%
Tesla	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%	0%
Toyota	-5%	-5%	0%	40%	34%	4%	0%	30%	0%	52%	5%	88%	34%	12%	0%	0%	0%	88%	88%	88%	77%	0%
Volkswagen	-13%	-9%	4%	6%	62%	3%	0%	20%	0%	65%	8%	93%	65%	31%	7%	1%	0%	100%	100%	93%	93%	0%
Fleet	-9%	-8%	1%	24%	57%	5%	0%	34%	0%	56%	6%	96%	59%	9%	2%	0%	0%	97%	97%	96%	90%	0%

Table 3.8-41 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
Aston Martin	-20%	-6%	14%	0%	0%	9%	0%	0%	0%	75%	2%	77%	9%	50%	23%	18%	0%	100%	100%	77%	77%	0%
BMW	-15%	-9%	6%	0%	52%	4%	0%	0%	0%	77%	8%	85%	57%	28%	15%	0%	0%	100%	100%	85%	85%	0%
Chrysler/Fiat	-12%	-9%	3%	6%	64%	2%	0%	2%	0%	88%	2%	92%	66%	20%	8%	0%	0%	100%	100%	92%	92%	0%
Daimler	-17%	-10%	7%	1%	42%	6%	0%	0%	0%	78%	4%	83%	48%	32%	17%	2%	0%	100%	100%	83%	82%	1%
Ferrari	-15%	-6%	9%	0%	0%	5%	0%	0%	0%	77%	0%	77%	5%	50%	23%	22%	5%	100%	100%	77%	77%	0%
Ford	-13%	-11%	3%	11%	61%	4%	0%	29%	0%	59%	4%	92%	65%	19%	7%	0%	0%	99%	99%	92%	92%	0%
Geely	-17%	-8%	8%	3%	30%	11%	0%	13%	0%	68%	1%	81%	41%	41%	19%	3%	0%	100%	100%	81%	81%	0%
General Motors	-13%	-10%	3%	7%	64%	2%	0%	28%	0%	62%	3%	93%	66%	20%	7%	0%	0%	100%	100%	93%	93%	0%
Honda	-6%	-6%	1%	14%	71%	0%	0%	0%	0%	85%	10%	96%	71%	13%	1%	0%	0%	97%	97%	96%	96%	0%
Hyundai	-8%	-8%	0%	16%	73%	0%	0%	22%	0%	71%	6%	98%	73%	9%	2%	0%	0%	100%	100%	98%	98%	0%
Kia	-6%	-6%	0%	25%	75%	0%	0%	7%	0%	84%	9%	100%	75%	0%	0%	0%	0%	100%	100%	100%	100%	0%
Lotus	-4%	0%	4%	0%	44%	0%	0%	0%	0%	36%	44%	80%	44%	25%	20%	11%	0%	100%	100%	80%	80%	0%
Mazda	-8%	-6%	2%	4%	70%	0%	0%	14%	0%	69%	12%	95%	70%	21%	5%	0%	0%	100%	100%	95%	95%	0%
Mitsubishi	-11%	-8%	3%	0%	64%	0%	0%	0%	0%	84%	6%	89%	64%	25%	11%	0%	0%	100%	100%	89%	89%	0%
Nissan	-8%	-6%	2%	2%	69%	0%	0%	4%	0%	87%	4%	94%	69%	24%	5%	0%	0%	99%	99%	94%	94%	0%
Porsche	-9%	-3%	7%	0%	30%	1%	0%	0%	0%	56%	21%	77%	31%	29%	23%	17%	0%	100%	100%	77%	77%	0%
Spyker	-19%	-11%	8%	0%	45%	1%	0%	0%	0%	76%	6%	82%	46%	29%	18%	7%	0%	100%	100%	82%	82%	0%
Subaru	-11%	-8%	2%	3%	68%	0%	0%	0%	0%	74%	19%	93%	68%	22%	7%	0%	0%	100%	100%	93%	93%	0%
Suzuki	-2%	0%	2%	0%	63%	0%	0%	0%	0%	81%	7%	88%	63%	25%	12%	0%	0%	100%	100%	88%	88%	0%
Tata	-20%	-10%	10%	0%	14%	22%	0%	0%	0%	81%	0%	81%	37%	44%	19%	0%	0%	100%	100%	81%	81%	0%
Tesla	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%	0%
Toyota	-7%	-6%	1%	8%	58%	1%	0%	3%	0%	74%	5%	82%	59%	30%	3%	0%	0%	85%	85%	82%	82%	0%
Volkswagen	-12%	-8%	4%	0%	57%	0%	0%	0%	0%	75%	9%	84%	57%	26%	16%	1%	0%	100%	100%	84%	84%	0%
Fleet	-10%	-8%	2%	8%	63%	2%	0%	11%	0%	73%	6%	90%	64%	21%	7%	0%	0%	96%	96%	90%	90%	0%

Table 3.8-42 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
Aston Martin	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
BMW	-18%	-11%	7%	30%	61%	10%	0%	100%	0%	0%	0%	100%	70%	50%	0%	0%	0%	100%	100%	100%	100%	0%
Chrysler/Fiat	-13%	-12%	2%	26%	59%	8%	0%	87%	0%	10%	2%	99%	68%	21%	1%	2%	0%	100%	100%	99%	98%	0%
Daimler	-20%	-12%	8%	46%	35%	19%	0%	100%	0%	0%	0%	100%	54%	50%	0%	0%	0%	100%	100%	100%	92%	8%
Ferrari	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Ford	-12%	-8%	4%	27%	38%	20%	0%	67%	0%	25%	2%	94%	58%	38%	5%	1%	0%	98%	98%	94%	94%	0%
Geely	-20%	-12%	8%	28%	66%	6%	0%	100%	0%	0%	0%	100%	72%	50%	0%	0%	0%	100%	100%	100%	100%	0%
General Motors	-14%	-9%	5%	31%	51%	15%	0%	93%	0%	6%	0%	99%	66%	39%	1%	0%	0%	100%	100%	99%	99%	0%
Honda	-15%	-14%	1%	15%	73%	0%	0%	62%	0%	37%	0%	98%	73%	10%	2%	0%	0%	100%	100%	98%	98%	0%
Hyundai	-20%	-19%	1%	23%	74%	0%	0%	90%	0%	9%	0%	99%	74%	2%	1%	0%	0%	100%	100%	99%	99%	0%
Kia	-18%	-18%	0%	25%	75%	0%	0%	99%	0%	0%	1%	100%	75%	0%	0%	0%	0%	100%	100%	100%	100%	0%
Lotus	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%	1%	17%	74%	0%	0%	66%	0%	31%	1%	99%	74%	8%	1%	0%	0%	100%	100%	99%	99%	0%
Mitsubishi	-20%	-18%	2%	16%	71%	0%	0%	65%	0%	31%	0%	96%	71%	9%	4%	0%	0%	100%	100%	96%	96%	0%
Nissan	-9%	-6%	3%	24%	59%	9%	0%	77%	0%	20%	1%	98%	68%	27%	2%	0%	0%	100%	100%	98%	98%	0%
Porsche	-20%	-12%	8%	39%	34%	28%	0%	99%	0%	0%	1%	100%	61%	50%	0%	0%	6%	100%	100%	100%	100%	0%
Spyker	-5%	-2%	3%	35%	46%	19%	0%	100%	0%	0%	0%	100%	65%	50%	0%	0%	19%	100%	100%	100%	100%	0%
Subaru	-20%	-17%	3%	6%	74%	0%	0%	25%	0%	69%	6%	99%	74%	19%	1%	0%	0%	100%	100%	99%	99%	0%
Suzuki	-16%	-16%	0%	20%	72%	0%	0%	79%	0%	17%	0%	97%	72%	5%	3%	0%	0%	100%	100%	97%	97%	0%
Tata	-14%	-7%	7%	33%	10%	33%	0%	66%	0%	26%	0%	92%	43%	41%	8%	7%	8%	100%	100%	92%	92%	0%
Tesla	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Toyota	-10%	-9%	1%	25%	58%	8%	0%	78%	0%	14%	2%	94%	66%	17%	0%	0%	0%	94%	94%	94%	94%	0%
Volkswagen	-19%	-11%	7%	31%	58%	11%	0%	100%	0%	0%	0%	100%	69%	50%	0%	0%	0%	100%	100%	100%	100%	0%
Fleet	-13%	-10%	3%	26%	56%	11%	0%	81%	0%	15%	1%	97%	67%	27%	1%	0%	0%	99%	99%	97%	97%	0%

Table 3.8-43 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
Aston Martin	-20%	-6%	14%	0%	0%	9%	0%	0%	0%	75%	2%	77%	9%	50%	23%	18%	0%	100%	100%	77%	77%	0%
BMW	-15%	-9%	6%	8%	55%	6%	0%	26%	0%	57%	6%	89%	60%	34%	11%	0%	0%	100%	100%	89%	89%	0%
Chrysler/Fiat	-13%	-10%	3%	15%	62%	5%	0%	39%	0%	54%	2%	95%	67%	20%	5%	1%	0%	100%	100%	95%	95%	0%
Daimler	-18%	-10%	7%	11%	41%	9%	0%	23%	0%	60%	3%	87%	50%	36%	13%	1%	0%	100%	100%	87%	85%	2%
Ferrari	-15%	-6%	9%	0%	0%	5%	0%	0%	0%	77%	0%	77%	5%	50%	23%	22%	5%	100%	100%	77%	77%	0%
Ford	-13%	-10%	3%	16%	54%	9%	0%	40%	0%	49%	3%	92%	63%	25%	6%	0%	0%	99%	99%	92%	92%	0%
Geely	-18%	-10%	8%	11%	41%	10%	0%	39%	0%	48%	1%	87%	50%	44%	13%	2%	0%	100%	100%	87%	87%	0%
General Motors	-13%	-9%	4%	18%	58%	8%	0%	59%	0%	35%	2%	96%	66%	29%	4%	0%	0%	100%	100%	96%	96%	0%
Honda	-9%	-8%	1%	14%	72%	0%	0%	18%	0%	71%	7%	96%	72%	12%	1%	0%	0%	98%	98%	96%	96%	0%
Hyundai	-11%	-10%	0%	18%	74%	0%	0%	35%	0%	58%	5%	99%	74%	7%	1%	0%	0%	100%	100%	99%	99%	0%
Kia	-8%	-8%	0%	25%	75%	0%	0%	27%	0%	66%	7%	100%	75%	0%	0%	0%	0%	100%	100%	100%	100%	0%
Lotus	-4%	0%	4%	0%	44%	0%	0%	0%	0%	36%	44%	80%	44%	25%	20%	11%	0%	100%	100%	80%	80%	0%
Mazda	-10%	-8%	2%	6%	71%	0%	0%	23%	0%	63%	10%	96%	71%	19%	4%	0%	0%	100%	100%	96%	96%	0%
Mitsubishi	-14%	-11%	3%	5%	66%	0%	0%	21%	0%	66%	4%	91%	66%	20%	9%	0%	0%	100%	100%	91%	91%	0%
Nissan	-9%	-6%	2%	8%	66%	3%	0%	25%	0%	67%	3%	95%	69%	25%	4%	0%	0%	100%	100%	95%	95%	0%
Porsche	-12%	-5%	7%	8%	31%	7%	0%	21%	0%	44%	17%	82%	38%	34%	18%	13%	1%	100%	100%	82%	82%	0%
Spyker	-17%	-10%	7%	5%	45%	3%	0%	13%	0%	66%	5%	84%	48%	32%	16%	6%	2%	100%	100%	84%	84%	0%
Subaru	-13%	-10%	3%	3%	69%	0%	0%	6%	0%	73%	16%	94%	69%	22%	6%	0%	0%	100%	100%	94%	94%	0%
Suzuki	-4%	-3%	1%	3%	65%	0%	0%	14%	0%	70%	6%	90%	65%	22%	10%	0%	0%	100%	100%	90%	90%	0%
Tata	-17%	-9%	9%	15%	13%	27%	0%	31%	0%	55%	0%	86%	40%	43%	14%	3%	4%	100%	100%	86%	86%	0%
Tesla	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%	0%
Toyota	-8%	-7%	1%	14%	58%	4%	0%	30%	0%	52%	4%	86%	62%	25%	2%	0%	0%	88%	88%	86%	86%	0%
Volkswagen	-13%	-8%	5%	6%	57%	3%	0%	20%	0%	60%	7%	87%	60%	31%	13%	1%	0%	100%	100%	87%	87%	0%
Fleet	-11%	-8%	3%	14%	60%	5%	0%	34%	0%	54%	4%	92%	65%	23%	5%	0%	0%	97%	97%	92%	92%	0%

Table 3.8-44 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
Aston Martin	-20%	-8%	12%	0%	0%	22%	0%	0%	0%	73%	4%	77%	22%	50%	23%	5%	0%	100%	100%	77%	77%	0%
BMW	-14%	-11%	3%	14%	62%	5%	0%	0%	0%	83%	12%	95%	67%	15%	5%	0%	0%	100%	100%	95%	95%	0%
Chrysler/Fiat	-10%	-9%	0%	24%	71%	3%	0%	2%	0%	95%	2%	100%	74%	2%	0%	0%	0%	100%	100%	100%	99%	0%
Daimler	-16%	-12%	4%	12%	50%	9%	0%	0%	0%	85%	7%	92%	60%	21%	8%	0%	0%	100%	100%	92%	92%	1%
Ferrari	-14%	-6%	8%	0%	0%	13%	0%	0%	0%	76%	1%	77%	13%	50%	23%	14%	0%	100%	100%	77%	77%	0%
Ford	-12%	-12%	0%	26%	68%	4%	0%	27%	0%	65%	7%	98%	72%	2%	0%	0%	0%	99%	99%	98%	98%	0%
Geely	-16%	-11%	5%	3%	35%	20%	0%	13%	0%	79%	1%	93%	55%	35%	7%	0%	0%	100%	100%	93%	93%	0%
General Motors	-11%	-11%	0%	18%	70%	3%	0%	28%	0%	66%	6%	100%	73%	0%	0%	0%	0%	100%	100%	100%	91%	0%
Honda	-4%	-4%	0%	12%	36%	0%	0%	0%	0%	85%	12%	97%	11%	3%	0%	0%	0%	97%	97%	97%	48%	0%
Hyundai	-5%	-5%	0%	31%	28%	0%	0%	22%	0%	71%	7%	100%	24%	0%	0%	0%	0%	100%	100%	100%	59%	0%
Kia	-4%	-4%	0%	14%	5%	0%	0%	7%	0%	84%	9%	100%	5%	0%	0%	0%	0%	100%	100%	100%	19%	0%
Lotus	-3%	0%	3%	0%	53%	0%	0%	0%	0%	31%	53%	85%	53%	25%	15%	6%	0%	100%	100%	85%	85%	0%
Mazda	-5%	-5%	0%	25%	75%	0%	0%	14%	0%	68%	18%	100%	47%	0%	0%	0%	0%	100%	100%	100%	100%	0%
Mitsubishi	-11%	-10%	1%	12%	75%	0%	0%	0%	0%	93%	7%	100%	75%	13%	0%	0%	0%	100%	100%	100%	100%	0%
Nissan	-6%	-6%	0%	25%	74%	0%	0%	4%	0%	91%	5%	99%	56%	1%	0%	0%	0%	99%	99%	99%	99%	0%
Porsche	-8%	-3%	5%	0%	45%	1%	0%	0%	0%	52%	31%	83%	46%	29%	17%	8%	0%	100%	100%	83%	83%	0%
Spyker	-19%	-13%	6%	0%	53%	6%	0%	0%	0%	80%	8%	88%	59%	29%	12%	0%	0%	100%	100%	88%	88%	0%
Subaru	-10%	-10%	0%	25%	74%	0%	0%	0%	0%	72%	27%	99%	74%	0%	1%	0%	0%	100%	100%	99%	99%	0%
Suzuki	0%	0%	0%	25%	69%	0%	0%	0%	0%	83%	11%	94%	69%	0%	6%	0%	0%	100%	100%	94%	94%	0%
Tata	-20%	-12%	8%	0%	16%	32%	0%	0%	0%	92%	0%	92%	48%	44%	8%	0%	0%	100%	100%	92%	92%	0%
Tesla	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%	0%
Toyota	-4%	-4%	0%	11%	17%	1%	0%	3%	0%	75%	7%	84%	14%	16%	0%	0%	0%	84%	84%	84%	29%	0%
Volkswagen	-11%	-8%	2%	15%	66%	2%	0%	0%	0%	80%	14%	93%	67%	11%	7%	0%	0%	100%	100%	93%	93%	0%
Fleet	-8%	-7%	1%	18%	50%	2%	0%	11%	0%	76%	8%	95%	46%	6%	1%	0%	0%	96%	96%	95%	73%	0%

Table 3.8-45 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
Aston Martin	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
BMW	-17%	-13%	4%	30%	61%	10%	0%	100%	0%	0%	0%	100%	70%	30%	0%	0%	0%	100%	100%	100%	100%	0%
Chrysler/Fiat	-12%	-12%	0%	24%	62%	8%	0%	86%	0%	11%	3%	100%	71%	0%	0%	0%	0%	100%	100%	100%	94%	0%
Daimler	-20%	-14%	6%	46%	35%	19%	0%	100%	0%	0%	0%	100%	54%	38%	0%	0%	0%	100%	100%	100%	92%	8%
Ferrari	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Ford	-11%	-10%	0%	32%	43%	20%	0%	67%	0%	28%	2%	97%	63%	5%	0%	0%	0%	97%	97%	97%	97%	0%
Geely	-20%	-15%	5%	28%	66%	6%	0%	100%	0%	0%	0%	100%	72%	30%	0%	0%	0%	100%	100%	100%	100%	0%
General Motors	-12%	-12%	0%	16%	52%	15%	0%	93%	0%	6%	0%	100%	67%	2%	0%	0%	0%	100%	100%	100%	85%	0%
Honda	-9%	-9%	0%	25%	75%	0%	0%	62%	0%	38%	0%	100%	75%	0%	0%	0%	0%	100%	100%	100%	100%	0%
Hyundai	-10%	-10%	0%	25%	75%	0%	0%	90%	0%	10%	0%	100%	75%	0%	0%	0%	0%	100%	100%	100%	100%	0%
Kia	-9%	-9%	0%	25%	75%	0%	0%	99%	0%	0%	1%	100%	74%	0%	0%	0%	0%	100%	100%	100%	100%	0%
Lotus	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Mazda	-15%	-15%	0%	25%	75%	0%	0%	66%	0%	32%	2%	100%	75%	0%	0%	0%	0%	100%	100%	100%	100%	0%
Mitsubishi	-20%	-19%	1%	22%	75%	0%	0%	65%	0%	35%	0%	100%	75%	3%	0%	0%	0%	100%	100%	100%	100%	0%
Nissan	-7%	-7%	0%	30%	61%	9%	0%	77%	0%	22%	2%	100%	70%	0%	0%	0%	0%	100%	100%	100%	100%	0%
Porsche	-20%	-12%	8%	39%	34%	28%	0%	99%	0%	0%	1%	100%	61%	50%	0%	0%	6%	100%	100%	100%	100%	0%
Spyker	-5%	-2%	3%	35%	46%	19%	0%	100%	0%	0%	0%	100%	65%	50%	0%	0%	0%	100%	100%	100%	100%	0%
Subaru	-20%	-20%	0%	25%	75%	0%	0%	25%	0%	67%	8%	100%	75%	0%	0%	0%	0%	100%	100%	100%	100%	0%
Suzuki	-16%	-16%	0%	20%	73%	0%	0%	79%	0%	19%	0%	98%	73%	5%	2%	0%	0%	100%	100%	98%	98%	0%
Tata	-13%	-7%	6%	33%	20%	33%	0%	66%	0%	29%	0%	95%	53%	41%	5%	0%	0%	100%	100%	95%	95%	0%
Tesla	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%	28%	59%	8%	0%	78%	0%	14%	3%	94%	67%	6%	0%	0%	0%	94%	94%	94%	94%	0%
Volkswagen	-19%	-11%	7%	31%	58%	11%	0%	100%	0%	0%	0%	100%	69%	50%	0%	0%	0%	100%	100%	100%	100%	0%
Fleet	-11%	-10%	1%	25%	58%	11%	0%	81%	0%	16%	1%	98%	68%	6%	0%	0%	0%	98%	98%	98%	94%	0%

Table 3.8-46 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
Aston Martin	-20%	-8%	12%	0%	0%	22%	0%	0%	0%	73%	4%	77%	22%	50%	23%	5%	0%	100%	100%	77%	77%	0%
BMW	-15%	-12%	3%	18%	62%	6%	0%	26%	0%	61%	9%	97%	68%	19%	3%	0%	0%	100%	100%	97%	97%	0%
Chrysler/Fiat	-11%	-11%	0%	24%	67%	5%	0%	38%	0%	59%	3%	100%	72%	1%	0%	0%	0%	100%	100%	100%	97%	0%
Daimler	-17%	-12%	5%	20%	47%	12%	0%	23%	0%	66%	5%	94%	58%	25%	6%	0%	0%	100%	100%	94%	92%	2%
Ferrari	-14%	-6%	8%	0%	0%	13%	0%	0%	0%	76%	1%	77%	13%	50%	23%	14%	0%	100%	100%	77%	77%	0%
Ford	-11%	-11%	0%	28%	60%	9%	0%	39%	0%	53%	5%	98%	69%	3%	0%	0%	0%	98%	98%	98%	98%	0%
Geely	-17%	-12%	5%	11%	44%	16%	0%	39%	0%	55%	1%	95%	60%	33%	5%	0%	0%	100%	100%	95%	95%	0%
General Motors	-11%	-11%	0%	17%	62%	9%	0%	59%	0%	38%	3%	100%	70%	1%	0%	0%	0%	100%	100%	100%	89%	0%
Honda	-5%	-5%	0%	16%	48%	0%	0%	18%	0%	71%	8%	98%	30%	2%	0%	0%	0%	98%	98%	98%	63%	0%
Hyundai	-6%	-6%	0%	30%	38%	0%	0%	35%	0%	59%	6%	100%	35%	0%	0%	0%	0%	100%	100%	100%	68%	0%
Kia	-5%	-5%	0%	16%	20%	0%	0%	27%	0%	66%	7%	100%	20%	0%	0%	0%	0%	100%	100%	100%	36%	0%
Lotus	-3%	0%	3%	0%	53%	0%	0%	0%	0%	31%	53%	85%	53%	25%	15%	6%	0%	100%	100%	85%	85%	0%
Mazda	-7%	-7%	0%	25%	75%	0%	0%	23%	0%	62%	15%	100%	52%	0%	0%	0%	0%	100%	100%	100%	100%	0%
Mitsubishi	-14%	-13%	1%	15%	75%	0%	0%	21%	0%	74%	5%	100%	75%	10%	0%	0%	0%	100%	100%	100%	100%	0%
Nissan	-7%	-7%	0%	26%	70%	3%	0%	25%	0%	70%	4%	99%	60%	1%	0%	0%	0%	99%	99%	99%	99%	0%
Porsche	-10%	-5%	5%	8%	43%	7%	0%	21%	0%	41%	25%	87%	49%	34%	13%	6%	1%	100%	100%	87%	87%	0%
Spyker	-17%	-12%	6%	5%	52%	8%	0%	13%	0%	70%	7%	90%	60%	32%	10%	0%	0%	100%	100%	90%	90%	0%
Subaru	-12%	-12%	0%	25%	75%	0%	0%	6%	0%	71%	23%	100%	75%	0%	0%	0%	0%	100%	100%	100%	100%	0%
Suzuki	-3%	-3%	0%	24%	70%	0%	0%	14%	0%	72%	9%	95%	70%	1%	5%	0%	0%	100%	100%	95%	95%	0%
Tata	-17%	-10%	7%	15%	18%	32%	0%	31%	0%	63%	0%	93%	51%	43%	7%	0%	0%	100%	100%	93%	93%	0%
Tesla	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%	0%
Toyota	-5%	-5%	0%	17%	32%	4%	0%	30%	0%	52%	5%	88%	33%	12%	0%	0%	0%	88%	88%	88%	53%	0%
Volkswagen	-12%	-9%	3%	18%	64%	3%	0%	20%	0%	64%	11%	95%	68%	19%	5%	0%	0%	100%	100%	95%	95%	0%
Fleet	-9%	-8%	1%	20%	53%	5%	0%	34%	0%	56%	6%	96%	54%	6%	1%	0%	0%	97%	97%	96%	80%	0%

Table 3.8-47 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
Aston Martin	-20%	-5%	15%	0%	0%	5%	0%	0%	0%	76%	1%	77%	5%	50%	23%	22%	5%	100%	100%	77%	77%	0%
BMW	-15%	-8%	7%	0%	48%	1%	0%	0%	0%	74%	7%	81%	48%	28%	19%	4%	0%	100%	100%	81%	81%	0%
Chrysler/Fiat	-12%	-8%	4%	2%	64%	2%	0%	2%	0%	88%	2%	92%	66%	24%	8%	0%	0%	100%	100%	92%	92%	0%
Daimler	-17%	-8%	9%	0%	38%	2%	0%	0%	0%	76%	4%	81%	39%	32%	19%	9%	0%	100%	100%	81%	80%	0%
Ferrari	-15%	-6%	9%	0%	0%	5%	0%	0%	0%	77%	0%	77%	5%	50%	23%	22%	5%	100%	100%	77%	77%	0%
Ford	-13%	-9%	5%	9%	58%	4%	0%	29%	0%	57%	4%	89%	61%	28%	10%	0%	0%	99%	99%	89%	89%	0%
Geely	-17%	-7%	9%	3%	26%	6%	0%	13%	0%	68%	1%	81%	32%	41%	19%	12%	0%	100%	100%	81%	81%	0%
General Motors	-13%	-10%	3%	7%	64%	2%	0%	28%	0%	62%	3%	93%	67%	20%	7%	0%	0%	100%	100%	93%	93%	0%
Honda	-6%	-5%	1%	12%	68%	0%	0%	0%	0%	83%	10%	92%	68%	16%	4%	0%	0%	97%	97%	92%	92%	0%
Hyundai	-9%	-7%	1%	5%	67%	0%	0%	22%	0%	66%	5%	92%	67%	20%	8%	0%	0%	100%	100%	92%	92%	0%
Kia	-6%	-5%	1%	5%	71%	0%	0%	7%	0%	83%	6%	96%	71%	20%	4%	0%	0%	100%	100%	96%	96%	0%
Lotus	-5%	0%	5%	0%	32%	0%	0%	0%	0%	45%	32%	77%	32%	25%	23%	20%	0%	100%	100%	77%	77%	0%
Mazda	-8%	-6%	2%	4%	62%	0%	0%	14%	0%	62%	10%	87%	62%	22%	13%	0%	0%	100%	100%	87%	87%	0%
Mitsubishi	-11%	-7%	4%	0%	61%	0%	0%	0%	0%	80%	6%	86%	61%	25%	14%	0%	0%	100%	100%	86%	86%	0%
Nissan	-8%	-6%	2%	1%	66%	0%	0%	4%	0%	84%	3%	91%	66%	25%	9%	0%	0%	99%	99%	91%	91%	0%
Porsche	-10%	-3%	8%	0%	0%	14%	0%	0%	0%	67%	10%	77%	14%	41%	23%	22%	14%	100%	100%	77%	77%	0%
Spyker	-19%	-10%	10%	0%	34%	1%	0%	0%	0%	74%	5%	78%	35%	29%	22%	14%	0%	100%	100%	78%	78%	0%
Subaru	-11%	-7%	3%	0%	63%	0%	0%	0%	0%	71%	17%	88%	63%	25%	12%	0%	0%	100%	100%	88%	88%	0%
Suzuki	-2%	0%	2%	0%	55%	0%	0%	0%	0%	78%	6%	85%	55%	25%	15%	4%	0%	100%	100%	85%	85%	0%
Tata	-20%	-10%	10%	0%	14%	20%	0%	0%	0%	79%	0%	79%	35%	44%	21%	0%	0%	100%	100%	79%	79%	0%
Tesla	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%	0%
Toyota	-7%	-6%	1%	8%	57%	1%	0%	3%	0%	73%	5%	81%	58%	30%	5%	0%	0%	85%	85%	81%	81%	0%
Volkswagen	-12%	-6%	6%	0%	47%	0%	0%	0%	0%	73%	8%	82%	47%	26%	18%	8%	0%	100%	100%	82%	82%	0%
Fleet	-10%	-7%	3%	6%	59%	1%	0%	11%	0%	71%	5%	88%	61%	24%	9%	1%	0%	96%	96%	88%	88%	0%

Table 3.8-48 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
Aston Martin	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
BMW	-18%	-11%	7%	30%	61%	10%	0%	100%	0%	0%	0%	100%	70%	50%	0%	0%	0%	100%	100%	100%	100%	0%
Chrysler/Fiat	-13%	-12%	2%	26%	59%	8%	0%	87%	0%	10%	2%	99%	68%	21%	1%	2%	0%	100%	100%	99%	98%	0%
Daimler	-20%	-12%	8%	46%	35%	19%	0%	100%	0%	0%	0%	100%	54%	50%	0%	0%	27%	100%	100%	100%	92%	8%
Ferrari	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Ford	-13%	-8%	5%	27%	38%	20%	0%	67%	0%	24%	2%	93%	58%	44%	5%	1%	0%	98%	98%	93%	93%	0%
Geely	-20%	-12%	8%	28%	66%	6%	0%	100%	0%	0%	0%	100%	72%	50%	0%	0%	0%	100%	100%	100%	100%	0%
General Motors	-14%	-9%	5%	31%	51%	15%	0%	93%	0%	6%	0%	99%	66%	39%	1%	0%	0%	100%	100%	99%	99%	0%
Honda	-16%	-13%	3%	15%	71%	0%	0%	62%	0%	34%	0%	96%	71%	17%	4%	0%	0%	100%	100%	96%	96%	0%
Hyundai	-20%	-19%	1%	23%	74%	0%	0%	90%	0%	8%	0%	99%	74%	7%	1%	0%	0%	100%	100%	99%	99%	0%
Kia	-18%	-18%	0%	25%	75%	0%	0%	99%	0%	0%	1%	100%	75%	0%	0%	0%	0%	100%	100%	100%	100%	0%
Lotus	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Mazda	-20%	-13%	7%	17%	72%	0%	0%	66%	0%	29%	1%	97%	72%	42%	3%	0%	0%	100%	100%	97%	97%	0%
Mitsubishi	-20%	-15%	5%	16%	70%	0%	0%	65%	0%	30%	0%	95%	70%	25%	5%	0%	0%	100%	100%	95%	95%	0%
Nissan	-10%	-6%	4%	24%	57%	9%	0%	77%	0%	19%	1%	96%	67%	39%	4%	0%	0%	100%	100%	96%	96%	0%
Porsche	-20%	-12%	8%	39%	11%	50%	0%	99%	0%	0%	1%	100%	61%	50%	0%	0%	50%	100%	100%	100%	100%	0%
Spyker	-5%	-2%	3%	35%	46%	19%	0%	100%	0%	0%	0%	100%	65%	50%	0%	0%	50%	100%	100%	100%	100%	0%
Subaru	-20%	-15%	5%	6%	69%	0%	0%	25%	0%	64%	5%	94%	69%	25%	6%	0%	0%	100%	100%	94%	94%	0%
Suzuki	-16%	-9%	7%	20%	72%	0%	0%	79%	0%	17%	0%	97%	72%	45%	3%	0%	0%	100%	100%	97%	97%	0%
Tata	-14%	-7%	7%	33%	10%	33%	0%	66%	0%	26%	0%	92%	43%	41%	8%	7%	8%	100%	100%	92%	92%	0%
Tesla	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Toyota	-11%	-8%	2%	25%	57%	8%	0%	79%	0%	13%	2%	94%	65%	26%	1%	0%	0%	96%	96%	94%	94%	0%
Volkswagen	-19%	-11%	7%	31%	58%	11%	0%	100%	0%	0%	0%	100%	69%	50%	0%	0%	50%	100%	100%	100%	100%	0%
Fleet	-14%	-10%	4%	26%	55%	11%	0%	81%	0%	14%	1%	97%	66%	33%	2%	0%	2%	99%	99%	97%	97%	0%

Table 3.8-49 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
Aston Martin	-20%	-5%	15%	0%	0%	5%	0%	0%	0%	76%	1%	77%	5%	50%	23%	22%	5%	100%	100%	77%	77%	0%
BMW	-16%	-9%	7%	8%	51%	3%	0%	26%	0%	55%	5%	86%	54%	34%	14%	3%	0%	100%	100%	86%	86%	0%
Chrysler/Fiat	-13%	-10%	3%	13%	62%	5%	0%	39%	0%	54%	2%	95%	67%	23%	5%	1%	0%	100%	100%	95%	95%	0%
Daimler	-18%	-9%	8%	11%	37%	6%	0%	23%	0%	59%	3%	85%	43%	36%	15%	7%	6%	100%	100%	85%	83%	2%
Ferrari	-15%	-6%	9%	0%	0%	5%	0%	0%	0%	77%	0%	77%	5%	50%	23%	22%	5%	100%	100%	77%	77%	0%
Ford	-13%	-8%	5%	15%	52%	9%	0%	41%	0%	47%	3%	90%	60%	33%	9%	0%	0%	99%	99%	90%	90%	0%
Geely	-18%	-9%	9%	11%	38%	6%	0%	39%	0%	48%	0%	87%	44%	44%	13%	8%	0%	100%	100%	87%	87%	0%
General Motors	-13%	-9%	4%	18%	58%	8%	0%	59%	0%	35%	2%	96%	67%	29%	4%	0%	0%	100%	100%	96%	96%	0%
Honda	-9%	-7%	2%	13%	69%	0%	0%	18%	0%	68%	7%	94%	69%	16%	4%	0%	0%	98%	98%	94%	94%	0%
Hyundai	-11%	-10%	1%	9%	69%	0%	0%	35%	0%	54%	4%	94%	69%	17%	6%	0%	0%	100%	100%	94%	94%	0%
Kia	-9%	-8%	1%	9%	72%	0%	0%	27%	0%	65%	5%	97%	72%	16%	3%	0%	0%	100%	100%	97%	97%	0%
Lotus	-5%	0%	5%	0%	32%	0%	0%	0%	0%	45%	32%	77%	32%	25%	23%	20%	0%	100%	100%	77%	77%	0%
Mazda	-10%	-7%	3%	6%	64%	0%	0%	23%	0%	57%	9%	89%	64%	25%	11%	0%	0%	100%	100%	89%	89%	0%
Mitsubishi	-14%	-10%	4%	5%	64%	0%	0%	21%	0%	63%	4%	89%	64%	25%	11%	0%	0%	100%	100%	89%	89%	0%
Nissan	-9%	-6%	3%	8%	63%	3%	0%	25%	0%	65%	2%	92%	66%	29%	7%	0%	0%	100%	100%	92%	92%	0%
Porsche	-13%	-5%	8%	8%	2%	22%	0%	21%	0%	53%	8%	82%	24%	43%	18%	17%	22%	100%	100%	82%	82%	0%
Spyker	-18%	-9%	9%	5%	36%	3%	0%	13%	0%	64%	4%	81%	39%	32%	19%	12%	7%	100%	100%	81%	81%	0%
Subaru	-13%	-9%	4%	1%	65%	0%	0%	6%	0%	69%	15%	90%	65%	25%	10%	0%	0%	100%	100%	90%	90%	0%
Suzuki	-5%	-2%	3%	3%	58%	0%	0%	14%	0%	68%	5%	87%	58%	28%	13%	3%	0%	100%	100%	87%	87%	0%
Tata	-17%	-9%	9%	15%	13%	26%	0%	31%	0%	54%	0%	85%	39%	43%	15%	3%	4%	100%	100%	85%	85%	0%
Tesla	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%	0%
Toyota	-8%	-7%	1%	14%	57%	4%	0%	31%	0%	51%	4%	86%	61%	28%	3%	0%	0%	89%	89%	86%	86%	0%
Volkswagen	-13%	-7%	6%	6%	49%	2%	0%	20%	0%	59%	7%	85%	51%	31%	15%	7%	10%	100%	100%	85%	85%	0%
Fleet	-11%	-8%	3%	12%	58%	4%	0%	34%	0%	53%	4%	91%	63%	27%	7%	1%	1%	97%	97%	91%	91%	0%

3.8.5 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 five vehicle classes.

Table 3.8-50 Aggregation of Vehicle types for Mass Reduction Presentation

Vehicle Type	Aggregated Type
1	Subcompact/Compact
2	Subcompact/Compact
3	Midsize Car
4	Subcompact/Compact
5	Midsize Car
6	Large Car
7	Midsize MPV/Small Truck
8	Midsize MPV/Small Truck
9	Large Truck/MPV/SUV
10	Large Truck/MPV/SUV
11	Large Truck/MPV/SUV
12	Large Truck/MPV/SUV
13	Large Truck/MPV/SUV
14	Large Truck/MPV/SUV
15	Large Car
16	Large Truck/MPV/SUV
17	Large Truck/MPV/SUV
18	Large Truck/MPV/SUV
19	Large Truck/MPV/SUV

After aggregations here are the weight reductions by vehicle class.

Net Mass Reduction				
	Reference		Control	
Category	MY 2021	MY 2025	MY 2021	MY 2025
Subcompact/Compact	-2%	-2%	-2%	-3%
Midsize Car	-7%	-7%	-8%	-12%
Midsize MPV/Small Truck	-5%	-5%	-7%	-11%
Large Truck/MPV/SUV	-7%	-7%	-8%	-13%
Large Car	-8%	-8%	-9%	-9%
Fleet	-5%	-5%	-6%	-9%

3.8.6 Air Conditioning Cost

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

Table 3.8-51 Total Costs for A/C Control Used in This Proposal (2009$)

Car/ Truck	Case	2021	2025
Car	Reference	$67	$63
	Control	$78	$69
	Total	$145	$132
Truck	Reference	$51	$48
	Control	$94	$84
	Total	$145	$132
Fleet	Total	$145	$132

3.8.7 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 3.8-53). 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) depend both on the stranded technology and the replacing technology.

Table 3.8-52 Potential Stranded Capital Costs

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 2008-2016, the eight year stranded capital costs were used. For 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. 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 2021, and then 27 bar BMEP engine technology in 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 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 3.8-53 Estimated Potential Stranded Capital[SS]

	MY2016			MY 2021			MY 2025		
Manufacturer	Engine	Trans-mission	Total	Engine	Trans-mission	Total	Engine	Trans-mission	Total
Aston Martin	$60	$15	$75	$21	$8	$29	$14	$3	$17
BMW	$20	$3	$23	$29	$15	$45	$3	$4	$7
Chrysler/Fiat	$54	$-	$54	$21	$14	$35	$9	$5	$15
Daimler	$18	$6	$24	$17	$9	$27	$6	$4	$10
Ferrari	$5	$1	$6	$22	$12	$34	$16	$3	$19
Ford	$8	$-	$8	$17	$12	$29	$6	$5	$10
Geely	$14	$0	$14	$22	$16	$38	$8	$5	$13
General Motors	$12	$-	$12	$8	$10	$18	$16	$5	$21
Honda	$2	$-	$2	$11	$10	$21	$11	$4	$15
Hyundai	$-	$-	$-	$11	$6	$17	$14	$4	$18
Kia	$-	$-	$-	$25	$16	$41	$16	$4	$21
Lotus	$40	$-	$40	$15	$0	$16	$1	$2	$2
Mazda	$5	$-	$5	$32	$15	$47	$14	$4	$18
Mitsubishi	$-	$-	$-	$25	$15	$40	$12	$4	$16
Nissan	$6	$-	$6	$10	$9	$19	$9	$4	$14
Porsche	$23	$1	$25	$15	$10	$24	$4	$3	$7
Spyker	$45	$-	$45	$14	$8	$22	$3	$3	$6
Subaru	$3	$-	$3	$18	$7	$25	$7	$3	$10
Suzuki	$20	$-	$20	$19	$8	$27	$2	$4	$6
Tata	$14	$4	$18	$20	$12	$32	$14	$4	$19
Tesla	$-	$-	$-	$-	$-	$-	$-	$-	$-
Toyota	$0	$-	$0	$17	$6	$23	$14	$9	$23
Volkswagen	$13	$2	$16	$21	$10	$31	$2	$4	$6
Fleet	**$9**	**$0**	**$10**	**$15**	**$10**	**$25**	**$11**	**$5**	**$16**

[SS] 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.

3.9 Per Vehicle Costs 2021 and 2025

As described above, the per-vehicle technology costs for this program alone must account for any cost that are incurred due to compliance with existing vehicle programs. EPA first used OMEGA to calculate costs reflected in the existing 2012-2016 program, which is the reference case for this analysis. The OMEGA estimates indicate that, on average, manufacturers will need to spend $830 to meet the 2016MY standards in the 2021MY, and $776 to meet the 2016MY standards in the 2025MY per vehicle. Reference case costs, inclusive of AC costs, are provided in Table 3.9-1 .

Table 3.9-1 Reference Case Costs

Company	2021			2025		
	Cars	**Trucks**	**Fleet**	**Cars**	**Trucks**	**Fleet**
Aston Martin	$2,589	$0	$2,589	$2,376	$0	$2,376
BMW	$1,988	$2,220	$2,049	$1,827	$2,029	$1,880
Chrysler/Fiat	$921	$945	$931	$803	$896	$843
Daimler	$2,227	$2,290	$2,243	$2,058	$2,118	$2,072
Ferrari	$2,470	$0	$2,470	$2,270	$0	$2,270
Ford	$893	$1,220	$1,004	$856	$1,134	$942
Geely-Volvo	$2,159	$2,199	$2,172	$1,987	$2,031	$2,000
GM	$859	$910	$884	$815	$869	$840
Honda	$320	$465	$365	$314	$440	$351
Hyundai	$441	$785	$511	$424	$761	$491
Kia	$384	$641	$442	$374	$576	$417
Lotus	$1,691	$0	$1,691	$1,563	$0	$1,563
Mazda	$611	$1,091	$696	$578	$1,032	$654
Mitsubishi	$1,046	$1,235	$1,112	$981	$1,162	$1,041
Nissan	$409	$1,021	$598	$391	$931	$551
Porsche	$1,934	$1,935	$1,934	$1,783	$1,777	$1,781
Spyker-Saab	$2,000	$2,460	$2,066	$1,840	$2,272	$1,896
Subaru	$714	$1,080	$801	$721	$1,016	$787
Suzuki	$1,068	$1,328	$1,115	$1,004	$1,251	$1,046
Tata-JLR	$2,529	$2,529	$2,529	$2,324	$2,338	$2,331
Tesla	$0	$0	$0	$0	$0	$0
Toyota	$290	$462	$357	$273	$436	$332
VW	$1,870	$1,909	$1,878	$1,717	$1,747	$1,723
Fleet	$776	$930	$830	$728	$873	$776

EPA then used OMEGA to calculate the costs of meeting the proposed standards in the years 2021 and 2025, which are shown in Table 3.9-2 . EPA has accounted for the cost to meet the standards in the reference case. In other words, Table 3.9-2 contains per-vehicle costs that are incremental to the reference case costs shown in Table 3.9-1 .

Table 3.9-2 Control Case Costs for the Proposed Standards MY 2021 (2009$)

Company	2021 Costs			2021 Sales		
	Cars	**Trucks**	**Fleet**	**Cars**	**Truck**	**Fleet**
Aston Martin	$6,424	$0	$6,424	1,058	-	1,058
BMW	$945	$915	$937	359,098	128,724	487,822
Chrysler/Fiat	$569	$853	$698	421,013	348,613	769,626
Daimler	$1,949	$956	$1,702	300,378	99,449	399,827
Ferrari	$6,351	$0	$6,351	7,059	-	7,059
Ford	$655	$776	$696	1,401,617	714,181	2,115,798
Geely-Volvo	$2,035	$1,086	$1,741	92,726	41,768	134,494
GM	$502	$680	$590	1,564,277	1,530,020	3,094,297
Honda	$467	$756	$556	1,198,880	535,916	1,734,796
Hyundai	$614	$884	$669	613,355	156,466	769,821
Kia	$483	$927	$582	331,319	95,432	426,751
Lotus	$3,324	$0	$3,324	278	-	278
Mazda	$924	$897	$919	274,740	59,227	333,967
Mitsubishi	$813	$998	$877	65,851	35,309	101,160
Nissan	$759	$662	$729	912,629	408,029	1,320,658
Porsche	$5,455	$1,328	$4,482	36,475	11,242	47,716
Spyker-Saab	$3,335	$898	$2,986	21,294	3,560	24,854
Subaru	$1,017	$922	$994	230,780	72,773	303,553
Suzuki	$1,160	$1,000	$1,132	95,725	20,767	116,492
Tata-JLR	$2,220	$1,648	$1,935	58,677	58,153	116,830
Tesla	$0	$0	$0	28,623	-	28,623
Toyota	$332	$713	$481	1,903,706	1,215,539	3,119,245
VW	$1,624	$797	$1,457	585,607	148,734	734,341
Fleet	$718	$764	$734	10,505,165	5,683,902	16,189,066

Table 3.9-3 Control Case Costs for the Proposed Standards MY 2025 (2009$)

Company	2025			2025 Sales		
	Cars	**Trucks**	**Fleet**	**Cars**	**Truck**	**Fleet**
Aston Martin	$6,862	$0	$6,862	1,182	-	1,182
BMW	$2,251	$1,959	$2,174	405,256	145,409	550,665
Chrysler/Fiat	$1,914	$2,212	$2,043	436,479	331,762	768,241
Daimler	$2,931	$1,952	$2,707	340,719	101,067	441,786
Ferrari	$7,109	$0	$7,109	7,658	-	7,658
Ford	$2,051	$2,463	$2,178	1,540,109	684,476	2,224,586
Geely-Volvo	$3,228	$2,040	$2,876	101,107	42,588	143,696
GM	$2,209	$1,834	$2,030	1,673,936	1,524,008	3,197,943
Honda	$1,452	$1,937	$1,595	1,340,321	557,697	1,898,018
Hyundai	$1,677	$1,988	$1,739	677,250	168,136	845,386
Kia	$1,442	$1,675	$1,491	362,783	97,653	460,436
Lotus	$3,705	$0	$3,705	316	-	316
Mazda	$2,196	$1,806	$2,131	306,804	61,368	368,172
Mitsubishi	$2,114	$2,171	$2,133	73,305	36,387	109,692
Nissan	$1,997	$2,212	$2,060	1,014,775	426,454	1,441,229
Porsche	$5,827	$2,054	$5,012	40,696	11,219	51,915
Spyker-Saab	$4,001	$1,468	$3,670	23,130	3,475	26,605
Subaru	$2,236	$2,087	$2,202	256,970	74,722	331,692
Suzuki	$2,307	$1,832	$2,225	103,154	21,374	124,528
Tata-JLR	$3,255	$2,653	$2,976	65,418	56,805	122,223
Tesla	$0	$0	$0	31,974	-	31,974
Toyota	$1,399	$1,631	$1,483	2,108,053	1,210,016	3,318,069
VW	$2,618	$2,048	$2,506	630,163	154,284	784,447
Fleet	$1,942	$1,954	$1,946	11,541,558	5,708,900	17,250,459

EPA estimates that the additional technology required for manufacturers to meet the GHG standards for this proposed rule will cost on average $734/vehicle and $1,946/vehicle in the 2021 and 2025 MYs, respectively. These costs include our estimates of stranded capital and costs associated with the A/C program from above.

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

Table 3.9-4 Sales by Technology

MY	ICE Sales	HEV Sales	EV+PHEV Sales	Total Sales
2017	14,940,135	840,896	25,290	15,806,322
2018	14,648,056	878,510	49,845	15,576,410
2019	14,575,393	928,488	74,778	15,578,658
2020	14,795,940	998,265	101,734	15,895,939
2021	14,991,075	1,068,478	129,513	16,189,066
2022	14,804,015	1,417,930	217,827	16,439,772
2023	14,573,553	1,773,810	308,127	16,655,489
2024	14,385,507	2,146,396	402,185	16,934,087
2025	14,214,379	2,535,818	500,263	17,250,459
Total	131,928,053	12,588,590	1,809,560	146,326,204
Fraction	90%	9%	1%	100%

3.10 Alternative Program Stringencies

Table 3.10-1 Control Case Costs for the Alternative 1 (Trucks +20) Standards (2009$)

Company	2021			2025		
	Cars	Trucks	Fleet	Cars	Trucks	Fleet
Aston Martin	$6,424	$0	$6,424	$6,862	$0	$6,862
BMW	$553	$76	$427	$1,945	$1,320	$1,780
Chrysler/Fiat	$121	$490	$280	$1,247	$1,728	$1,455
Daimler	$1,344	$954	$1,255	$2,461	$1,952	$2,345
Ferrari	$6,351	$0	$6,351	$7,109	$0	$7,109
Ford	$371	$361	$368	$1,445	$2,180	$1,671
Geely-Volvo	$1,290	$953	$1,190	$2,515	$2,040	$2,374
GM	$99	$316	$202	$1,296	$1,418	$1,355
Honda	$305	$665	$411	$1,249	$1,515	$1,327
Hyundai	$528	$680	$559	$1,491	$1,580	$1,509
Kia	$395	$791	$479	$1,234	$1,464	$1,282
Lotus	$3,324	$0	$3,324	$3,705	$0	$3,705
Mazda	$809	$536	$763	$1,918	$1,777	$1,895
Mitsubishi	$491	$540	$507	$1,706	$1,865	$1,758
Nissan	$403	$602	$462	$1,674	$1,478	$1,616
Porsche	$4,929	$953	$4,070	$5,244	$2,054	$4,555
Spyker-Saab	$2,981	$805	$2,696	$3,630	$1,397	$3,338
Subaru	$790	$682	$766	$2,052	$1,486	$1,925
Suzuki	$867	$1,000	$890	$2,147	$1,588	$2,051
Tata-JLR	$688	$1,567	$1,097	$2,506	$2,143	$2,337
Tesla	$0	$0	$0	$0	$0	$0
Toyota	$233	$472	$320	$1,000	$1,366	$1,133
VW	$1,092	$797	$1,034	$2,197	$2,048	$2,168
Fleet	$436	$487	$453	$1,484	$1,580	$1,516

Table 3.10-2 Control Case Costs for the Alternative 2 (Trucks -20) Standards (2009$)

Company	2021			2025		
	Cars	Trucks	Fleet	Cars	Trucks	Fleet
Aston Martin	$6,424	$0	$6,424	$6,862	$0	$6,862
BMW	$1,511	$915	$1,354	$2,840	$1,959	$2,607
Chrysler/Fiat	$841	$1,498	$1,125	$2,570	$2,808	$2,673
Daimler	$2,579	$956	$2,208	$3,475	$1,952	$3,127
Ferrari	$6,351	$0	$6,351	$7,109	$0	$7,109
Ford	$1,010	$1,404	$1,131	$2,558	$2,923	$2,670
Geely-Volvo	$3,006	$1,086	$2,437	$4,181	$2,040	$3,546
GM	$1,121	$1,126	$1,123	$2,753	$3,013	$2,877
Honda	$640	$1,043	$758	$1,854	$2,307	$1,987
Hyundai	$815	$884	$829	$2,008	$1,988	$2,004
Kia	$628	$988	$704	$1,635	$2,011	$1,715
Lotus	$3,324	$0	$3,324	$3,705	$0	$3,705
Mazda	$1,135	$1,000	$1,113	$2,440	$1,882	$2,347
Mitsubishi	$1,358	$1,438	$1,384	$2,775	$2,171	$2,574
Nissan	$1,066	$793	$985	$2,561	$2,311	$2,487
Porsche	$6,182	$1,400	$5,148	$6,421	$2,054	$5,477
Spyker-Saab	$3,709	$898	$3,342	$4,250	$1,468	$3,887
Subaru	$1,434	$922	$1,319	$2,558	$2,087	$2,452
Suzuki	$1,407	$1,194	$1,370	$2,561	$1,832	$2,436
Tata-JLR	$2,800	$2,845	$2,821	$3,981	$3,563	$3,787
Tesla	$0	$0	$0	$0	$0	$0
Toyota	$494	$999	$678	$2,009	$2,023	$2,014
VW	$2,032	$914	$1,812	$3,072	$2,048	$2,871
Fleet	$1,055	$1,121	$1,077	$2,443	$2,501	$2,462

Table 3.10-3 Control Case Costs for the Alternative 3 (Cars +20) Standards (2009$)

Company	2021			2025		
	Cars	**Trucks**	**Fleet**	**Cars**	**Trucks**	**Fleet**
Aston Martin	$6,424	$0	$6,424	$5,348	$0	$5,348
BMW	-$240	-$154	-$218	$1,108	$1,320	$1,164
Chrysler/Fiat	$121	$471	$272	$1,242	$1,663	$1,424
Daimler	$592	$481	$567	$1,623	$1,591	$1,616
Ferrari	$6,351	$0	$6,351	$6,292	$0	$6,292
Ford	$278	$156	$240	$1,322	$1,246	$1,299
Geely-Volvo	$923	$44	$662	$1,946	$1,420	$1,790
GM	$109	$394	$245	$1,350	$1,456	$1,400
Honda	$215	$476	$292	$913	$1,428	$1,064
Hyundai	$304	$374	$318	$1,016	$1,156	$1,044
Kia	$253	$597	$326	$776	$1,397	$908
Lotus	$2,114	$0	$2,114	$2,628	$0	$2,628
Mazda	$356	$350	$355	$1,251	$1,118	$1,229
Mitsubishi	$284	$409	$326	$1,371	$1,501	$1,414
Nissan	$323	$202	$287	$1,323	$1,063	$1,246
Porsche	$3,732	$953	$3,131	$4,135	$2,054	$3,685
Spyker-Saab	$1,733	$625	$1,588	$2,431	$1,397	$2,296
Subaru	$574	$151	$478	$1,375	$1,486	$1,400
Suzuki	$321	$381	$331	$1,341	$1,588	$1,383
Tata-JLR	$688	$1,567	$1,097	$2,336	$2,143	$2,246
Tesla	$0	$0	$0	$0	$0	$0
Toyota	$201	$466	$298	$780	$1,334	$982
VW	$36	$797	$186	$1,230	$2,048	$1,391
Fleet	$244	$390	$292	$1,161	$1,394	$1,238

Table 3.10-4 Control Case Costs for the Alternative 4 (Cars -20) Standards (2009$)

Company	2021			2025		
	Cars	**Trucks**	**Fleet**	**Cars**	**Trucks**	**Fleet**
Aston Martin	$6,424	$0	$6,424	$7,231	$0	$7,231
BMW	$2,583	$915	$2,143	$3,956	$1,959	$3,428
Chrysler/Fiat	$866	$1,505	$1,142	$2,718	$2,808	$2,757
Daimler	$3,734	$1,025	$3,114	$4,693	$2,044	$4,087
Ferrari	$6,351	$0	$6,351	$7,109	$0	$7,109
Ford	$1,333	$1,878	$1,501	$3,235	$3,169	$3,214
Geely-Volvo	$4,111	$1,086	$3,215	$5,262	$2,040	$4,307
GM	$1,064	$1,017	$1,042	$2,689	$3,013	$2,843
Honda	$909	$1,194	$993	$2,224	$2,777	$2,387
Hyundai	$1,335	$1,440	$1,356	$2,901	$2,249	$2,771
Kia	$1,049	$1,126	$1,066	$2,500	$2,064	$2,408
Lotus	$4,861	$0	$4,861	$4,812	$0	$4,812
Mazda	$2,064	$1,420	$1,957	$3,312	$3,117	$3,279
Mitsubishi	$1,926	$1,555	$1,803	$3,184	$2,780	$3,050
Nissan	$1,485	$1,429	$1,469	$2,965	$2,938	$2,957
Porsche	$6,519	$1,678	$5,473	$7,428	$2,299	$6,320
Spyker-Saab	$5,406	$898	$4,817	$5,814	$1,575	$5,261
Subaru	$1,959	$1,724	$1,906	$3,091	$2,866	$3,040
Suzuki	$2,276	$1,410	$2,128	$3,324	$3,032	$3,274
Tata-JLR	$2,877	$2,845	$2,862	$4,291	$3,563	$3,953
Tesla	$0	$0	$0	$0	$0	$0
Toyota	$563	$1,099	$758	$2,140	$2,449	$2,252
VW	$3,267	$1,166	$2,854	$4,438	$2,219	$4,001
Fleet	$1,415	$1,275	$1,369	$2,923	$2,760	$2,869

3.11 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 3.11-1 shows the cost per gram per mile of going from the 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 incentives.

Table 3.11-1 Gram/mile cost of advanced technologies

	Reference Case CO2	MY 2021 CO2 (Proposed)	Delta g/mile	Delta Cost^	$ per g/mile

OMEGA projection of average 2021 Car in Proposal Case	225	178	47	$625	$ 13
EV100 (45 sqft, VT 3, no multiplier)	263	0	263	$16,066	$61
EV100 (45 sqft, VT 3, 1.5 multiplier)	263	0	395	$16,066	$41
OMEGA projection of average 2021 Truck in Proposal Case	297	239	58	$654	$11
HEV (65 sqft, VT 13, no credit)	344	243	101	$6,264	$62
HEV (65 sqft, VT 13, 20 g credit)	344	223	121	$6,264	$52

^Note that we use average reference case cost of $704 for cars and $858 for trucks, not the vehicle specific cost. If these vehicles reference case costs were higher than average, then their costs under the proposal 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. The HEV in this example has an effectiveness of 51.4% relative to a baseline (no technology) vehicle with a CO_2 of 500 g/mile.

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

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

As part of its evaluation of the feasibility of the proposed standards , EPA evaluated all MY2011 and MY2012 vehicles sold in the U.S. today against the proposed CO2 footprint-based standard curves to determine which of these vehicles would meet or be lower than the proposed MY 2017 –MY 2025 footprint-based CO2 targets assuming air conditioning credit generation consistent with today’s proposal. Under the proposed 2017-2025 greenhouse gas emissions standards, each vehicle will have a unique CO2 target based on the vehicle’s footprint (with each manufacturer having its own unique fleetwide standard)) . In this analysis, EPA assumed 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 assuming such credits does 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. 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 MY2017 proposed CO2 targets, and a few meet even the proposed MY2025 CO_2 targets.

Using publicly available data[TT], 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 MY2011 vehicles and some MY2012 vehicles. EPA gathered vehicle footprint data from EPA reports,[23] manufacturer submitted CAFE reports, and manufacturer websites. .

Table 3.12-1 shows that a significant number of vehicles sold today would meet or be lower than the proposed footprint-based CO2 targets with current powertrain designs, assuming air conditioning credit generation consistent with our proposal. The table highlights the vehicles with CO2 emissions that meet or are lower than the applicable proposed footprint targets from MY 2017 to 2025 in green, and shows the percentage below the proposed 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 proposed 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 proposed MY2017 footprint CO2 target with only simple improvements in air conditioning systems.

Vehicles that are above, but within 5%, of the proposed 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 proposed targets through at least 2021. This includes two engine options (the 3.7L V6 and the 3.5L V6), and three wheelbase options[UU].

EPA also receives projected sales data prior to each model year from each manufacturer. Based on this data, approximately 7% of MY2011 sales will be vehicles that would meet or be better than the proposed MY 2017 targets for those vehicles, requiring only improvements in air conditioning systems. In addition, nearly 30% of projected MY2011 sales would be within 10% of the proposed MY2017 footprint CO2 target with only simple improvements to air conditioning systems, a full six model years before the proposed standard would take effect.

[TT] www.fueleconomy.gov

[UU] The F-150 engine and wheelbase combinations listed in Table 3.12-1 correspond to models that are currently available. Not all possible engine and wheelbase combinations are produced.

With improvements to air conditioning systems, the most efficient gasoline internal combustion engines would meet the MY 2020 proposed footprint targets. After MY2020, the only current vehicles that continue to meet the proposed footprint-based CO2 targets (assuming improvements in air conditioning) are hybrid-electric, plug-in hybrid-electric, and fully electric vehicles. However, the proposed MY 2020 standards will not be in effect for another nine 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 Chapter 3 of the draft Joint TSD and as discussed in Preamble Section III.D) assuming air conditioner improvements . Today's Toyota Prius, Ford Fusion Hybrid, Chevrolet Volt, Nissan Leaf, Honda Civic Hybrid, and Hyundai Sonata Hybrid all meet or surpass the proposed footprint-based CO2 targets through MY2025. In fact, the current Prius, Volt, and Leaf meet the proposed 2025 CO2 targets without air conditioning credits.

This assessment of MY2011 and MY2012 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 proposed standards. Notably, based on the OMEGA modeling, we project that the MY2017-2025 standards can primarily be achieved by advanced gasoline vehicles – for example, in MY2025, we project more than 80 percent of the new vehicles could be advanced gasoline powertrains. The assessment of MY2011 and MY2012 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 proposed standards (i.e., model years 2017-2020) 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 proposed 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 draft 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 MY2016, there are also many of the key technologies we project as being needed to achieve the proposed 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 MY2016, and which even by MY2021 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 then 5 years, typically on the order of 10 years or more. Thus major powertrain technologies generally take longer to penetrate the new vehicle fleet then can be done in a 5-year redesign cycle. As detailed in Chapter 3.5 of the draft 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 project that 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 proposed MY2017-2025 standards and the product development and introduction process which is fairly standard in the automotive industry today, our assessment of the MY2011 and MY2012 vehicles in comparison to the proposed standards supports our overall feasibility assessment, and reinforces our assessment of the lead time needed for the industry to achieve the proposed standards.

[23] EPA's "Light Duty Automotive Technology, Carbon Dioxide Emissions, and Fuel Economy Trends Report, 1975 through 2010"

Table 3.12-1 Vehicles that Meet or Exceed Proposed Targets With Current Powertrain Designs

Model Year	Manufacturer	Vehicle	Unadjusted Fuel Economy (mpg)	Tailpipe CO_2 (ft^2)	Footprint (ft^2)	Powertrain Type	Transmission	Engine Displacement (L)	Vehicle Class	Car/ Truck	Compliance								
											2017	2018	2019	2020	2021	2022	2023	2024	2025
2011	Mercedes-Benz	Smart fortwo (cabriolet)	123.9	0.0	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	0.0	26.8	EV	A1	n/a	Two Seaters	C	100%	100%	100%	100%	100%	100%	100%	100%	100%
2011	Nissan	LEAF	141.7	0.0	44.7	EV	A1	n/a	Midsize Cars	C	100%	100%	100%	100%	100%	100%	100%	100%	100%
2011	Chevrolet	VOLT	48.4	56.0	45.3	PHEV	CVT	1.4	Compact Cars	C	76%	76%	75%	73%	72%	71%	69%	68%	66%
2011	Toyota	PRIUS	70.8	125.6	44.2	HEV	CVT	1.8	Midsize Cars	C	46%	44%	42%	40%	37%	34%	31%	28%	24%
2012	Honda	CIVIC HYBRID	63.1	140.9	43.5	HEV	A5	1.5	Compact Cars	C	38%	35%	33%	30%	27%	23%	20%	16%	12%
2011	Hyundai	SONATA HYBRID	52.2	170.3	48.0	HEV	A6	2.4	Midsize Cars	C	30%	28%	24%	21%	18%	14%	10%	6%	1%
2012	Ford	FUSION HYBRID FWD	54.2	164.0	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	164.0	45.6	HEV	CVT	2.5	Midsize Cars	C	30%	27%	24%	21%	17%	13%	9%	5%	0%
2011	Lexus	CT 200h	57.5	154.6	42.6	HEV	CVT	1.8	Compact Cars	C	30%	27%	24%	21%	17%	13%	9%	5%	0%
2011	Honda	INSIGHT	57.3	155.1	40.8	HEV	CVT	1.3	Compact Cars	C	27%	24%	21%	17%	13%	9%	5%	0%	-4%
2011	Toyota	HIGHLANDER HYBRID 4WD	38.7	229.7	48.8	HEV	CVT	3.5	Sport Utility Vehicle	T	21%	20%	18%	16%	10%	6%	1%	-4%	
2011	Lexus	RX 450h AWD	38.6	230.4	48.6	HEV	CVT	3.5	Sport Utility Vehicle	T	21%	19%	18%	16%	10%	5%	0%	-5%	
2011	Honda	CIVIC CNG	37.5	175.7	43.4	CNG	A5	1.8	Subcompact Cars	C	21%	17%	14%	10%	6%	1%	-3%		
2011	Chevrolet	SILVERADO 2WD HYBRID	28.5	311.4	67.3	HEV	CVT	6.0	Standard Pick-up Trucks	T	14%	14%	14%	13%	7%	2%	-3%		
2011	GMC	SIERRA 2WD HYBRID	28.5	311.4	67.3	HEV	CVT	6.0	Standard Pick-up Trucks	T	14%	14%	14%	13%	7%	2%	-3%		
2011	Chevrolet	SILVERADO 4WD HYBRID	28.4	313.2	67.3	HEV	CVT	6.0	Standard Pick-up Trucks	T	13%	13%	14%	12%	6%	1%	-3%		
2011	GMC	SIERRA 4WD HYBRID	28.4	313.2	67.3	HEV	CVT	6.0	Standard Pick-up Trucks	T	13%	13%	14%	12%	6%	1%	-3%		
2011	Nissan	ALTIMA HYBRID	46.7	190.3	46.3	HEV	CVT	2.5	Midsize Cars	C	19%	15%	12%	8%	3%	-1%			
2011	Toyota	CAMRY HYBRID	45.9	193.4	46.9	HEV	CVT	2.4	Midsize Cars	C	18%	15%	11%	7%	3%	-2%			
2011	Lexus	HS 250h	47.3	188.0	44.5	HEV	CVT	2.4	Compact Cars	C	17%	13%	9%	5%	1%	-4%			
2012	Ford	ESCAPE HYBRID AWD	39.0	227.6	43.3	HEV	CVT	2.5	Sport Utility Vehicle	T	13%	12%	10%	8%	1%	-4%			
2011	Honda	CR-Z	50.1	177.3	39.5	HEV	CVT	1.5	Two Seaters	C	15%	12%	8%	4%	-1%				
2011	Mercedes-Benz	Smart fortwo (cabriolet)	49.5	179.5	26.8	Gasoline	A5	1.0	Two Seaters	C	14%	11%	7%	2%	-2%				
2011	Mercedes-Benz	Smart fortwo (coupe)	49.5	179.5	26.8	Gasoline	A5	1.0	Two Seaters	C	14%	11%	7%	2%	-2%				
2012	Hyundai	ELANTRA	44.7	198.7	45.2	Gasoline	M6	1.8	Midsize Cars	C	13%	9%	5%	1%	-4%				
2012	Hyundai	ELANTRA	44.4	200.2	45.2	Gasoline	A6	1.8	Midsize Cars	C	12%	9%	4%	0%	-5%				
2011	Toyota	TACOMA 2WD	30.2	294.5	55.9	Gasoline	M5	2.7	Small Pick-up Trucks	T	9%	7%	5%	3%	-4%				
2011	Toyota	SIENNA	29.4	302.0	56.1	Gasoline	A6	2.7	Minivan	T	7%	5%	3%	1%					
2012	Chevrolet	CRUZE ECO	44.4	200.3	44.8	Gasoline	M6	1.4	Midsize Cars	C	11%	8%	3%	-1%					
2011	Lexus	RX 450h	40.4	220.2	48.6	HEV	CVT	3.5	Sport Utility Vehicle	C	9%	6%	1%	-3%					
2012	Ford	Focus SFE FWD	43.6	203.7	44.2	Gasoline	A6	2.0	Compact Cars	C	9%	5%	0%	-4%					
2012	Honda	CIVIC HF	44.3	200.6	43.4	Gasoline	A5	1.8	Compact Cars	C	9%	5%	0%	-4%					
2011	Honda	ODYSSEY 2WD	29.0	306.7	55.9	Gasoline	A6	3.5	Minivan	T	5%	3%	1%	-1%					
2011	Ford	RANGER 2WD	31.2	284.5	50.6	Gasoline	M5	2.3	Small Pick-up Trucks	T	4%	2%	0%	-2%					
2012	Ford	ESCAPE HYBRID FWD	44.1	201.4	43.3	HEV	CVT	2.5	Sport Utility Vehicle	C	8%	4%	0%	-5%					
2011	Toyota	TACOMA 2WD	28.3	313.6	55.9	Gasoline	A4	2.7	Small Pick-up Trucks	T	3%	1%	-1%	-4%					
2012	Hyundai	ACCENT	45.5	195.1	41.7	Gasoline	A6	1.6	Compact Cars	C	8%	4%	-1%	-5%					
2012	Infiniti	M35h	38.8	229.1	49.1	HEV	A7	3.5	Midsize Cars	C	6%	2%	-2%						
2012	Honda	CIVIC	43.0	206.7	43.4	Gasoline	A5	1.8	Compact Cars	C	6%	2%	-3%						
2012	Ford	FOCUS FWD	42.1	211.0	44.2	Gasoline	A6	2.0	Compact Cars	C	5%	1%	-4%						
2011	Honda	CR-Z	44.9	197.9	39.5	HEV	M6	1.5	Two Seaters	C	5%	1%	-4%						
2011	Ford	Fiesta SFE FWD	44.9	198.0	39.3	Gasoline	A6	1.6	Subcompact Cars	C	5%	1%	-4%						
2012	Fiat	500	44.5	199.6	34.7	Gasoline	M5	1.4	Minicompact Cars	C	4%	0%	-5%						
2011	Cadillac	ESCALADE 2WD HYBRID	28.5	311.4	54.8	HEV	CVT	6.0	Sport Utility Vehicle	T	2%	-1%	-2%	-5%					
2011	Chevrolet	TAHOE 2WD HYBRID	28.5	311.4	54.8	HEV	CVT	6.0	Sport Utility Vehicle	T	2%	-1%	-2%	-5%					
2011	GMC	YUKON 2WD HYBRID	28.5	311.4	54.8	HEV	CVT	6.0	Sport Utility Vehicle	T	2%	-1%	-2%	-5%					
2011	Chevrolet	TAHOE 4WD HYBRID	28.4	313.2	54.8	HEV	CVT	6.0	Sport Utility Vehicle	T	1%	-1%	-3%						
2011	GMC	YUKON 4WD HYBRID	28.4	313.2	54.8	HEV	CVT	6.0	Sport Utility Vehicle	T	1%	-1%	-3%						
2012	Chevrolet	CRUZE ECO	40.9	217.1	44.8	Gasoline	A6	1.4	Midsize Cars	C	4%	-1%	-5%						
2012	Volkswagen	Passat	46.4	219.5	45.3	Diesel	M6	2.0	Midsize Cars	C	3%	-1%							
2012	Honda	CIVIC	41.8	212.4	43.4	Gasoline	M5	1.8	Compact Cars	C	3%	-1%							
2012	Ford	FOCUS FWD	41.1	216.1	44.2	Gasoline	A6	2.0	Compact Cars	C	3%	-2%							

Model Year	Manufacturer	Vehicle	Unadjusted Fuel Economy (mpg)	Tailpipe CO_2 (ft^2)	Footprint (ft^2)	Powertrain Type	Transmission	Engine Displacement (L)	Vehicle Class	Car/ Truck	Compliance								
											2017	2018	2019	2020	2021	2022	2023	2024	2025
2011	Ford	Fiesta FWD	44.0	202.2	39.3	Gasoline	A6	1.6	Subcompact Cars	C	3%	-2%							
2012	Buick	LACROSSE	38.1	233.3	48.0	Gasoline	A6	2.4	Midsize Cars	C	3%	-2%							
2011	Kia	FORTE ECO	40.7	218.3	44.5	Gasoline	A6	2.0	Midsize Cars	C	2%	-2%							
2012	Chevrolet	CRUZE	40.4	219.8	44.8	Gasoline	M6	1.4	Midsize Cars	C	2%	-2%							
2011	Mini	Mini Cooper	43.6	203.9	38.8	Gasoline	M6	1.6	Minicompact Cars	C	2%	-3%							
2012	Chevrolet	CRUZE	40.1	221.7	44.8	Gasoline	A6	1.4	Midsize Cars	C	1%	-3%							
2012	Buick	REGAL	38.1	233.3	46.8	Gasoline	A6	2.4	Midsize Cars	C	0%	-4%							
2011	Ford	F150 PICKUP 2WD	23.9	372.3	75.9	Gasoline	A6	3.5	Standard Pick-up Trucks	T	-4%	-4%	-4%	-4%	-4%	-4%			
2011	Ford	F150 PICKUP 2WD	23.9	372.3	72.8	Gasoline	A6	3.5	Standard Pick-up Trucks	T	-4%	-4%	-4%	-4%	-4%	-5%			
2011	Ford	F150 PICKUP 2WD	23.9	372.3	67.2	Gasoline	A6	3.5	Standard Pick-up Trucks	T	-4%	-4%	-4%	-4%	-5%				
2011	Ford	F150 PICKUP 2WD	24.4	363.8	67.2	Gasoline	A6	3.7	Standard Pick-up Trucks	T	-2%	-1%	-1%	-1%	-3%				
2011	Cadillac	ESCALADE 4WD HYBRID	28.0	317.4	54.8	HEV	CVT	6.0	Sport Utility Vehicle	T	0%	-3%	-4%						
2011	GMC	YUKON DENALI HYBRID 4WD	28.0	317.4	54.8	HEV	CVT	6.0	Sport Utility Vehicle	T	0%	-3%	-4%						
2011	Mercedes-Benz	ML450 HYBRID 4MATIC	29.6	300.4	51.0	HEV	CVT	3.5	Sport Utility Vehicle	T	-1%	-3%	-5%						
2012	Ford	TRANSIT CONNECT FWD	31.1	286.0	47.9	Gasoline	M5	1.6	Special Purpose Vehicle	T	-1%	-3%	-5%						
2011	Mini	Mini Cooper Countryman	41.0	216.8	43.0	Gasoline	M6	1.6	Compact Cars	C	0%	-5%							
2012	Volkswagen	Jetta	46.1	220.7	43.8	Gasoline	A6	2.0	Compact Cars	C	0%	-5%							
2011	Ford	Fiesta FWD	42.7	208.1	39.3	Gasoline	A6	2.7	Subcompact Cars	C	0%	-5%							
2012	Volkswagen	Jetta	46.1	220.9	43.8	Diesel	CVT	3.5	Compact Cars	C	0%	-5%							
2011	Toyota	VENZA AWD	30.2	294.3	48.8	Gasoline	A4	2.0	Sport Utility Vehicle	T	-2%	-5%							
2011	Nissan	QUEST	27.2	326.7	55.9	Gasoline	M6	2.0	Minivan	T	-1%	-4%							
2011	Nissan	FRONTIER 2WD	27.4	324.8	54.8	Gasoline	M5	2.5	Small Pick-up Trucks	T	-3%	-5%							
2011	Mazda	MAZDA2	42.6	208.6	39.4	Gasoline	M5	1.5	Compact Cars	C	-1%	-5%							
2012	Ford	Transit Connect Van	30.5	291.8	47.9	Gasoline	A4	2.0	Vans, Cargo Types	T	-3%								
2011	Toyota	SIENNA	26.7	333.0	56.1	Gasoline	A6	3.5	Minivan	T	-3%								
2012	Kia	SORENTO 4WD	30.6	290.8	47.1	Gasoline	A6	2.4	Sport Utility Vehicle	T	-4%								
2012	Kia	SPORTAGE 4WD	31.0	286.9	46.0	Gasoline	A6	2.4	Sport Utility Vehicle	T	-5%								
2011	Suzuki	EQUATOR 2WD	27.3	325.3	54.0	Gasoline	M5	2.5	Small Pick-up Trucks	T	-4%								
2011	Toyota	YARIS	42.6	208.7	39.9	Gasoline	M5	1.5	Subcompact Cars	C	-1%								
2012	Volkswagen	Passat	44.6	228.2	45.3	Diesel	A6	2.0	Midsize Cars	C	-1%								
2011	Honda	FIT	42.5	208.9	39.9	Gasoline	A5	1.5	Small Station Wagons	C	-1%								
2012	Nissan	SENTRA	39.5	224.9	44.3	Gasoline	CVT	2.0	Midsize Cars	C	-1%								
2011	Toyota	COROLLA	41.0	217.0	42.5	Gasoline	M5	1.8	Compact Cars	C	-1%								
2012	Ford	FOCUS FWD	39.4	225.4	44.2	Gasoline	M5	2.0	Compact Cars	C	-2%								
2012	Hyundai	SONATA	36.5	243.3	48.0	Gasoline	A6	2.4	Large Cars	C	-2%								
2011	Kia	OPTIMA	36.5	243.8	48.1	Gasoline	M6	2.4	Midsize Cars	C	-2%								
2012	Hyundai	SONATA	36.5	243.6	48.0	Gasoline	M6	2.4	Large Cars	C	-2%								
2011	Kia	FORTE	38.9	228.4	44.5	Gasoline	A6	2.0	Midsize Cars	C	-2%								
2011	Toyota	YARIS	41.9	212.2	39.9	Gasoline	A4	1.5	Subcompact Cars	C	-2%								
2011	Kia	OPTIMA	36.3	245.1	48.1	Gasoline	A6	2.4	Midsize Cars	C	-2%								
2012	Chevrolet	CRUZE	38.5	230.5	44.8	Gasoline	M6	1.8	Midsize Cars	C	-3%								
2011	Mini	Mini Cooper	41.7	213.3	38.8	Gasoline	A6	1.6	Minicompact Cars	C	-3%								
2012	Volkswagen	GOLF	46.1	220.7	42.4	Diesel	A6	2.0	Compact Cars	C	-3%								
2012	Volkswagen	GOLF	46.1	220.9	42.4	Diesel	M6	2.0	Compact Cars	C	-4%								
2011	Kia	RIO	41.1	216.0	41.3	Gasoline	M5	1.6	Compact Cars	C	-4%								
2012	Volkswagen	JETTA SPORTWAGEN	46.1	220.9	42.3	Diesel	M6	2.0	Small Station Wagons	C	-4%								
2011	Kia	FORTE KOUP	38.3	232.1	44.6	Gasoline	A6	2.0	Compact Cars	C	-4%								
2012	Audi	A6	35.4	251.0	48.6	Gasoline	CVT	2.0	Midsize Cars	C	-4%								
2011	Nissan	VERSA	40.8	217.9	41.4	Gasoline	CVT	1.8	Midsize Cars	C	-4%								
2011	Hyundai	ENTOURAGE	26.8	331.6	54.8	Gasoline	A6	3.5	Minivan	T	-5%								
2012	Kia	SEDONA	26.8	331.6	54.7	Gasoline	A6	3.5	Minivan	T	-5%								
2011	Mini	Mini Clubman	41.0	216.8	40.1	Gasoline	M6	1.6	Subcompact Cars	C	-5%								
2011	Mini	Mini Convertible	41.0	216.8	38.8	Gasoline	M6	1.6	Minicompact Cars	C	-5%								
2012	Audi	A3	46.1	220.7	41.8	Diesel	A6	2.0	Small Station Wagons	C	-5%								

3.13 Analysis of Ferrari & Chrysler/Fiat

Note that in the primary analyses, Ferrari is shown as a separate entity, but in this side-analysis, 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. 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. Also note that in Section III.B., EPA is requesting comment on the concept of allowing companies that are able to demonstrate "operational independence" to be eligible for SVM alternative standards. If EPA were to adopt such provisions, and Ferrari were to qualify, they would likely petition for an alternative standard under the proposed SVM provisions, rather than comply as part of Chrysler/Fiat.

Under the MY 2025 OMEGA projections, Ferrari falls short of its 2025 target (150 grams/mile CO_2) by nine grams. [VV] 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 $7,100 relative to the MY 2016 standards.

If Ferrari is included in the Chrysler/Fiat GHG compliance fleet, Chrylser/Fiat's starting 2008 CO_2 is 2 grams higher (347.6 vs. 345.6). As a result, the cost of complying with the reference case standards would increase by approximately $65, and the cost of complying with the proposed standards would increase by $91 for a net average increase in MY 2025 compliance costs of $36 per vehicle for Chrysler/Fiat. Net program costs would not change significantly.

3.14 Cost Sensitivities

3.14.1 Overview

We have conducted several sensitivity analyses on a variety of input parameters. For the analyses presented in and 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

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

Table 3.14-1 , with the summarized results in

Table 3.14-10 . Additional sensitivities with regard to benefits are shown in DRIA Chapter 4.

Table 3.14-1 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.

3.14.2 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 3.14-2 along with the cost equation used for each side of the mass reduction cost sensitivity.

Table 3.14-2 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

We did not re-rank OMEGA packages for the mass reduction cost sensitivities but rather used the same input files used for our primary analysis with new mass costs. This should have no impact on the results other than making them conservative since re-ranking packages would serve to move the modeling to more cost effective technologies, thus reducing the cost impact of this sensitivity. Because mass reduction is a cost effective technology, even with higher costs, OMEGA would still choose a similar degree of mass reduction given the stringency of the MY 2025 standards. By contrast, even with lower costs, mass reduction would still be limited by the fatality analysis. As a result, the mass reduction sensitivity does not have any impact on the relative ranking of packages or the engine and hybridization technologies that would be added in response to our proposed standards.

The high mass cost inputs increased the average compliance costs of the reference case by $31 and the control case by $133, for a net average per-vehicle cost increase of $102 in MY 2025. The low mass cost inputs decreased the average compliance costs of the reference case by $31 and the control case by $133 for a net average cost decrease of $102 These impacts would be greater on manufacturers that use more mass reduction technology, and less on those that use less.

3.14.3 Battery Sensitivity

For the battery pack cost sensitivities, we decreased/increased the battery pack DMCs by the amounts shown in Table 3.14-3. As presented in Chapter 3 of the draft 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 3.14-3 and Table 3.14-5 show the linear regressions used for our low side and high side sensitivity analyses, respectively, while Table 3.14-4 presents the linear regressions used for our primary analysis (as presented in Chapter 3 of the draft joint TSD).

Table 3.14-3 Linear Regressions of Battery Pack Direct Manufacturing Costs vs Net Weight Reduction used for Low Side Sensitivity (2009$)

Vehicle Class	P2 HEV	PHEV20	PHEV40	EV75	EV100	EV150
Subcompact	-$159x+$645	-$690x+$2,082	-$694x+$2,919	-$1,080x+$4,339	-$1,651x+$5,088	-$1,615x+$6,633
Small car	-$196x+$682	-$798x+$2,197	-$1,675x+$3,229	-$1,626x+$4,710	-$2,279x+$5,603	-$2,480x+$7,350
Large car	-$270x+$777	-$1,255x+$2,664	-$2,521x+$4,153	-$2,768x+$5,738	-$3,215x+$6,481	-$3,016x+$8,791
Minivan	-$265x+$763	-$1,152x+$2,637	-$1,672x+$4,028	-$2,784x+$5,761	-$2,472x+$6,731	-$3,653x+$9,397
Small truck	-$249x+$740	-$1,071x+$2,514	-$1,955x+$3,829	-$2,518x+$5,463	-$2,377x+$6,436	$9,003
Minivan+towing	-$265x+$836					
Large truck	-$285x+$868					

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 (-$159)x(15%)+$645=$621.

The small truck EV150 regression has no slope since the net weight reduction is always 0 due to the 20% weight reduction hit.

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

Table 3.14-4 Linear Regressions of Battery Pack Direct Manufacturing Costs vs Net Weight Reduction used for the Primary Analysis (2009$)

Vehicle Class	P2 HEV	PHEV20	PHEV40	EV75	EV100	EV150
Subcompact	-$177x+$716	-$862x+$2,602	-$867x+$3,649	-$1,350x+$5,424	-$2,064x+$6,360	-$2,019x+$8,292
Small car	-$218x+$758	-$998x+$2,746	-$2,093x+$4,037	-$2,033x+$5,888	-$2,849x+$7,004	-$3,100x+$9,187
Large car	-$300x+$864	-$1,568x+$3,331	-$3,152x+$5,192	-$3,460x+$7,173	-$4,019x+$8,101	-$3,770x+$10,989
Minivan	-$294x+$848	-$1,439x+$3,296	-$2,090x+$5,035	-$3,480x+$7,201	-$3,090x+$8,414	-$4,566x+$11,746
Small truck	-$277x+$822	-$1,338x+$3,143	-$2,444x+$4,787	-$3,148x+$6,828	-$2,971x+$8,045	$11,253
Minivan+towing	-$294x+$929					
Large truck	-$317x+$964					

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 (-$177)x(15%)+$716=$689.

The small truck EV150 regression has no slope since the net weight reduction is always 0 due to the 20% weight reduction hit.

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

Table 3.14-5 Linear Regressions of Battery Pack Direct Manufacturing Costs vs Net Weight Reduction used for the High Side Sensitivity (2009$)

Vehicle Class	P2 HEV	PHEV20	PHEV40	EV75	EV100	EV150
Subcompact	-$194x+$788	-$1,034x+$3,123	-$1,041x+$4,378	-$1,620x+$6,509	-$2,477x+$7,632	-$2,423x+$9,950
Small car	-$240x+$834	-$1,197x+$3,295	-$2,512x+$4,844	-$2,439x+$7,065	-$3,419x+$8,404	-$3,720x+$11,024
Large car	-$330x+$950	-$1,882x+$3,997	-$3,782x+$6,230	-$4,152x+$8,607	-$4,823x+$9,722	-$4,524x+$13,187
Minivan	-$324x+$933	-$1,727x+$3,955	-$2,508x+$6,042	-$4,176x+$8,641	-$3,708x+$10,097	-$5,479x+$14,096
Small truck	-$304x+$904	-$1,606x+$3,771	-$2,933x+$5,744	-$3,777x+$8,194	-$3,565x+$9,654	$13,504
Minivan+towing	-$324x+$1,022					
Large truck	-$348x+$1,061					

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 (-$194)x(15%)+$788=$759.

The small truck EV150 regression has no slope since the net weight reduction is always 0 due to the 20% weight reduction hit.

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

For the battery pack sensitivities, unlike the mass reduction sensitivities, we did re-rank OMEGA packages. However, we started with the master-sets of packages as described in Chapter 1 of this draft RIA for both the 2016MY and 2025MY and did not start with preliminary-sets of packages and conduct a full package building/ranking process. Using the master-sets of packages, we inserted new battery pack costs, re-ranked the master-sets of packages to get the proper ordering of packages for each sensitivity case, then ran OMEGA. As noted above, this should have no impact on the results other than making them conservative since starting with a preliminary-set of packages and re-ranking would serve to move the modeling to more cost effective technologies, thus reducing the cost impact.

The high battery cost inputs increased the average compliance costs of the reference case by $2 and the control case by $63, for a net cost increase of $61. In the high case, the penetration of EVs decreased from 2.8% to 2.2%, as companies chose more cost effective options. MY 2025 HEV penetration increased from 15% to 17%. The low battery cost inputs decreased the average compliance costs of the reference case by $2 and the control case by $103 for a net decrease of $101. In the low cost case, the MY 2025 penetration of EVs increased to 3.9%, while the HEV penetration decreased to 10%. 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 little changed.

3.14.4 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 draft joint TSD and provide details in a memorandum to the docket (EPA-HQ-OAR-2010-

0799).[WW] 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 3.14-6 and Table 3.14-8 show the ICMs used for the low side and high side sensitivity analyses, respectively, while Table 3.14-7 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 3.14-6 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 3.14-7 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

Table 3.14-8 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

Like done for the battery pack sensitivities, we re-ranked OMEGA packages using the master-sets of packages as described in Chapter 1 of this draft RIA for the 2016MY and 2025MY. We did not start with preliminary-sets of packages and conduct a full package building/ranking process. Using the master-sets of packages, we inserted new costs calculated using the low/high IMCs, re-ranked the master-sets of packages to get the proper ordering of packages for each sensitivity case, then ran OMEGA. As noted above, this should have no impact on the results other than making them conservative since starting with a preliminary-set of packages and re-ranking would serve to move the modeling to more cost effective technologies, thus reducing the cost impact.

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

The high ICM inputs increased the average compliance costs of the reference case by $63 and the control case by $312, for a net average per-vehicle cost increase of $249 in MY 2025. The low ICM inputs decreased the average compliance costs of the reference case by $105 and the control case by $349 for a net average cost decrease of $244.

3.14.5 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 draft 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 3.14-9 shows how we have adjusted these learning rates for both the low and high side sensitivities.

Table 3.14-9 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%

For the learning sensitivity, we re-ranked OMEGA packages using the master-sets of packages as described in Chapter 1 of this draft RIA for the 2016MY and 2025MY. We did not start with preliminary-sets of packages and conduct a full package building/ranking process. Using the master-sets of packages, we inserted new costs calculated using the low/high learning rates, re-ranked the master-sets of packages to get the proper ordering of packages for each sensitivity case, then ran OMEGA. As noted above, this should have no impact on the results other than making them conservative since starting with a preliminary-set of packages and re-ranking would serve to move the modeling to more cost effective technologies, thus reducing the cost impact.

The high learning inputs increased the average compliance costs of the reference case by $48 and the control case by $154, for a net average per-vehicle cost increase of $106 in MY 2025. The low ICM inputs decreased the average compliance costs of the reference case by $63 and the control case by $158 for a net average cost decrease of $97.

3.14.6 Summary of Sensitivity Impacts

The average per-vehicle impacts of the sensitivity runs are shown in

Table 3.14-10. Note that the majority of these impacts are less than $100 relative to the primary analysis costs. The ICM impacts are larger.

Table 3.14-10 Summary of Per-vehicle Cost Impacts of Sensitivity Analyses in MY 2025 relative to Primary Analysis

Sensitivity Title	Low ($)	High ($)
Primary Case	$1946	
Mass Cost	-$102	$102
Battery Cost	$101	$61
ICM	$244	$249
Learning Rates	$97	$106

3.14.7 NAS report

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 draft Joint Technical Support Document for this proposal, 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 proposal, 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 proposal, 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. 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 & NHTSA assessment for this proposal. For example, there are a number of technologies that EPA and NHTSA discuss in Chapter 3 of the draft 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 2012-2016 rulemaking. However, for the 2017-2025 proposals, where EPA and NHTSA are using a model year 2008 baseline set of vehicles, the agencies estimate that for each these technologies two increments of improvement can be implemented across the fleet between 2008 and 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 2012-2016 rule. But, for the 2017-2025 proposal, 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 CO2/fuel consumption reductions. Those additioal 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 proposal, 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 draft 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"[24], 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”[25] 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.”[26] 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”[27]. 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”[28], 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.[29]

- “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.[30]

- “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.[31]

- “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.[32] 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.[33]

- "Documentation of the Development of Indirect Cost Multipliers for Three Automotive Technologies," EPA Technical Memorandum, Helfand, G., Sherwood, T., August 2009.[34]

- 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.

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 proposal, 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 this proposal.

EPA requests comment on our overall approach for this proposal of basing our assessment on technology feasibility, lead time, costs and effectiveness on the full range of information described in the draft 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 also requests comment specifically on EPA's use of the 2011 Ricardo study (listed above), and we seek comment on 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 request comment on the 2011 Ricardo Study and the Ricardo response to comments report with respect to the peer review conducted on the draft Ricardo report. 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 draft Joint Technical Support Document.

References

[24] 2011 Ricardo Report "Computer Simulation of Light-duty Vehicle Technologies for Greenhouse Gas Emission Reductions in the 2020-2025 Timeframe"

[25] Argonne National Laboratories 2011 Report "Modeling the Performance and Cost of Lithium-Ion Batteries for Electric-Drive Vehicles"

[26] 2011 FEV Report "Light-Duty Technology Cost Analysis Power-split and P2 HEV Case Studies"

[27] 2011 FEV Report "Light-Duty Technology Cost Analysis: Advanced 8-speed Transmissions"

[28] 2010 Lotus Engineer Study "An Assessment of Mass Reduction Opportunities for a 2017 – 2020 Model Year Vehicle Program"

[29] "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

[30] "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

[31] "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

[32] "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

[33] "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

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

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 proposed 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.

Mobile sources represent a large and growing 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 2007, all 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.

This proposal, if finalized, 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 proposed rule. This analysis quantifies the proposed 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 are also shown in this chapter.

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 discussed 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.

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 Draft 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 proposal. 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). 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 Draft Joint Technical Support Document. Specifically, Draft Joint TSD Chapter 1 discusses the development of the vehicle fleet, Draft Joint TSD Chapter 2 discusses the attribute based curves which define the CO_2 targets, Draft Joint TSD Chapter 3 discusses the technologies which may be used to meet those targets,[XX] and Draft 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.

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, [YY] (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 4.3-16).[ZZ] EPA additionally accounted for the greenhouse gas impacts of additional vehicle miles travelled (VMT) due to the "rebound" effect discussed in Section III.H.

[XX] Specifically, the power consumption of plug-in hybrid and battery electric vehicles are discussed in Draft Joint TSD Chapter 3 and used in this analysis. Mass reduction, an input to the mass-safety analysis, is also discussed therein.

[YY] 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 proposed action.

[ZZ] As discussed in TSD Chapter 4, 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.

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 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 proposed program would be small compared to total U.S. inventories across all sectors.

As discussed in the preamble, while 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.[35] Consequently, EPA assumes neither tailpipe pollutant benefit (other than CO_2) 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 2 - Emissions

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

$SO_{2,}$ which is largely controlled by the sulfur content of the fuel, is an exception to this basic equation. As discussed inTSD 4, decreasing the quantity of fuel consumed decreases tailpipe SO_2 emissions roughly proportionally to the decrease in fuel consumed.

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. The global warming potentials used in this rule are consistent with 100-year time frame values in the 2007 Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report

(FAR).[36] At this time, the 100-year global warming potential values from the 1996 IPCC Second Assessment Report are used in the official U.S. greenhouse gas inventory submission to the United Nations Framework Convention on Climate Change (per the reporting requirements under that international convention, which were last updated in 2006) . The FAR values were used in the MYs 2012-2016 light duty rule and the MY 2014-2018 Medium and Heavy duty rule.

Table 4.3-1 Global Warming Potentials for the Inventory GHGs

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 proposal in calendar years 2020, 2030, 2040 and 2050. We also present the emission impacts over the estimated full lifetime of MYs 2017-2025.[AAA] The program was quantified as the difference in mass emissions between a control case under proposed standards and a reference case as described in Section 4.3.3.

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 Draft Joint TSD. For MYs between 2025 and 2035, EPA used the Volpe Center run of the NEMs model (discussed in Draft 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.

[AAA] The "full lifetime" is the timespan 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.

Table 4.3-2 MY 2011 and later Car and Truck Definitions[BBB]

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[CCC]

TSD 4 also describes the derivation of the survival schedule, which is shown below. The proportions of passenger cars and light trucks expected to remain in service at each age are drawn from a 2006 NHTSA study, and are shown in (Table 4.3-16)[DDD, 37] Note that these survival rates were calculated against the pre-MY 2011 definitions of cars and light trucks, because the NHTSA study has not been updated since 2006. Because the agencies are unaware of a better data source, these values were used unchanged, and are the same values used in the MYs 2012-2016 rule and the interim Joint TAR. No changes in survival rates were explicitly projected into the future.

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.[EEE]

[BBB] While the formal definitions are lengthy, brief summaries of the classifications are shown here.

[CCC] A lengthier discussion of both survival and mileage schedules are provides in Draft Joint TSD Chapter 4

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

[EEE] Historic values are derived from the Fuel Economy Trends report (http://www.epa.gov/otaq/fetrends.htm), future values are discussed in Table 4.3-7.

Table 4.3-3 Survival Rates

VEHICLE AGE	ESTIMATED SURVIVAL FRACTION CARS	ESTIMATED SURVIVAL FRACTION LIGHT TRUCKS
1	0.9950	0.9950
2	0.9900	0.9741
3	0.9831	0.9603
4	0.9731	0.9420
5	0.9593	0.9190
6	0.9413	0.8913
7	0.9188	0.8590
8	0.8918	0.8226
9	0.8604	0.7827
10	0.8252	0.7401
11	0.7866	0.6956
12	0.7170	0.6501
13	0.6125	0.6042
14	0.5094	0.5517
15	0.4142	0.5009
16	0.3308	0.4522
17	0.2604	0.4062
18	0.2028	0.3633
19	0.1565	0.3236
20	0.1200	0.2873
21	0.0916	0.2542
22	0.0696	0.2244
23	0.0527	0.1975
24	0.0399	0.1735
25	0.0301	0.1522
26	0.0227	0.1332
27	0	0.1165
28	0	0.1017
29	0	0.0887
30	0	0.0773
31	0	0.0673
32	0	0.0586
33	0	0.0509
34	0	0.0443
35	0	0.0385
36	0	0.0334

4.3.2.3 VMT schedules

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 calendar year 2001 cars and light trucks of various ages were developed by NHTSA from the Federal Highway Administration's 2001 National Household Transportation Survey (NHTS), and are reported in(Table 4.3-4). These estimates represent the typical 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.

Table 4.3-4 CY 2001 Mileage Schedules

VEHICLE AGE	ESTIMATED VEHICLE MILES TRAVELED CARS	ESTIMATED VEHICLE MILES TRAVELED LIGHT TRUCKS
1	14,231	16,085
2	13,961	15,782
3	13,669	15,442
4	13,357	15,069
5	13,028	14,667
6	12,683	14,239
7	12,325	13,790
8	11,956	13,323
9	11,578	12,844
10	11,193	12,356
11	10,804	11,863
12	10,413	11,369
13	10,022	10,879
14	9,633	10,396
15	9,249	9,924
16	8,871	9,468
17	8,502	9,032
18	8,144	8,619
19	7,799	8,234
20	7,469	7,881
21	7,157	7,565
22	6,866	7,288
23	6,596	7,055
24	6,350	6,871
25	6,131	6,739
26	5,940	6,663
27	0	6,648
28	0	6,648
29	0	6,648
30	0	6,648
31	0	6,648
32	0	6,648
33	0	6,648
34	0	6,648
35	0	6,648
36	0	6,648

4.3.2.4 Adjusting vehicle use for years after 2001

For this rulemaking, the agencies updated the estimates of average vehicle use reported in Table 4-4 using forecasts of future fuel prices reported in the AEO 2011 Reference Case and projected fuel economy levels in the reference and control cases.[FFF] This adjustment accounts for the difference between the average retail price per gallon of fuel forecast during each calendar year over the expected lifetimes of model year 2017-25 passenger cars and light trucks, and the average price that prevailed when the NHTS was conducted in 2001.[GGG] This adjustment also accounts for the potential rebound effect from vehicles of a specific age in future years having higher fuel economy than vehicles of the same age in 2001 (discussed further in section 4.5.1). Like the survival schedule, this VMT schedule was not adjusted for differences in car and truck definitions post MY 2011.

Specifically, 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; see section 4.5.1) was applied to the difference between the combination of each future year's fuel prices and vehicle fuel economy and those prevailing in 2001.[HHH,III]

The estimates of annual miles driven by passenger cars and light trucks at each age were also adjusted to reflect projected future growth trends in average use for vehicles of all ages. In order to develop reasonable estimates of future growth in the average number of miles driven by cars and light trucks of all ages, the agencies calculated the rate of growth in the reference mileage schedules necessary for total car and light truck travel to increase at the rate forecast in the AEO 2011 Reference Case. The growth rate in average annual car and light truck use produced by this calculation is approximately 1.1 percent per year through 2030, and 0.5% per year from 2031-2050.[JJJ] As shown in TSD 4, this roughly calibrates the total calculated VMT to an extrapolation from AEO 2011. This growth was applied to the mileage figures reported in Table 4.3-4 (after adjusting them as described previously for future fuel prices, fuel economy, and expected vehicle survival rates) to estimate average annual mileage during each calendar year analyzed and during the expected lifetimes of

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[FFF] Historic values are derived from the Fuel Economy Trends report (http://www.epa.gov/otaq/fetrends.htm), future values are discussed in Table 4.3-7

[GGG] Under the assumption that people tend to drive more as the cost of driving decreases, the higher fuel prices that are forecast for future years would be expected to reduce average vehicle use. We assume that fuel prices will be the same in both the reference and control cases;, however, in section III.H.7 of the preamble to the proposed rule, we discuss the potential for this proposal to decrease world oil prices.

[HHH] See Draft Joint TSD Chapter 4

[III] For our VMT analysis, we assume consumers respond the same way to changes in fuel efficiency and fuel prices. Consistent with this assumption, we use the same elasticity to measure consumer responses to changes in fuel prices as we do to measure the rebound effect of consumers driving more in response to increased fuel efficiency. See section Draft Joint TSD Chapter 4 and section 4.5.1 for additional discussion.

[JJJ] 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.

model year 2017-25 cars and light trucks[KKK] The net impact resulting from these two separate 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. Observed aggregate VMT in recent years has actually declined, but it is unclear if the underlying cause is general shift in behavior or a response to a set of temporary economic conditions. The agencies intend to consider new data on the VMT growth estimates as it becomes available, and are requesting comment on this topic.[LLL]

Because the effects of fuel prices, fuel economy, and growth in average vehicle use differ for each year, these adjustments result in different VMT schedules for each future year. While the adjustment for future fuel prices generally *reduces* average mileage at each age from the values tabulated from the 2001 NHTS, the adjustment for expected future growth in average vehicle use and improvements in fuel economy *increases* it. The net impact resulting from these separate adjustments is continued growth over time in the average number of miles that vehicles of each age are driven, although at slower rates.

4.3.2.5 Final VMT equation

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 2001 NHTS to derive the estimates of average miles driven by vehicles of each model year (denoted MY) during future calendar years (denoted CY) that are used in this analysis. The equation has three multiplicative components; the CY2001 VMT by age, the adjustment for a growth rate, and the adjustment for changes in fuel prices and fuel economy.

Equation 3 – VMT growth

$$VMT_{calendar\ year\ \ x\ ,age\ y} = (V_y) * (1 + GR1)^{YS1} * (1 + G2)^{YS2} * (1 - \ R * (FCPM_{2001,y} - \ FCPM_{x,y})/FCPM_{2001,y}$$

Where:

V_y = Average miles driven in CY 2001 (from NHTSA analysis of 2001 NHTS data) by a vehicle of age $_y$ during 2001

GR1 = Growth Rate for average miles driven by vehicles of each age from 2001 to 2030

YS1 = Lesser of (Years since 2001) and (29).

GR2 = Growth Rate for average miles driven by vehicles of each age from 2030 to 2050

YS2 = Greater of (Years since 2030) and (0).

[KKK] 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.

[LLL] 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 slow down. See the 2009 National Household Travel Survey (http://nhts.ornl.gov/2009/pub/stt.pdf) and National transportation Statistics

R= Magnitude of consumer responsiveness to changes in fuel cost per mile, equivalent to the rebound effect rate assumption and expressed as an elasticity (-0.10)
$FCPM_{x,y}$ = Fuel cost per mile of a vehicle of age *y* in calendar year *x*

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:

$$FCPM_{Calendar\ year\ x} = EC_y * EP_x + GC_y * GP_x + DC_y * DP_x$$

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*

Table 4.3-5 presents the EPA's estimates of the average number of miles driven by model year 2021 and 2025 cars and light trucks at over their estimated average lifetimes. While these values may appear large relative to current vehicles, the full useful life of MY 2025 vehicles (36 years) ends in CY 2061. A more extensive discussion of the VMT schedule development relative to AEO and current data is presented in TSD 4. The control case VMT schedules, due to the lower cost per mile, have somewhat higher VMT.

Table 4.3-5–Reference VMT used in EPA's analyses

MY 2021		MY 2025	
Cars	Light Trucks	Cars	Light Trucks
204,668	242,576	210,898	249,713

4.3.2.6 Non CO_2 Emission Factors

As documented in Draft Joint TSD Chapter 4, emission factors for this analysis were derived from several sources. A more complete documentation of these sources is provided in that chapter. Tailpipe emission factors other than CO_2 were derived from MOVES 2010a.[38] Upstream emission factors for petroleum refining, transport and distribution were derived from EPA's "Impact spreadsheet" based on Argon National Labs Greet 1.8.[39, 40] Electricity related emission factors for were derived from EPA's Integrated Planning Model (IPM). These emission factors were used as inputs to the OMEGA post-processor.[41]

4.3.3 Scenarios

4.3.3.1 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 for 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 4.3-6 – 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 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.

4.3.3.2 Reference Case

As described in DRIA chapter 3 and Preamble III.D, we assume a flat reference case of MY 2016 standards. No additional compliance flexibilities were explicitly modeled for the

MY 2016 standards. The EPA flexible fueled vehicle (FFV) credit expires before MY 2016.[MMM] 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 incentive credits are projected to be available to the reference case. Off-cycle credits, which are designed to be environmentally neutral, would only lower costs. These credits are not modeled here due to the difficult in predicting manufacturers use of these credits under the MY 2016 program.

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 DRIA Chapter 3.

CO_2 emission rates for MY 2016, 2021 and 2025 were taken from OMEGA model outputs. Intermediate years were interpolated, and CO_2 g/mile rates past MY 2025 were kept the same. 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 4.3-7). As no EVs were modeled, there is no increase in electricity consumption in the reference Case. The air conditioning impacts as discussed in Section 4.3.3.1 were also incorporated.

Table 4.3-7 – Reference Case Two Cycle CO_2

MY	Car	Truck	Fleet
2017	233	314	263
2018	233	315	263
2019	233	315	262
2020	233	315	262
2021	233	315	262
2022	233	315	261
2023	232	315	261
2024	232	314	260
2025	232	314	259

4.3.3.3 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 car-truck trading, but the results should be environmentally equivalent. A/C refrigerant and efficiency credit estimates are discussed in Section4.3.3.1, while the EV/PHEV/FCV multiplier credit and pickup related credits are discussed in the following sections. Off-cycle

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[MMM] The credit available for producing FFVs will have expired, although the real world usage credits will be available.

credits were not modeled explicitly, as they have been designed to be environmentally neutral. These estimates are summarized in Table 4.3-8 through

Table 4.3-10. 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.

Table 4.3-8 Passenger Cars (Grams per mile)

Model Year	Projected CO_2 Compliance Target	EV/PHEV/FCV Multiplier	A/C Refrigerant	A/C Efficiency	Projected 2-cycle CO_2
2016 (base)	225	--	5.4	4.8	235
2017	213	2.2	7.8	5.0	228
2018	202	2.1	9.3	5.0	219
2019	192	2.0	10.8	5.0	210
2020	182	1.5	12.3	5.0	201
2021	173	1.0	13.8	5.0	193
2022	165	--	13.8	5.0	184
2023	158	--	13.8	5.0	177
2024	151	--	13.8	5.0	169
2025	144	--	13.8	5.0	163

Table 4.3-9 Light Trucks (Grams per mile)

Model Year	Projected CO_2 Compliance Target	EV/PHEV/FCV Multiplier	Pickup Mild HEV + Perf	Pickup Strong HEV + Perf	A/C Refrigerant	A/C Efficiency	2-cycle CO_2 (3)
2017	295	0.0	0.3	0.0	7.0	5.0	307
2018	285	0.0	0.4	0.1	11.0	6.5	303
2019	277	0.1	0.6	0.2	13.4	7.2	299
2020	270	0.1	0.7	0.2	15.3	7.2	293
2021	250	0.0	0.8	0.4	17.2	7.2	275
2022	237	--	--	0.5	17.2	7.2	262
2023	225	--	--	0.6	17.2	7.2	250
2024	214	--	--	0.6	17.2	7.2	239
2025	203	--	--	0.7	17.2	7.2	228

Table 4.3-10 Combined Cars and Trucks (Grams per mile)

Model Year	Projected CO_2 Compliance Target	EV/PHEV/FCV Multiplier	Pickup Mild HEV + Perf	Pickup Strong HEV + Perf	A/C Refrigerant	A/C Efficiency	2-cycle CO_2
2017	243	1.4	0.1	0.0	7.5	5.0	257
2018	232	1.3	0.2	0.0	9.9	5.5	249
2019	223	1.3	0.2	0.1	11.7	5.8	242
2020	213	1.0	0.3	0.1	13.4	5.8	234
2021	200	0.6	0.3	0.1	15.0	5.8	222
2022	190	--	--	0.2	15.0	5.8	211
2023	181	--	--	0.2	15.0	5.8	202
2024	172	--	--	0.2	14.9	5.7	193
2025	163	--	--	0.2	14.9	5.7	184

4.3.3.3.1 EV/PHEV/FCVs

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 proposed. For purposes of this modeling, we assume that this cap is never reached. This does not imply that EPA has proposed 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 4.5.2of the DRIA Costs beyond MY 2025 assume no technology changes on the vehicles, and implicitly assume EVs used for compliance remain at zero gram/mile.[NNN] Upstream emissions from electric vehicles, regardless of the zero-gram mile credit, are always modeled in this analysis.

For the benefits analysis, 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. 2017 EV penetrations were setat 1% of the fleet. PHEV sales, as projected by OMEGA, are not significant.[OOO]

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

[OOO] 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 2017-2021 timeframe.

Table 4.3-11 – EV Fraction of the MY Fleets

Model Year	Cars	Truck	EV multiplier
2017	1.0%	0.0%	2
2018	1.0%	0.0%	2
2019	1.1%	0.0%	2
2020	1.1%	0.0%	1.75
2021	1.1%	0.0%	1.5
2022	1.7%	0.3%	0
2023	2.4%	0.5%	0
2024	3.0%	0.8%	0
2025	3.6%	1.0%	0

The EV multiplier credit was calculated by following formula

Equation 4 – Impact of EV multiplier

GHG Target with multiplier = (GHG Target without multiplier * (Total MY Sales + Multiplier * Number of EV sales))/Total sales

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 5 – Impact of EV multiplier: example

GHG Target with multiplier =

(172.8 * (10.5 million+ 1.5 * 1.1% EV sales * 10.5 million sales))/10.5 million sales

= 173.8 or a delta of 1.0 grams.

4.3.3.3.2 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. As we did not consider these credits directly in the OMEGA cost modeling, we did two post-process exercises to project likely benefits.

Table 4.3-12 Pickup Trucks as a Fraction of the Fleet

Model Year	Projected Sales of Full Size Pickup Trucks[PPP]	Pickup Trucks (of Trucks)	Pickup Trucks (of Fleet)	Trucks (of fleet)
2017	1,240,844	21%	8%	37%
2018	1,186,474	21%	8%	36%
2019	1,133,605	20%	7%	36%
2020	1,157,114	21%	7%	35%
2021	1,122,173	20%	7%	35%
2022	1,103,058	19%	7%	35%
2023	1,045,507	18%	6%	34%
2024	1,011,897	18%	6%	34%
2025	1,002,806	18%	6%	33%

Based on these fleet fractions, and the credit available the maximum potential credit can be calculated.

Table 4.3-13 Maximum Potential Impact of Pickup Credits on Truck Fleet

Model Year	Mild HEV Credit	Mild HEV Max impact (Trucks)	Strong HEV Credit	Strong HEV Max Credit (Trucks)
2017	10.0	2.1	20.0	4.3
2018	10.0	2.1	20.0	4.2
2019	10.0	2.0	20.0	4.1
2020	10.0	2.1	20.0	4.1
2021	10.0	2.0	20.0	3.9
2022	0.0	0.0	20.0	3.9
2023	0.0	0.0	20.0	3.7
2024	0.0	0.0	20.0	3.6
2025	0.0	0.0	20.0	3.5

Not every pickup truck will get these credits. For the each credit, there is a minimum fleet fraction required for a manufacturer to receive the credit. For the mild credit, we assumed that one-half of this minimum percentage received the credit. For the strong HEV credit we assumed that 0% received the credit in MY 2017, 10% received the credit in MY 2021, and 20% received the credit in MY 2025. Because these penetrations are in all cases

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[PPP] These totals include 1 model with 30,000 sales which would not be classified as a full size pickup under the proposal. Therefore, the credit impact is be overstated by about 3%.

higher than the penetrations projected by the OMEGA model, we consider these estimates to adequately bound the potential utilization of the performance based credit.

Table 4.3-14 – Pickup Credits

MY	Mild Credit(% of Pickups)	Truck Credit from Mild (g/mile)	Strong Credit(% of Pickups)	Truck Credit from Strong (g/mile)
2017	30%	0.3	0%	0.0
2018	40%	0.4	2%	0.1
2019	55%	0.6	4%	0.2
2020	70%	0.7	6%	0.2
2021	80%	0.8	10%	0.4
2022			13%	0.5
2023			15%	0.6
2024			18%	0.6
2025			20%	0.7

4.3.3.4 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 the Interim Joint TAR, and are 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.[42,43] The upstream emission factor is applied to total electricity production, rather than simply power consumed at the wheel.[QQQ] It is assumed that electrically power vehicles drive the same drive schedule as the rest of the fleet.

[QQQ] 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.

Table 4.3-15 Average Electricity Consumption

	Average 2 cycle Electricity Consumption for the fleet (kwh/mile)	
Model Year	Cars	Trucks
2017	0.000	0.000
2018	0.001	0.000
2019	0.001	0.000
2020	0.002	0.000
2021	0.002	0.000
2022	0.004	0.001
2023	0.005	0.002
2024	0.007	0.002
2025	0.009	0.003

4.3.4 Emission Results

4.3.4.1 Calendar Year Analyses

Table 4.3-16 Impacts of Program on GHG Emissions

Calendar Year:	2020	2030	2040	2050
Net Delta[*]	**-29**	**-297**	**-462**	**-547**
Net CO_2	*-24*	*-268*	*-420*	*-497*
Net other GHG	*-4*	*-29*	*-42*	*-50*
Downstream	**-24**	**-249**	**-389**	**-461**
CO_2 (excluding A/C)	*-19*	*-224*	*-355*	*-421*
A/C – indirect CO_2	*-1*	*-3*	*-4*	*-4*
A/C – direct HFCs	*-4*	*-21*	*-30*	*-36*
CH_4 (rebound effect)	*0*	*0*	*0*	*0*
N_2O (rebound effect)	*0*	*0*	*0*	*0*
Gasoline Upstream	***-6***	***-63***	***-100***	***-119***
CO_2	*-5*	*-55*	*-87*	*-103*
CH_4	*-1*	*-8*	*-12*	*-15*
N_2O	*0*	*0*	*0*	*0*
Electricity Upstream	**1**	**15**	**27**	**32**
CO_2	*1*	*15*	*26*	*32*
CH_4	*0*	*0*	*0*	*0*
N_2O	*0*	*0*	*0*	*0*

Table 4.3-17 Annual Criteria 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	-12,467	-0.1%	-135,566	-1.1%
	CO	21,242	0.0%	397,861	0.7%
	NO_X	-2,449	0.0%	-16,008	-0.2%
	PM2.5	-351	0.0%	-3,123	-0.1%
	SO_X	-1,650	0.0%	-9,443	-0.1%
Downstream	VOC	379	0.0%	8,623	0.1%
	CO	22,212	0.0%	405,260	0.7%
	NO_X	779	0.0%	14,872	0.1%
	PM2.5	63	0.0%	1,023	0.0%
	SO_X	-449	0.0%	-5,051	-0.1%
Fuel Production and Distribution	VOC	-12,860	-0.1%	-144,503	-1.1%
	CO	-1,229	0.0%	-13,810	0.0%
	NO_X	-3,846	0.0%	-43,215	-0.4%
	PM2.5	-524	0.0%	-5,890	-0.1%
	SO_X	-2,353	0.0%	-26,443	-0.3%
Electricity	VOC	14	0.0%	6,411	0.1%
	CO	259	0.0%	6,411	0.0%
	NO_X	617	0.0%	12,335	0.1%
	PM2.5	110	0.0%	1,743	0.0%
	SO_X	1,153	0.0%	22,051	0.3%

Table 4.3-18 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	2	0.02%	47	0.4%
	Acetaldehyde	4	0.00%	112	0.2%
	Acrolein	0	0.01%	-6	0.0%
	Benzene	-15	-0.01%	-26	0.0%
	Formaldehyde	-5	0.00%	3	0.0%
Downstream	1,3- Butadiene	2	0.02%	49	0.4%
	Acetaldehyde	6	0.01%	124	0.2%
	Acrolein	0	0.01%	5	0.0%
	Benzene	13	0.01%	285	0.1%
	Formaldehyde	5	0.00%	118	0.1%
Fuel Production and Distribution	1,3- Butadiene	0	0.00%	-3	0.0%
	Acetaldehyde	-1	0.00%	-15	0.0%
	Acrolein	0	-0.01%	-15	0.0%
	Benzene	-28	-0.01%	-313	-0.1%
	Formaldehyde	-10	0.00%	-115	-0.1%
Electricity	1,3- Butadiene	0	0.00%	2	0.0%
	Acetaldehyde	0	0.00%	3	0.0%
	Acrolein	0	0.01%	4	0.0%
	Benzene	0	0.00%	2	0.0%
	Formaldehyde	0	0.00%	1	0.0%

4.3.4.2 Model Year Analyses

Table 4.3-19 Projected Net GHG Deltas (MMTCO$_2$eq per model year)

MY	Downstream	Upstream (Gasoline)	Electricity	Total CO2e
2017	-24	-6	1	**-29**
2018	-58	-14	2	**-70**
2019	-90	-21	3	**-108**
2020	-125	-30	4	**-151**
2021	-181	-44	5	**-220**
2022	-226	-56	9	**-273**
2023	-268	-68	13	**-322**
2024	-311	-79	18	**-372**
2025	-354	-91	23	**-422**
Total	-1,637	-408	77	**-1,967**

Table 4.3-20 Projected Net Non-GHG Deltas (MMT per model year)

Criteria Emission Impacts of Program (short tons)					
MY	VOC	CO	NOx	PM2.5	SO2[RRR]
2017	-11,990	49,315	-1,324	-290	-1,569
2018	-27,915	115,855	-3,324	-723	-4,108
2019	-43,158	179,978	-5,169	-1,132	-6,425
2020	-60,523	253,119	-7,281	-1,603	-9,107
2021	-89,344	373,036	-11,199	-2,450	-14,516
2022	-114,882	477,853	-12,202	-2,821	-14,590
2023	-138,334	574,020	-12,700	-3,112	-13,918
2024	-162,591	673,516	-13,127	-3,413	-13,086
2025	-187,085	774,071	-13,404	-3,705	-12,006
Sum	-835,821	3,470,763	-79,729	-19,247	-89,322
Model Year Lifetime Air Toxic Emissions (short tons)					
MY	Benzene	1,3 Butadiene	Formaldehyde	Acetaldehyde	Acrolein
2017	15	7	7	17	1
2018	35	17	17	40	2

[RRR] 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.

2019	54	26	27	63	3
2020	76	37	38	88	4
2021	112	54	56	130	6
2022	141	69	71	166	8
2023	167	83	84	200	11
2024	194	97	98	234	13
2025	222	112	113	269	16
Sum	1,014	502	512	1,207	63

4.3.5 Fuel Consumption Impacts

The fuel consumption analyses relied on the same set of fleet and activity inputs as the emission analysis. Because the OMEGA penetrations of diesel technology are small (<1% in MY 2025), EPA modeled the entire fleet as 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 a lower energy content . This topic is further discussed in TSD 4.

Table 4.3-21 Calendar Year Fuel Consumption Impacts

CY	Fuel Delta (Billion Gallons petroleum gasoline)	Fuel Delta (Billion Barrels petroleum gasoline)	Electricity Delta (Billion kwh)
2020	-2	-0.1	1
2030	-26	-0.6	26
2040	-40	-1.0	46
2050	-48	-1.1	55
Sum 2017-2050	-942	-22.4	1,023

Table 4.3-22 Model Year Fuel Consumption Impacts

MY	Fuel Delta (Billion Gallons petroleum gasoline)	Fuel Delta (Billion Barrels petroleum gasoline)	Electricity Delta (Billion kwh)
2017	-2	-0.1	2
2018	-6	-0.1	3
2019	-9	-0.2	5
2020	-12	-0.3	6
2021	-18	-0.4	8
2022	-23	-0.5	16
2023	-27	-0.6	23
2024	-32	-0.8	32
2025	-37	-0.9	40
Sum	-165	-3.9	135

4.3.6 GHG and Fuel Consumption Impacts from Alternatives

Table 4.3-23 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	-29	-297	-462	-547	-2.3	-25.6	-40.4	-47.9
A - Cars +20 g/mile	-20	-248	-396	-471	-1.4	-20.3	-33.0	-39.2
B - Cars -20 g/mile	-35	-335	-511	-604	-2.9	-30.8	-48.1	-56.9
C - Trucks +20 g/mile	-28	-275	-431	-510	-2.2	-23.0	-36.5	-43.3
D - Trucks -20 g/mile	-39	-322	-492	-582	-3.2	-28.6	-44.4	-52.7

Table 4.3-24 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	-1,967	-165	-3.9
A - Cars +20 g/mile	-1,567	-125	-3.0
B - Cars -20 g/mile	-2,283	-202	-4.8
C - Trucks +20 g/mile	-1,788	-146	-3.5
D - Trucks -20 g/mile	-2,254	-194	-4.6

4.4 Safety Analysis

As described in Preamble Section II.G and DRIA 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 DRIA Chapter 3.

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	135	137	142	149	155	160	166	172	178	1,395
	Light trucks	-160	-156	-153	-154	-156	-157	-158	-158	-159	-1,411
	Total	-24	-18	-12	-5	-1	3	8	14	19	-16
Control Case	Passenger cars	133	132	133	138	141	169	198	230	264	1,538
	Light trucks	-160	-157	-155	-156	-160	-192	-224	-257	-292	-1,754
	Total	-28	-25	-22	-19	-19	-24	-26	-27	-28	-217
Delta	Passenger cars	-3	-5	-8	-11	-14	8	32	58	86	143
	Light trucks	-1	-1	-2	-2	-4	-35	-67	-99	-133	-343
	Total	-3	-7	-10	-13	-18	-27	-34	-41	-47	-201

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.[SSS] 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.[TTT] 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 proposal means that a 10 percent decrease in fuel cost per mile is expected to result in a 1 percent increase in VMT.[UUU]

As described in TSD 4 and section 4.3.2 of this DRIA, we estimate the VMT impact from consumer responses to changes in fuel prices and fuel efficiency in both the control and reference cases against CY 2001 NHTS data.[VVV] Below, we use the same 1.1% per-vehicle VMT growth rates as in the primary case. As shown in Equation 3 – VMT growth, varying the rebound rate changes both the control and reference VMT schedules. Therefore, this sensitivity varies the total amount of both reference and control VMT.[WWW]

[SSS] 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.

[TTT] 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.

[UUU] 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.

[VVV] As discussed in above in 4.3.2.4, we assume consumers respond the same way to changes in fuel efficiency and fuel prices. Consistent with this assumption, we use the same elasticity to measure consumer responses to changes in fuel prices as we do to measure the rebound effect of consumers driving more in response to increased fuel efficiency.

[WWW] One important validation of the VMT equations used in this analysis is a strong resemblance to total historic VMT data, and future AEO projections. Changing the rebound rate without changing the growth rates may weaken that relationship, which is why they must be evaluated together when parameterizing the equation. Consequently, while this sensitivity analysis varies the rebound rate in isolation, were any of these rebound rates to be used for the primary analysis,EPA would also revisit the per-vehicle VMT growth rates.

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%	2,342	197	352	30
5%	2,155	181	325	28
10%	1,967	165	297	26
15%	1,780	149	270	23
20%	1,593	133	242	21

In the analysis, EPA applies the rebound rate to the change in the fuel cost of driving in future years relative to CY 2001 NHTS values for all MYs, all ages, and in both the reference and control cases. This allows the agency to directly tie the future VMT schedules back to known source data. A major benefit of this approach is the consistency, in that future values of the fuel cost per mile in both the reference and control cases are always compared back against the same reference point. However, it also means that the theoretical consumer is comparing back against 2001 driving costs, which may not be an accurate representation of the real-world process (i.e., in practice, consumers are more likely to be internalizing a change in the fuel cost of driving that they experienced recently, rather than 15-40 years ago).

An alternative approach considered by the agency is to calculate the rebound effect relative to the reference case. Thus, the reference case would be calculated relative to the 2001 data, and the control case would be calculated relative to the derived reference VMT schedules. Tying the rebound effect to a shifting reference point (the current year of the reference case) would make VMT increase proportional to the difference in the fuel cost per mile between the two cases, rather than the difference being proportional to the CY 2001 fuel cost per mile. However, this change implies that consumers are responding to the impact of changes in fuel cost per mile differently between the reference case and the control case than between the reference case and CY 2001. Hence the absolute change in VMT from a given rebound rate is different for the control case in this alternative approach.

The current application of the rebound effect in both the reference and control cases is demonstrated in Equation 2. The alternative approach for evaluating the rebound effect in the control case would be to use Equation 5 (below) after calculating the reference case with Equation 2. Following this alternative approach would also allow EPA to vary the rebound effect in the control case while holding the reference case VMT constant for sensitivity cases.

Equation 5 – Rebound Equation Relative to the Reference Case

$$VMT_{calendar\ year\ \ X\ ,age\ Y} = (VR\ x,y\ \ ) * \quad (1 - \ R * \frac{FCPM_{reference\ Case\ year\ x,y} - \ FCPM_{control\ Calendar\ year\ x,y}}{FCPM_{reference\ case\ year\ x,y}})$$

Where:
VR $_{x,y}$ = Average miles driven in a vehicle of age $_{y}$ in calendar year x in the reference case
R= Magnitude of the rebound effect, expressed as an elasticity (e.g., -0.10)
FCPM$_{x,y}$ = Fuel cost per mile of a vehicle of age *y* in calendar year *x*

EPA may consider alternative methods of implementing the rebound effect in the final rulemaking.

4.5.2 EV impacts

In section III.C.2 of the preamble, EPA presented an analysis of the GHG impacts of the EV zero gram/mile and EV/PHEV multiplier impacts on the cumulative GHG savings from the fleet. In this projection, EPA varied the number of electric and plug-in hybrid electric assumed in the future fleet.

This projection of the impact of the EV/PHEV/FCV incentives on the overall program GHG emissions reductions assumes that EPA would have proposed 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, it is clear that not allowing a 0 gram per mile compliance value would change the technology mix and cost projected for the proposed standard.

To conduct this analysis, EPA first ran the OMEGA model post-processor assuming that no vehicles operated on wall electricity. Thus, the 2 cycle standard was simply the CO2 targets adjusted for air conditioning and the pickup related credits (Table 4.3-8,

Table 4.3-9). 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 final scenario, involving 2 million EVs+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 ~1.495 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.

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+PHEVs in order to approximate the lesser reliance of EVs on electric power. [XXX]

In table 4.5-2, the number of metric tons represents the number of additional tons that would be reduced if the standards stayed the same and there was no 0 gram per mile compliance value. The percentage change represents the ratio of the cumulative decrease in GHG emissions reductions from the prior column to the total cumulative GHG emissions reductions associated with the proposed standards and the proposed 0 gram per mile compliance value.

If EPA proposed the exact same tailpipe standards, and provided no additional flexibilities, the program impacts would be estimated at 2,180 MMT if there were no electric vehicles or plug-in electric vehicles used for compliance.

4.5-2 – EV/PHEV Impacts

Scenario	Cumulative EV/PHEV/FCV Sales 2017-2025	Cumulative EV/PHEV/FCV Sales 2022-2025	Cumulative Decrease in GHG Emissions Reductions 2017-2025	Percentage Decrease in GHG Emissions Reductions 2017-2025
No EV/PHEVs	0	0	0 millon metric tons	0
EPA OMEGA model projection	1.9 million	1.3 million	80 million metric tons	3.6%
EPA alternative projection	2.8 million	2.0 million	110 million metric tons	5.4%

4.6 Calculation of Impacts from An Electric Vehicle

As one illustrative example, using the most recent national average electricity GHG emissions factors to calculate upstream fuel production and distribution GHG emissions, the Nissan Leaf would have an upstream GHG emissions value of 161 grams per mile. This is calculated as follows.

[XXX] While have PHEVs rather than EVs would also change the multiplier, this 2.0 million vehicle scenario is meant to approximate the impacts of a larger fleet of electric vehicles.

- The Leaf consumes 238 watt-hours of electricity per mile over the EPA city and highway tests. Note that the EPA electricity consumption values reported here and on the fuel economy label include both the electricity needed to propel the vehicle as well as vehicle charging losses, which are typically on the order of 10 percent. This EPA test value is divided by 0.7 to get the official label value for the 2011 Leaf of 340 watt-hours per mile, or 0.34 kilowatt-hours per mile.
- To reflect average electricity grid/transmission losses of about 7 percent, we divide the 238 watt-hours per mile by 0.93 to get 256 watt-hours per mile, which is the amount of electricity that would to be generated at the powerplant to power the Leaf for one mile.
- Multiplying the 256 watt-hours/mile value by a nationwide average electricity upstream GHG emissions rate (powerplant plus feedstock) of 0.628 grams GHG per watt-hour at the powerplant[YYY] to get 161 grams GHG per mile.

[YYY] The most recent nationwide average electricity upstream GHG rate of 0.628 grams GHG per watt-hour at the powerplant was calculated from 2007 nationwide powerplant data for CO2, CH4, and N2O emissions from eGRID2010 at http://www.epa.gov/cleanenergy/energy-resources/egrid/index.html, converting to CO2-e using Global Warming Potentials of 25 for CH4 and 298 for N2O, yielding a value of 0.592 grams GHG per watt-hour generated at the powerplant, and multiplying by a factor of 1.06 to account for GHG emissions associated with feedstock extraction, transportation, and processing (based on Argonne National Laboratory's The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) Model, Version 1.8c.0, available at http://www.transportation.anl.gov/modeling simulation/GREET/). EPA Docket EPA-HQ-OAR-2009-0472. Of course, EVs sold in various areas of the country would have different upstream GHG gram per mile values. For example, using an average California electricity upstream GHG rate of 0.349 grams GHG per watt-hour at the powerplant, from the same EPA eGRID 2010 database, would yield a Leaf upstream GHG emissions value of 89 grams per mile.

References

[35] Historically, manufacturers have reduced precious metal loading in catalysts in order to reduce costs. See http://www.platinum.matthey.com/media-room/our-view-on-.-.-./thrifting-of-precious-metals-in-autocatalysts/ Accessed 11/08/2011. Alternatively, manufacturers could also modify vehicle calibration.

[36] Intergovernmental Panel on Climate Change. Chapter 2. Changes in Atmospheric Constituents and in Radiative Forcing. September 2007. http://www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4-wg1-chapter2.pdf . Docket ID: EPA-HQ-OAR-2009-0472-0117

[37] Lu, S., NHTSA, Regulatory Analysis and Evaluation Division, "Vehicle Survivability and Travel Mileage Schedules," DOT HS 809 952, 8-11 (January 2006). *Available at* http://www-nrd.nhtsa.dot.gov/pdf/nrd-30/NCSA/Rpts/2006/809952.pdf (last accessed Sept. 9, 2011).

[38] EPA MOVES 2010a. August 2010. http://www.epa.gov/otaq/models/moves/index.htm

[39] Craig Harvey, EPA, "Calculation of Upstream Emissions for the GHG Vehicle Rule." 2009. Docket ID: EPA-HQ-OAR-2009-0472-0216

[40] Argonne National Laboratory. The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) Model versions 1.7 and 1.8. http://www.transportation.anl.gov/modeling_simulation/GREET/. Docket ID: EPA-HQ-OAR-2009-0472-0215

[41] OMEGA Benefits post-processor.

[42] Argonne National Laboratory's The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) Model, Version 1.8c.0, available at http://www.transportation.anl.gov/modeling_simulation/GREET/). EPA Docket EPA-HQ-OAR-2009-0472.

[43] EPA. eGrid 2010, http://www.epa.gov/cleanenergy/energy-resources/egrid/index.html

5 Vehicle Program Costs and Fuel Savings

In this chapter, EPA presents our estimate of the costs associated with the proposed vehicle program. The presentation here summarizes the vehicle level costs associated with the new technologies expected to be added to meet the proposed GHG standards, including hardware costs to comply with the proposed 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.

The presentation here summarizes the outputs of the OMEGA model that were discussed in some detail in Chapter 3 of this draft 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 draft RIA, and Chapter 3 of the draft Joint TSD.

5.1 Costs per Vehicle

To develop costs per vehicle, EPA has used the same methodology as that used in the recent 2012-2016 final rule and the 2010 TAR. 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 2012-2016 final rule. All of these individual technology costs are described in detail in Chapter 3 of the draft joint TSD. Also described there are the ICMs used in this proposal and the ways the ICMs have been updated and revised since the 2012-2016 final rule which results in considerably higher indirect costs in this proposal than estimated in the 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 2012-2016 final rule which applied learning to both direct and indirect costs. 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 proposal). Again, this is detailed in Chapter 3 of the draft joint TSD.

EPA then 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). 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 draft RIA. These packages are then used as inputs to the OMEGA model to estimate the most cost effective means of compliance with the proposed 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 5 years. Further, we do not expect manufacturers to redesign or refresh 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 draft 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 (2009$)

Company	2021MY			2025MY		
	Car	Truck	Combined	Car	Truck	Combined
Aston Martin	$6,400	$73	$6,400	$6,850	$59	$6,850
BMW	$905	$860	$893	$2,249	$1,942	$2,168
Chrysler/Fiat	$540	$808	$661	$1,905	$2,187	$2,027
Daimler	$1,928	$945	$1,683	$2,926	$1,942	$2,701
Ferrari	$6,323	$73	$6,323	$7,095	$59	$7,095
Ford	$631	$736	$667	$2,046	$2,443	$2,168
Geely-Volvo	$2,003	$1,038	$1,703	$3,220	$2,017	$2,864
GM	$489	$651	$569	$2,193	$1,803	$2,007
Honda	$451	$724	$536	$1,442	$1,912	$1,580
Hyundai	$602	$857	$654	$1,664	$1,960	$1,723
Kia	$448	$875	$543	$1,426	$1,645	$1,473
Lotus	$3,314	$73	$3,314	$3,708	$59	$3,708
Mazda	$882	$887	$883	$2,184	$1,797	$2,119
Mitsubishi	$778	$947	$837	$2,103	$2,145	$2,117
Nissan	$745	$632	$710	$1,988	$2,189	$2,048
Porsche	$5,436	$1,293	$4,460	$5,825	$2,038	$5,007
Spyker-Saab	$3,318	$865	$2,967	$4,000	$1,452	$3,667
Subaru	$998	$887	$971	$2,230	$2,067	$2,194
Suzuki	$1,139	$963	$1,108	$2,306	$1,816	$2,222
Tata-JLR	$2,194	$1,606	$1,901	$3,242	$2,625	$2,955
Tesla	$0	$0	$0	$0	$0	$0
Toyota	$314	$680	$457	$1,381	$1,598	$1,460
Volkswagen	$1,599	$755	$1,428	$2,618	$2,032	$2,503
Fleet	$697	$728	$708	$1,931	$1,928	$1,930

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 proposal, those target CO_2 levels were presented in Chapter 3 of this draft 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 by MY for Cars (g/mi)

Company	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Aston Martin	233	223	214	206	197	189	182	174	167	161
BMW	239	229	220	211	202	194	186	179	172	165
Chrysler/Fiat	243	230	221	212	204	195	187	179	172	165
Daimler	248	239	230	220	211	203	194	187	179	172
Ferrari	245	235	226	217	208	200	191	184	176	169
Ford	239	231	221	212	204	196	188	180	173	166
Geely-Volvo	243	232	223	214	205	197	189	182	174	167
GM	241	230	220	211	203	195	187	179	172	165
Honda	232	223	214	205	197	189	181	174	167	160
Hyundai	233	224	215	206	198	190	182	175	168	161
Kia	235	226	216	208	199	191	183	176	169	162
Lotus	216	208	199	191	183	176	169	162	156	149
Mazda	232	223	214	206	197	190	182	175	168	161
Mitsubishi	230	220	211	203	194	187	179	172	165	158
Nissan	236	227	218	209	201	193	185	178	171	164
Prosche	216	208	199	191	183	176	169	162	156	149
Spyker-Saab	232	223	214	205	197	189	181	174	167	160
Subaru	226	217	208	200	192	184	176	169	163	156
Suzuki	218	209	201	193	185	177	170	163	157	150
Tata-JLR	260	250	240	230	221	212	203	195	187	180
Tesla	216	208	199	191	183	176	169	162	156	149
Toyota	231	222	213	204	196	188	181	173	166	160
Volkswagen	229	220	211	202	194	186	179	171	165	158
Fleet	235	226	217	208	200	192	184	176	169	162

Table 5.1-3 Target CO_2 Levels 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
BMW	294	295	289	284	278	261	249	238	228	218
Chrysler/Fiat	307	305	301	296	289	271	259	247	236	226
Daimler	306	311	306	301	295	277	265	254	243	232
Ferrari	0	0	0	0	0	0	0	0	0	0
Ford	318	317	313	309	305	287	274	261	249	237
Geely-Volvo	292	290	284	279	272	255	244	233	223	213
GM	324	321	316	311	306	286	273	261	249	238
Honda	292	292	286	282	275	258	246	236	225	215
Hyundai	290	289	283	278	272	255	244	233	223	213
Kia	301	301	297	292	285	267	255	244	233	223
Lotus	0	0	0	0	0	0	0	0	0	0
Mazda	282	284	277	272	266	251	240	230	220	210
Mitsubishi	281	278	271	267	261	244	233	223	213	204
Nissan	306	305	300	295	288	272	260	248	237	226
Prosche	298	298	292	287	280	262	251	240	229	219
Spyker-Saab	291	290	283	278	272	255	243	233	222	213
Subaru	278	275	268	264	257	241	231	220	211	201
Suzuki	283	281	274	269	263	247	236	225	215	206
Tata-JLR	284	282	275	270	264	247	236	226	216	206
Tesla	0	0	0	0	0	0	0	0	0	0
Toyota	306	304	298	293	288	270	258	247	235	225
Volkswagen	304	307	301	296	290	272	260	249	238	227
Fleet	309	307	302	298	292	274	262	250	238	228

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 draft 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 draft 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 while the latter scalar was used for the interpolations between 2021 and 2025. 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 draft 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 draft 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 (2009$)

Company	2017	2018	2019	2020	2021	2022	2023	2024	2025
Aston Martin	$66	$57	$48	$39	$29	$26	$23	$20	$17
BMW	$28	$32	$36	$40	$45	$35	$26	$16	$7
Chrysler/Fiat	$50	$46	$42	$38	$35	$30	$25	$20	$15
Daimler	$25	$25	$26	$26	$27	$23	$18	$14	$10
Ferrari	$12	$17	$23	$28	$34	$30	$27	$23	$19
Ford	$12	$17	$21	$25	$29	$25	$20	$15	$10
Geely-Volvo	$19	$24	$29	$33	$38	$32	$25	$19	$13
GM	$13	$14	$16	$17	$18	$19	$20	$20	$21
Honda	$6	$10	$14	$17	$21	$20	$18	$17	$15
Hyundai	$3	$7	$10	$14	$17	$17	$18	$18	$18
Kia	$8	$16	$25	$33	$41	$36	$31	$26	$21
Lotus	$35	$30	$26	$21	$16	$12	$9	$6	$2
Mazda	$14	$22	$30	$39	$47	$40	$33	$25	$18
Mitsubishi	$8	$16	$24	$32	$40	$34	$28	$22	$16
Nissan	$9	$12	$14	$17	$19	$18	$16	$15	$14
Prosche	$25	$25	$25	$25	$24	$20	$16	$11	$7
Spyker-Saab	$40	$36	$31	$27	$22	$18	$14	$10	$6
Subaru	$7	$12	$16	$20	$25	$21	$18	$14	$10
Suzuki	$21	$22	$24	$25	$27	$22	$16	$11	$6
Tata-JLR	$21	$24	$26	$29	$32	$29	$25	$22	$19
Tesla	$0	$0	$0	$0	$0	$0	$0	$0	$0
Toyota	$5	$10	$14	$19	$23	$23	$23	$23	$23
Volkswagen	$19	$22	$25	$28	$31	$25	$18	$12	$6
Fleet	$12	$16	$19	$22	$26	$23	$21	$18	$16

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 (2009$)

Company	2017	2018	2019	2020	2021	2022	2023	2024	2025
Aston Martin	$1,708	$3,157	$4,245	$5,341	$6,424	$7,353	$7,383	$7,409	$6,862
BMW	$263	$470	$631	$787	$945	$1,442	$1,794	$2,125	$2,251
Chrysler/Fiat	$215	$326	$411	$482	$569	$1,047	$1,401	$1,758	$1,914
Daimler	$476	$914	$1,254	$1,604	$1,949	$2,482	$2,730	$2,950	$2,931
Ferrari	$1,634	$3,080	$4,170	$5,267	$6,351	$7,367	$7,487	$7,598	$7,109
Ford	$168	$318	$436	$542	$655	$1,147	$1,525	$1,885	$2,051
Geely-Volvo	$553	$1,007	$1,351	$1,691	$2,035	$2,633	$2,938	$3,226	$3,228
GM	$152	$259	$343	$419	$502	$1,066	$1,527	$1,975	$2,209
Honda	$126	$228	$312	$387	$467	$808	$1,072	$1,329	$1,452
Hyundai	$155	$293	$404	$507	$614	$999	$1,283	$1,555	$1,677
Kia	$123	$230	$318	$399	$483	$818	$1,076	$1,324	$1,442
Lotus	$887	$1,635	$2,200	$2,764	$3,324	$3,847	$3,905	$3,960	$3,705
Mazda	$232	$441	$609	$765	$924	$1,399	$1,738	$2,068	$2,196
Mitsubishi	$217	$397	$539	$674	$813	$1,292	$1,642	$1,975	$2,114
Nissan	$193	$366	$502	$629	$759	$1,212	$1,543	$1,861	$1,997
Prosche	$1,420	$2,657	$3,590	$4,527	$5,455	$6,243	$6,268	$6,291	$5,827
Spyker-Saab	$893	$1,643	$2,209	$2,774	$3,335	$3,944	$4,082	$4,211	$4,001
Subaru	$269	$496	$674	$844	$1,017	$1,497	$1,820	$2,129	$2,236
Suzuki	$314	$572	$772	$965	$1,160	$1,639	$1,943	$2,228	$2,307
Tata-JLR	$586	$1,086	$1,466	$1,844	$2,220	$2,798	$3,055	$3,297	$3,255
Tesla	$0	$0	$0	$0	$0	$0	$0	$0	$0
Toyota	$89	$161	$222	$275	$332	$682	$972	$1,250	$1,399
Volkswagen	$427	$790	$1,070	$1,348	$1,624	$2,116	$2,371	$2,608	$2,618
Fleet	$194	$353	$479	$595	$718	$1,165	$1,492	$1,806	$1,942

Table 5.1-7 Control Case Costs by Manufacturer by MY including AC & Stranded Capital Costs -- Trucks (2009$)

Company	2017	2018	2019	2020	2021	2022	2023	2024	2025
Aston Martin	$0	$0	$0	$0	$0	$0	$0	$0	$0
BMW	-$148	$91	$253	$443	$915	$1,331	$1,610	$1,873	$1,959
Chrysler/Fiat	$43	$194	$313	$465	$853	$1,352	$1,724	$2,070	$2,212
Daimler	-$284	-$62	$150	$370	$956	$1,364	$1,629	$1,877	$1,952
Ferrari	$0	$0	$0	$0	$0	$0	$0	$0	$0
Ford	$106	$243	$339	$422	$776	$1,345	$1,814	$2,269	$2,463
Geely-Volvo	-$117	$168	$347	$557	$1,086	$1,497	$1,749	$1,984	$2,040
GM	$123	$235	$321	$401	$680	$1,096	$1,414	$1,712	$1,834
Honda	-$104	$78	$213	$371	$756	$1,194	$1,509	$1,816	$1,937
Hyundai	-$132	$93	$248	$433	$884	$1,316	$1,608	$1,890	$1,988
Kia	-$93	$86	$249	$453	$927	$1,254	$1,449	$1,636	$1,675
Lotus	$0	$0	$0	$0	$0	$0	$0	$0	$0
Mazda	-$317	-$4	$185	$378	$897	$1,262	$1,496	$1,734	$1,806
Mitsubishi	-$144	$130	$298	$501	$998	$1,464	$1,776	$2,072	$2,171
Nissan	$58	$194	$294	$400	$662	$1,184	$1,616	$2,026	$2,212
Prosche	-$142	$196	$409	$667	$1,328	$1,702	$1,886	$2,059	$2,054
Spyker-Saab	-$71	$163	$305	$471	$898	$1,171	$1,318	$1,456	$1,468
Subaru	-$112	$137	$292	$472	$922	$1,377	$1,689	$1,982	$2,087
Suzuki	-$104	$159	$323	$515	$1,000	$1,364	$1,583	$1,788	$1,832
Tata-JLR	-$233	$197	$472	$817	$1,648	$2,144	$2,403	$2,646	$2,653
Tesla	$0	$0	$0	$0	$0	$0	$0	$0	$0
Toyota	$42	$194	$301	$400	$713	$1,062	$1,312	$1,547	$1,631
Volkswagen	-$121	$70	$224	$384	$797	$1,254	$1,589	$1,914	$2,048
Fleet	$55	$198	$305	$417	$764	$1,200	$1,525	$1,834	$1,954

Table 5.1-8 Control Case Costs by Manufacturer by MY including AC & Stranded Capital Costs – Combined Fleet (2009$)

Company	2017	2018	2019	2020	2021	2022	2023	2024	2025
Aston Martin	$1,708	$3,157	$4,245	$5,341	$6,424	$7,353	$7,383	$7,409	$6,862
BMW	$154	$370	$531	$696	$937	$1,413	$1,746	$2,058	$2,174
Chrysler/Fiat	$137	$266	$367	$475	$698	$1,179	$1,541	$1,893	$2,043
Daimler	$287	$671	$980	$1,297	$1,702	$2,226	$2,478	$2,704	$2,707
Ferrari	$1,634	$3,080	$4,170	$5,267	$6,351	$7,367	$7,487	$7,598	$7,109
Ford	$147	$293	$403	$501	$696	$1,208	$1,614	$2,003	$2,178
Geely-Volvo	$345	$746	$1,039	$1,339	$1,741	$2,297	$2,585	$2,858	$2,876
GM	$138	$247	$332	$410	$590	$1,080	$1,473	$1,850	$2,030
Honda	$55	$182	$281	$382	$556	$922	$1,201	$1,472	$1,595
Hyundai	$97	$253	$372	$492	$669	$1,062	$1,347	$1,622	$1,739
Kia	$75	$198	$303	$411	$582	$910	$1,155	$1,391	$1,491
Lotus	$887	$1,635	$2,200	$2,764	$3,324	$3,847	$3,905	$3,960	$3,705
Mazda	$134	$362	$534	$696	$919	$1,377	$1,697	$2,012	$2,131
Mitsubishi	$91	$304	$455	$614	$877	$1,349	$1,687	$2,007	$2,133
Nissan	$151	$312	$437	$558	$729	$1,204	$1,565	$1,910	$2,060
Prosche	$1,052	$2,077	$2,840	$3,618	$4,482	$5,262	$5,321	$5,377	$5,012
Spyker-Saab	$755	$1,431	$1,936	$2,444	$2,986	$3,582	$3,721	$3,851	$3,670
Subaru	$178	$410	$582	$755	$994	$1,470	$1,790	$2,096	$2,202
Suzuki	$239	$498	$692	$885	$1,132	$1,592	$1,881	$2,153	$2,225
Tata-JLR	$178	$644	$972	$1,333	$1,935	$2,494	$2,752	$2,994	$2,976
Tesla	$0	$0	$0	$0	$0	$0	$0	$0	$0
Toyota	$71	$174	$253	$324	$481	$820	$1,096	$1,358	$1,483
Volkswagen	$316	$644	$898	$1,153	$1,457	$1,947	$2,218	$2,472	$2,506
Fleet	$146	$299	$418	$533	$734	$1,176	$1,503	$1,815	$1,946

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 Proposed Standards (2009$)

Model Year	2017	2018	2019	2020	2021	2022	2023	2024	2025	2030	2040	2050
$/car	$194	$353	$479	$595	$718	$1,165	$1,492	$1,806	$1,942	$1,926	$1,926	$1,926
$/truck	$55	$198	$305	$417	$764	$1,200	$1,525	$1,834	$1,954	$1,938	$1,938	$1,938
Combined	$146	$299	$418	$533	$734	$1,176	$1,503	$1,815	$1,946	$1,930	$1,929	$1,929

5.2 Annual Costs of the Proposed National Program

The costs presented here represent the costs for newly added technology to comply with the proposed 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 5.1-9 above result in the total annual 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. Note also that the costs presented here represent costs estimated to occur presuming that the proposed MY 2025 standard would continue in perpetuity. Any changes to the proposed standards would be considered as part of a future rulemaking. In other words, the proposed 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 Costs & Costs of the Program Discounted back to 2012 at 3% and 7% Discount Rates (2009 dollars)

Calendar Year	Sales		$/unit		$Million/year		
	Cars	Trucks	$/car	$/truck	Cars	Trucks	Combined
2017	9,987,667	5,818,655	$194	$55	$1,940	$322	$2,300
2018	9,905,364	5,671,046	$353	$198	$3,500	$1,130	$4,660
2019	9,995,696	5,582,962	$479	$305	$4,780	$1,700	$6,510
2020	10,291,562	5,604,377	$595	$417	$6,120	$2,340	$8,470
2021	10,505,165	5,683,902	$718	$764	$7,540	$4,340	$11,900
2022	10,735,777	5,703,996	$1,165	$1,200	$12,500	$6,840	$19,300
2023	10,968,003	5,687,486	$1,492	$1,525	$16,400	$8,680	$25,000
2024	11,258,138	5,675,949	$1,806	$1,834	$20,300	$10,400	$30,700
2025	11,541,560	5,708,899	$1,942	$1,954	$22,400	$11,200	$33,600
2030	12,535,870	5,986,092	$1,926	$1,938	$24,100	$11,600	$35,700
2040	14,097,092	6,505,226	$1,926	$1,938	$27,100	$12,600	$39,800
2050	15,822,370	7,301,371	$1,926	$1,938	$30,500	$14,100	$44,600
NPV, 3%					$373,000	$177,000	$551,000
NPV, 7%					$165,000	$78,300	$243,000

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 draft Joint TSD.

5.3 Cost per Ton of Emissions Reduced

EPA has calculated the cost per ton of GHG reductions associated with the proposed GHG standards on a CO_2eq basis using the costs and the emissions reductions described in Section III.F. 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). 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 (2009 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	$6,120	$4,840	19	$318	$67
	2030	$24,100	$54,300	183	$132	-$165
	2040	$27,100	$91,200	284	$95	-$226
	2050	$30,500	$117,000	332	$92	-$260
Trucks	2020	$2,340	$2,340	10	$245	$0
	2030	$11,600	$34,000	114	$102	-$196
	2040	$12,600	$57,500	178	$71	-$252
	2050	$14,100	$76,000	215	$66	-$288
Combined	2020	$8,470	$7,180	29	$294	$45
	2030	$35,700	$88,300	297	$120	-$177
	2040	$39,800	$149,000	462	$86	-$236
	2050	$44,600	$193,000	547	$81	-$271

5.4 Reduction in Fuel Consumption and its Impacts

5.4.1 What Are the Projected Changes in Fuel Consumption?

The proposed 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 proposed GHG standards, electricity consumption would increase slightly due to the small penetration of EVs and PHEVs (1-3% for the 2021 and 2025 MYs). 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 of the draft 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 proposed CO_2 standards, including the A/C credit program, and include increased consumption resulting from the rebound effect.

Table 5.4-1 Fuel Consumption Impacts of the Proposed Standards and A/C Credit Programs

Calendar Year	Petroleum-based Gasoline Reference (million gallons)	Petroleum-based Gasoline Reduced (million gallons)	Electricity Increased (million kWh)[a]
2017	130,544	194	115
2018	129,503	641	345
2019	128,680	1,326	695
2020	128,229	2,277	1,177
2021	128,387	3,673	1,796
2022	128,599	5,424	2,952
2023	129,312	7,520	4,673
2024	130,087	9,919	6,980
2025	131,289	12,658	9,911
2030	140,602	25,581	24,298
2040	159,582	40,391	42,369
2050	184,136	47,883	51,123
Total	5,079,096	941,839	951,392

[a] Electricity increase by vehicles not by power plants.

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 proposed 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 2011 Final Release.[ZZZ] AEO is a standard reference used by NHTSA and EPA and many other government agencies to estimate the projected price of fuel. The agencies also used the AEO's fuel price estimate 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.[AAAA] In addition, since future fuel prices are not known with certainty, there could be a distribution of possible fuel price outcomes, as opposed to a

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[ZZZ] In the Preface to AEO 2011, the Energy Information Administration describes the reference case used in AEO 2011. They state that, "Projections by EIA are not statements of what will happen but of what might happen, given the assumptions and methodologies used for any particular scenario. The Reference case projection is a business-as-usual trend estimate, given known technology and technological and demographic trends.

[AAAA] 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 DRIA). 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.

set of known higher price- and a set of known lower price-pathways. For the final rule, EPA may to do a sensitivity analysis on future fuel prices.

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 $82 million in 2017 and $17 billion by 2050. These results are shown in Table 5.4-1. Note that in Chapter 7 of this DRIA, the overall benefits and costs of the proposal are presented and, for that reason, only the pre-tax fuel savings are presented there.

Table 5.4-1 Undiscounted Annual Fuel Savings & Fuel Savings Discounted back to 2012 at 3% and 7% Discount Rates (millions of 2009 dollars)

Calendar Year	Gasoline Savings (pre-tax)	Gasoline Savings (taxed)	Electricity Costs	Total Fuel Savings (pre-tax)	Total Fuel Savings (taxed)
2017	$581	$663	$11.1	$570	$652
2018	$1,950	$2,230	$32.8	$1,920	$2,200
2019	$4,120	$4,670	$66.0	$4,060	$4,600
2020	$7,180	$8,110	$113	$7,060	$7,990
2021	$11,600	$13,100	$172	$11,400	$12,900
2022	$17,400	$19,700	$286	$17,100	$19,400
2023	$24,400	$27,500	$458	$24,000	$27,000
2024	$32,700	$36,800	$691	$32,000	$36,100
2025	$42,400	$47,200	$1,000	$41,400	$46,200
2030	$88,300	$98,100	$2,550	$85,800	$95,600
2040	$149,000	$164,000	$4,850	$144,000	$159,000
2050	$193,000	$210,000	$6,350	$187,000	$204,000
NPV, 3%	$1,550,000	$1,720,000	$47,800	$1,510,000	$1,670,000
NPV, 7%	$596,000	$660,000	$17,800	$579,000	$642,000

Annual values represent undiscounted values; net present values represent annual costs discounted to 2012.

As shown in Table 5.4-1, the agencies are projecting that consumers would realize very large fuel savings as a result of the proposed standards. These calculations are based on the assumption, discussed in Preamble Section III.D., that the fuel economy of vehicles would be constant at MY 2016 levels in the absence of the rule. As discussed further in Chapter 8.1.2.6 of this DRIA, 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. Regardless 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 provide actual money in consumers' pockets.

5.5 Consumer Payback Period and Lifetime Savings on New Vehicle Purchases

Another factor of interest is the payback period that consumers would experience on the purchase of a new vehicle that meets the proposed standards. In other words, how long would it take for the expected fuel savings to outweigh the increased cost of a new vehicle? For example, a new 2025 MY vehicle is estimated to cost $1,946 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 upfront costs?

Table 5.5-1 provides the answer to this question for a vehicle purchaser who pays for the new vehicle upfront in cash (we discuss later in this section the payback period for consumers who finance the new vehicle purchase with a loan). 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 draft Joint TSD. The control case includes fuel savings associated with A/C controls. Not included here are the possible A/C-related maintenance savings as discussed in Chapter 5 of the draft joint TSD. 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. To estimate the upfront vehicle cost (i.e., the lifetime increased cost discounted back to purchase), 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.[44] Car/truck fleet weighting is handled as described in Chapter 1 of the draft Joint TSD. The present value of the increased vehicle costs shown in the table are $2,189 at a 3% discount rate and $2,180 at a 7% discount rate. As can be seen in the table, it will take just over 3.5 years at a 3% discount rate, and just under 4 years at a 7% discount rate, for the cumulative discounted fuel savings to exceed the present value of increased vehicle costs.

Table 5.5-1 Payback Period on a 2025 MY New Vehicle Purchase via Cash (2009 dollars)

Year of Ownership	Increased Vehicle Cost[a] (undiscounted)	Annual Fuel Savings[b] (undiscounted)	Cumulative Discounted Fuel Savings at 3%	Cumulative Discounted Fuel Savings at 7%
1	-$2,087	$643	$634	$622
2	-$31	$634	$1,240	$1,195
3	-$26	$630	$1,826	$1,728
4	-$21	$614	$2,379	$2,213
5	-$16	$601	$2,906	$2,656
6	-$11	$572	$3,392	$3,051
7	-$6	$543	$3,840	$3,401
8	-$1	$512	$4,250	$3,709

[a] Increased vehicle cost due to the rule is $1,946; the value here includes nationwide average sales tax of 5.32% and increased insurance premiums of 1.85% in year one decreasing to 0% by year 9. Both of these percentages are discussed in Section 8.1.1 of this DRIA. This results in a present value of increased costs of $2,189 at 3% discounting and $2,180 at 7% discounting. These present value costs are used in

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determining the payback period.

[b] Calculated using AEO 2011 reference case fuel prices including taxes.

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 of July, 2011, the national average interest rate for a 5 year new car loan was 5.52 percent.[45] If the increased vehicle cost is spread out over 5 years at 5.52 percent, the analysis would look like that shown in Table 5.5-2. As can be seen in this table, the fuel savings immediately outweigh the increased payments on the car loan, amounting to $145 in discounted net savings (3% discount rate) in the first year and similar savings for the next four years although savings decline somewhat due to reduced VMT as the average vehicle ages. Results are similar using a 7% discount rate. This means that for every month that the average owner is making a payment for the financing of the average new vehicle their monthly fuel savings would be greater than the increase in the loan payments. This amounts to a savings on the order of $12 per month throughout the duration of the 5 year loan. Note that in year six when the car loan is paid off, the net savings equal the fuel savings less the increased insurance premiums (as would be the case for the remaining years of ownership).

Table 5.5-2 Payback Period on a 2025 MY New Vehicle Purchase via Credit (2009 dollars)

Year of Ownership	Increased Vehicle Cost[a] (undiscounted)	Annual Fuel Savings[b] (undiscounted)	Annual Discounted Net Savings at 3%[c]	Annual Discounted Net Savings at 7%[c]
1	-$489	$643	$145	$133
2	-$488	$634	$133	$117
3	-$487	$630	$127	$107
4	-$485	$614	$109	$88
5	-$484	$601	$96	$74
6	-$11	$572	$477	$387
7	-$6	$543	$443	$346
8	-$1	$512	$409	$308

[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 5.52 percent.

[b] Calculated using AEO 2011 reference case fuel prices including taxes.

[c] Note that the cumulative discounted fuel savings are identical to those shown in Table 5.5-1. Here we show discounted net savings.

The lifetime fuel savings and net savings can also be calculated for those who purchase the vehicle using cash and for those who purchase the vehicle with credit. This calculation applies to the vehicle owner who retains the vehicle for its entire life and drives the vehicle each year at the rate equal to the national projected average. The results are shown in Table 5.5-3. In either case, the present value of the lifetime net savings is greater than $4,200 at a 3% discount rate, or $2,900 at a 7% discount rate.

Table 5.5-3 Lifetime Discounted Net Savings on a 2025 MY New Vehicle Purchase (2009 dollars)

Purchase Option	Increased Discounted Vehicle Cost	Lifetime Discounted Fuel Savings [b]	Lifetime Discounted Net Savings
3% discount rate			
Cash	$2,189	$6,568	$4,378
Credit [a]	$2,310	$6,568	$4,258
7% discount rate			
Cash	$2,180	$5,154	$2,972
Credit [a]	$2,147	$5,154	$3,004

[a] Assumes a 5 year loan at 5.52 percent.

[b] Fuel savings here were calculated using AEO 2011 reference case fuel prices including taxes.

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.

References

[44] U.S. Department of Energy, 2011. "Transportation and the Economy," Chapter 10 in "Transportation Energy Data Book," http://cta.ornl.gov/data/tedb30/Edition30_Chapter10.pdf, accessed 8/22/11, Table 14..

[45] "National Auto Loan Rates for July 21, 2011," http://www.bankrate.com/finance/auto/national-auto-loan-rates-for-july-21-2011.aspx, accessed 7/26/11.

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 will 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 generic term for a broad class of chemically and physically diverse substances. It can be principally characterized as discrete particles that exist in the condensed (liquid or solid) phase spanning several orders of magnitude in size. Since 1987, EPA has delineated that subset of inhalable particles small enough to penetrate to the thoracic region (including the tracheobronchial and alveolar regions) of the respiratory tract (referred to as thoracic particles).[BBBB] Current National Ambient Air Quality Standards (NAAQS) use $PM_{2.5}$ as the indicator for fine particles (with $PM_{2.5}$ generally referring to particles with a nominal mean aerodynamic diameter less than or equal to 2.5 micrometers (µm)), and use PM_{10} as the indicator for purposes of regulating the coarse fraction of PM_{10} (referred to as thoracic coarse particles or coarse-fraction particles; generally including particles with a nominal mean aerodynamic diameter greater than 2.5 µm and less than or equal to 10 µm, or $PM_{10-2.5}$). Ultrafine particles (UFPs) are a subset of fine particles, generally less than 100 nanometers (0.1 µm) in diameter.

Particles span many sizes and shapes and consist of numerous different components. Particles originate 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. In addition, there are also physical, non-chemical reaction mechanisms that contribute to 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 a particle’s ability to shift between solid/liquid and gaseous phases, which is influenced by concentration, meteorology, and 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.[46]

[BBBB] 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.[CCCC] 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).[DDDD]

The ISA concludes that ambient concentrations of PM are associated with a number of adverse health effects.[EEEE] 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 $PM_{2.5}$.[47] 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.[48] 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.

[CCCC] 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.

[DDDD] The ISA is available at http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=216546

[EEEE] 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.

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 $PM_{2.5}$.[49] The ISA concludes that available evidence is suggestive of a causal relationship between short-term exposures to $PM_{10-2.5}$ and cardiovascular 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 $PM_{10-2.5}$.[50]

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).[51]

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.[52]

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.[FFFF] These health effects are well documented and are critically assessed in the EPA ozone air quality criteria document (ozone AQCD) and EPA staff paper.[53,54] 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.[55] 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.

[FFFF] 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.

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.[56, 57, 58, 59, 60, 61] Repeated exposure to ozone can increase susceptibility to respiratory infection and lung inflammation and can aggravate preexisting respiratory diseases, such as asthma.[62, 63, 64, 65, 66] Repeated exposure to sufficient concentrations of ozone can also cause inflammation of the lung, 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.[67, 68, 69, 70]

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.[71] For example, summer camp studies have reported statistically significant reductions in lung function in children who are active outdoors.[72, 73, 74, 75, 76, 77, 78, 79] 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.[80, 81, 82, 83]

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.[84] 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 ≥ 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 (≥ 65 years), and for asthma. A limited subset of epidemiologic studies have 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.[85] 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. 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.[86] The ISA concludes that ambient concentrations of CO are associated with a number of adverse health effects.[GGGG] This section provides a summary of the health effects associated with exposure to ambient concentrations of CO.[HHHH]

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

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[GGGG] 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.

[HHHH] 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.

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.

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.[87] 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.[IIII]

Noncancer health effects can result from chronic,[JJJJ] subchronic,[KKKK] or acute[LLLL] 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.[88]

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.[89] 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.[90,91,92] 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.[93,94]

[IIII] 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.

[JJJJ] 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).

[KKKK] Defined in the IRIS database as exposure to a substance spanning approximately 10% of the lifetime of an organism.

[LLLL] Defined in the IRIS database as exposure by the oral, dermal, or inhalation route for 24 hours or less.

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.[95,96] The most sensitive noncancer effect observed in humans, based on current data, is the depression of the absolute lymphocyte count in blood.[97,98] 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.[99,100,101,102] EPA's IRIS program has not yet evaluated these new data.

6.1.1.9.2 1,3-Butadiene

EPA has characterized 1,3-butadiene as carcinogenic to humans by inhalation.[103,104] 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.[105,106,107] 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.[108]

6.1.1.9.3 Formaldehyde

Since 1987, EPA has classified formaldehyde as a probable human carcinogen based on evidence in humans and in rats, mice, hamsters, and monkeys.[109] Substantial additional research since that time informs current scientific understanding of the health effects associated with exposure to formaldehyde. These include recently published research conducted by the National Cancer Institute (NCI) which found an increased risk of nasopharyngeal cancer and lymphohematopoietic malignancies such as leukemia among workers exposed to formaldehyde.[110,111] In an analysis of the lymphohematopoietic cancer mortality from an extended follow-up of these workers, NCI confirmed an association between lymphohematopoietic cancer risk and peak formaldehyde exposures.[112] A recent NIOSH study of garment workers also found increased risk of death due to leukemia among workers exposed to formaldehyde.[113] Extended follow-up of a cohort of British chemical workers did not find evidence of an increase in nasopharyngeal or lymphohematopoietic cancers, but a continuing statistically significant excess in lung cancers was reported.[114]

In the past 15 years there has been substantial research on the inhalation dosimetry for formaldehyde in rodents and primates by the Chemical Industry Institute of Toxicology (CIIT, now renamed the Hamner Institutes for Health Sciences), with a focus on use of rodent data for refinement of the quantitative cancer dose-response assessment.[115,116,117] CIIT's risk assessment of formaldehyde incorporated mechanistic and dosimetric information on formaldehyde. These data were modeled using a biologically-motivated two-stage clonal growth model for cancer and also a point of departure based on a Benchmark Dose approach. However, it should be noted that recent research published by EPA indicates that when two-stage modeling assumptions are varied, resulting dose-response estimates can vary by several orders of magnitude.[118,119,120,121] These findings are not supportive of interpreting the CIIT model results as providing a conservative (health protective) estimate of human risk.[122] EPA research also examined the contribution of the two-stage modeling for formaldehyde towards characterizing the relative weights of key events in the mode-of-action of a carcinogen. For example, the model-based inference in the published CIIT study that formaldehyde's direct mutagenic action is not relevant to the compound's tumorigenicity was found not to hold under variations of modeling assumptions.[123]

Based on the developments of the last decade, in 2004, the working group of the IARC concluded that formaldehyde is carcinogenic to humans (Group 1), on the basis of sufficient evidence in humans and sufficient evidence in experimental animals - a higher classification than previous IARC evaluations. After reviewing the currently available epidemiological evidence, the IARC (2006) characterized the human evidence for formaldehyde carcinogenicity as "sufficient," based upon the data on nasopharyngeal cancers; the epidemiologic evidence on leukemia was characterized as "strong."[124]

Formaldehyde exposure also causes a range of noncancer health effects, including irritation of the eyes (burning and watering of the eyes), nose and throat. Effects from repeated exposure in humans include respiratory tract irritation, chronic bronchitis and nasal epithelial lesions such as metaplasia and loss of cilia. Animal studies suggest that formaldehyde may also cause airway inflammation – including eosinophil infiltration into the airways. There are several studies that suggest that formaldehyde may increase the risk of asthma – particularly in the young.[125,126]

The above-mentioned rodent and human studies, as well as mechanistic information and their analyses, were evaluated in EPA's recent Draft Toxicological Review of Formaldehyde – Inhalation Assessment through the Integrated Risk Information System (IRIS) program. This draft IRIS assessment was released in June 2010 for public review and comment and external peer review by the National Research Council (NRC). The NRC released their review report in April 2011 (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.[127] 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.[128,129] 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.[130] In short-term (4 week) rat studies, degeneration of olfactory epithelium was observed at various concentration levels of acetaldehyde exposure.[131,132] 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.[133] 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.[134] 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.[135] 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.[136] Lesions to the lungs and upper respiratory tract of rats, rabbits, and hamsters have been observed after subchronic exposure to acrolein.[137] Acute exposure effects in animal studies report bronchial hyperresponsiveness.[138] 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.[139] 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.[140] The IARC determined in 1995 that acrolein was not classifiable as to its carcinogenicity in humans.[141]

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.[MMMM142] Animal studies have reported respiratory tract tumors from inhalation exposure to benzo[a]pyrene and

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[MMMM] Agency for Toxic Substances and Disease Registry (ATSDR). 1995. Toxicological profile for Polycyclic Aromatic Hydrocarbons (PAHs)· Atlanta, GA: U.S. Department of Health and Human Services, Public Health Service. Available electronically at http://www.atsdr.cdc.gov/ToxProfiles/TP.asp?id=122&tid=25.

alimentary tract and liver tumors from oral exposure to benzo[a]pyrene. 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.[143] 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).[144,145] EPA has not yet evaluated these studies.

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. EPA released an external review draft of a reassessment of the inhalation carcinogenicity of naphthalene based on a number of recent animal carcinogenicity studies.[146] The draft reassessment completed external peer review.[147] Based on external peer review comments received, additional analyses are being undertaken. This 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.[148] 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.[149] Naphthalene also causes a number of chronic non-cancer effects in animals, including abnormal cell changes and growth in respiratory and nasal tissues.[150]

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 this proposal. 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.[NNNN]

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

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[NNNN] U.S. EPA Integrated Risk Information System (IRIS) database is available at: www.epa.gov/iris 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.[151] 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.[152] 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.[153] 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.[154]

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 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.[155]

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.[156]

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.[157] 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.[158,159,160]

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.[161] 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.[162,163,164] 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.[161]

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

Airborne particles degrade visibility by scattering and absorbing light. Good visibility increases the quality of life where individuals live and work, and where they engage in recreational activities.

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.

* Rainbow Lake, WI and Bradwell Bay, FL are Class 1 Areas where visibility is not an important air quality related value

Produced by NPS Air Resources Division

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.[165]

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.[166] 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.”[167] Like carbon dioxide (CO_2) and other gaseous substances, ozone enters plant tissues primarily through apertures (stomata) in leaves in a process called “uptake.”[168] 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.[169,170] 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,[171] 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.[172,173]

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)[174,175,176] 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.[177]

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.[178]

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.[179,180] 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.[181,182]

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.[183] 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.[184,185,186] 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.[187] 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.[188] 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."[189] In addition, economic studies have shown reduced economic benefits as a result of predicted reductions in crop yields associated with observed ozone levels.[190,191,192]

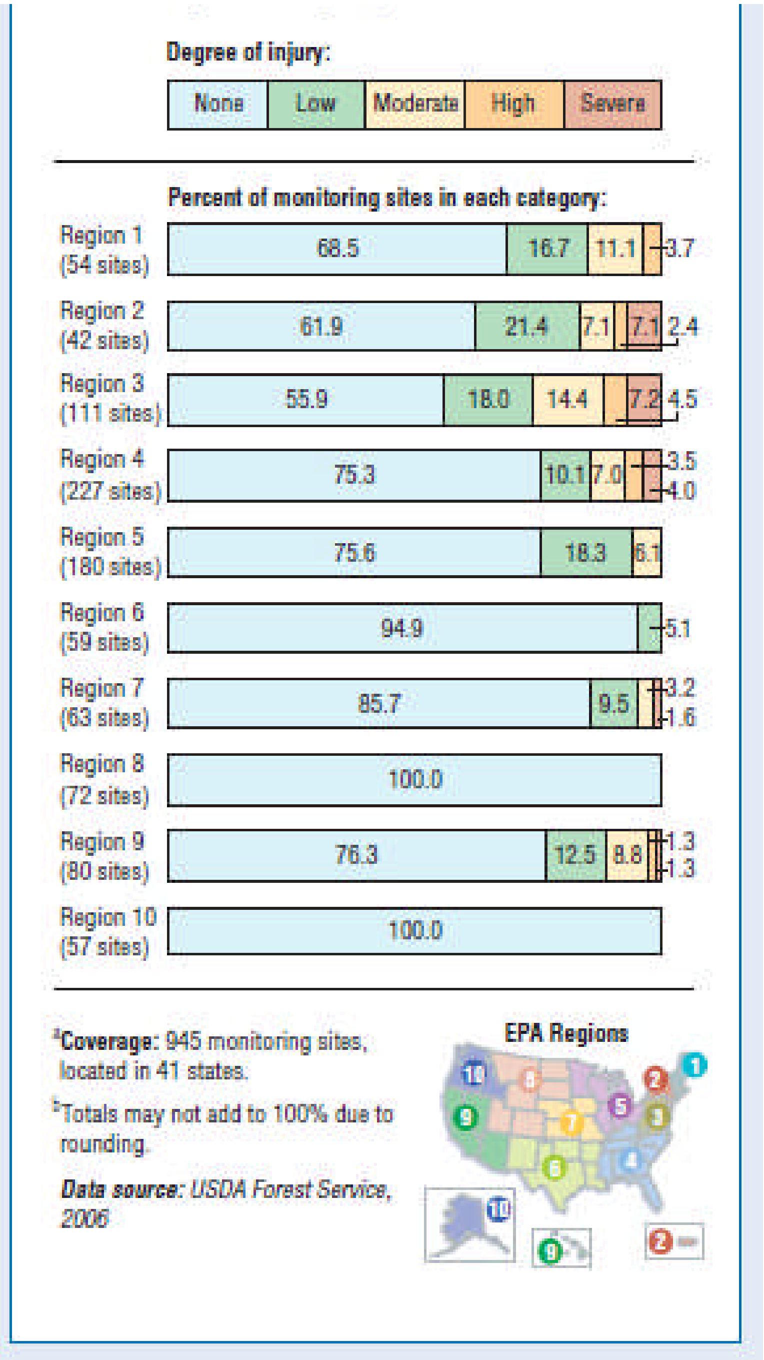
Urban ornamentals represent an additional vegetation category likely to experience some degree of negative effects associated with exposure to ambient ozone levels. It is estimated that more than $20 billion (1990 dollars) are spent annually on landscaping using ornamentals, both by private property owners/tenants and by governmental units responsible for public areas.[193] 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 Recent Ozone Visible Foliar Injury Data for 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.[194,195] 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.[196,197]

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.



[a]**Coverage:** 945 monitoring sites, located in 41 states.

[b]Totals may not add to 100% due to rounding.

Data source: *USDA Forest Service, 2006*

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.[198] 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.[199]

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.[200,201,202]

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.[203]

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.[204] 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.[205] 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.[206]

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.[207]

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.[208] 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.[209] 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.[210,211] 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.[212]

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.[213,214] Over fifty percent of the mercury in the Chesapeake Bay has been attributed to atmospheric deposition.[215] Overall, the National Science and Technology Council identifies atmospheric deposition as the primary source of mercury to aquatic systems.[216] 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.[217,218] 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.[219] 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.[220] 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.[221]

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.[222,223] Analyses of PAH deposition in Chesapeake and Galveston Bay indicate that dry deposition and gas exchange from the atmosphere to the surface water predominate.[224,225] 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.[226] 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.[227] 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.[228] 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.[229]

Cousins et al. estimate that more than ninety percent of semi-volatile organic compound (SVOC) emissions in the United Kingdom deposit on soil.[230] An analysis of PAH concentrations near a Czechoslovakian roadway indicated that concentrations were thirty times greater than background.[231]

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.[232] In laboratory experiments, a wide range of tolerance to VOCs has been observed.[233] 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.[234]

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.[235,236,237] 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 DRIA presents the projected emissions changes due to the proposed rule. 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 this proposal is to address greenhouse gas emissions, this proposed rule would also impact emissions of criteria and air toxics. Section 6.2.1 describes current ambient levels of PM, ozone and some air toxics without the standards being proposed in this rule. No air quality modeling was done for this DRIA to project the impacts of the proposed rule. EPA plans to conduct such modeling, however, and those plans are discussed in Section 6.2.2.

6.2.1 Current Levels of Non-GHG Pollutants

6.2.1.1 Particulate Matter

As described in Section 6.1.1.2, exposure to $PM_{2.5}$ causes adverse health effects, and the U.S. government has set national standards to provide requisite protection against those health effects. There are two U.S. national ambient air quality standards (NAAQS) for $PM_{2.5}$: an annual standard (15 $\mu g/m^3$) and a 24-hour standard (35 $\mu g/m^3$). The most recent revisions to these standards were in 1997 and 2006. In 2005 the U.S. EPA designated nonattainment areas for the 1997 $PM_{2.5}$ NAAQS (70 FR 19844, April 14, 2005).[OOOO] As of April 21, 2011, approximately 88 million people live in the 39 areas that are designated as nonattainment for the 1997 $PM_{2.5}$ NAAQS. These $PM_{2.5}$ nonattainment areas are comprised of 208 full or partial counties. 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

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[OOOO] 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.

include 32 areas composed of 121 full or partial counties with a population of over 70 million. In total, there are 54 $PM_{2.5}$ nonattainment areas composed of 245 counties with a population of 101 million people.

States with $PM_{2.5}$ nonattainment areas will be required to take action to bring those areas into compliance in the future. Most 1997 $PM_{2.5}$ nonattainment areas are required to attain the 1997 $PM_{2.5}$ NAAQS in the 2010 to 2015 time frame and then be required to maintain the 1997 $PM_{2.5}$ NAAQS thereafter.[238] 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 be required to maintain the 2006 24-hour $PM_{2.5}$ NAAQS thereafter.[239] The vehicle standards proposed here first apply to model year 2017 vehicles.

6.2.1.2 Ozone

As described in Section 6.1.1.4, ozone causes adverse health effects, and the U.S. government has set national standards to protect against those health effects. The primary NAAQS for 8-hour ozone was set at 0.075 ppm in 2008. The previous 8-hour ozone standard, set in 1997, had been 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).[PPPP] As of August 30, 2011 there are 44 1997 8-hour ozone nonattainment areas comprised of 242 full or partial counties with a total population of over 118 million.[240] Nonattainment designations for the 2008 8-hour ozone standard are currently under development.

States with ozone nonattainment areas are required to take action to bring those areas into compliance 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 and then to maintain it thereafter.[QQQQ] The attainment dates associated with the potential nonattainment areas based on the 2008 8-hour ozone NAAQS will likely be in the 2015 to 2035 timeframe, depending on the severity of the problem in each area. In addition, EPA is working to complete the current review of the ozone NAAQS by mid-2014. The attainment dates associated with the potential nonattainment areas based on the 2014 8-hour ozone NAAQS will likely be in the 2019 to 2036 timeframe, depending on the severity of the problem in each area. As mentioned above, the vehicle standards proposed here first apply to model year 2017 vehicles.

[PPPP] 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.

[QQQQ] The Los Angeles South Coast Air Basin 8-hour ozone nonattainment area is designated as severe and will have to attain before June 15, 2021. The South Coast Air Basin has requested to be reclassified as an extreme nonattainment area which will make its attainment date June 15, 2024. The San Joaquin Valley Air Basin 8-hour ozone nonattainment area is designated as serious and will have to attain before June 15, 2013. The San Joaquin Valley Air Basin has requested to be reclassified as an extreme nonattainment area which will make its attainment date June 15, 2024.

6.2.1.3 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.[RRRR,SSSS,241] 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.[242] 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.[243]

6.2.2 Impacts on Future Air Quality

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 from local, regional, national, and global. Section 6.2.2.1 provides more detail on the photochemical model, the Community Multi-scale Air Quality (CMAQ) model, which will be utilized for the final rule analysis.

6.2.2.1 Community Multi-Scale Air Quality (CMAQ) Modeling Plans

Full-scale photochemical air quality modeling is necessary to accurately project levels of $PM_{2.5}$, ozone and air toxics. For the final rule, a national-scale air quality modeling analysis will be performed to analyze the impacts of the vehicle standards on $PM_{2.5}$, ozone, and selected air toxics (i.e., benzene, formaldehyde, acetaldehyde, acrolein and 1,3-butadiene). The length of time needed to prepare the necessary emissions inventories, in addition to the processing time associated with the modeling itself, has precluded us from performing air quality modeling for this proposal.

[RRRR] 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.

[SSSS] 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.

Section III.G of the preamble presents projections of the changes in criteria pollutant and air toxics emissions due to the proposed vehicle standards; the basis for those estimates is set out in Chapter 4 of the DRIA. The atmospheric chemistry related to ambient concentrations of $PM_{2.5}$, ozone and air toxics is very complex, and making predictions based solely on emissions changes is extremely difficult. However, based on the magnitude of the emissions changes predicted to result from the proposed vehicle standards, we expect that there will be an improvement in ambient air quality, pending a more comprehensive analysis for the final rule.

For the final rule, EPA intends to use a Community Multi-scale Air Quality (CMAQ) modeling platform as the tool for the air quality modeling. The CMAQ modeling system is a comprehensive three-dimensional grid-based Eulerian air quality model designed to estimate the formation and fate of oxidant precursors, primary and secondary PM concentrations and deposition, and air toxics, over regional and urban spatial scales (e.g., over the contiguous U.S.).[244,245,246] The CMAQ model is a well-known and well-established tool and is commonly used by EPA for regulatory analyses, for instance the 2012-2016 final rule, and by States in developing attainment demonstrations for their State Implementation Plans.[247] The CMAQ model (version 4.7) was most recently peer-reviewed in February of 2009 for the U.S. EPA.[248] The CMAQ model also has been used in numerous national and international applications.[249,250,251]

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. EPA intends to use the most recent version of CMAQ, which reflects updates to version 4.7 to improve the underlying science.[252] 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.

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. boundary within which air quality is modeled at the 36 kilometer (km) grid cell level and two 12 km boundaries (an Eastern US and a Western US domain) within which air quality is modeled at the 12 km grid cell level. These are 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).

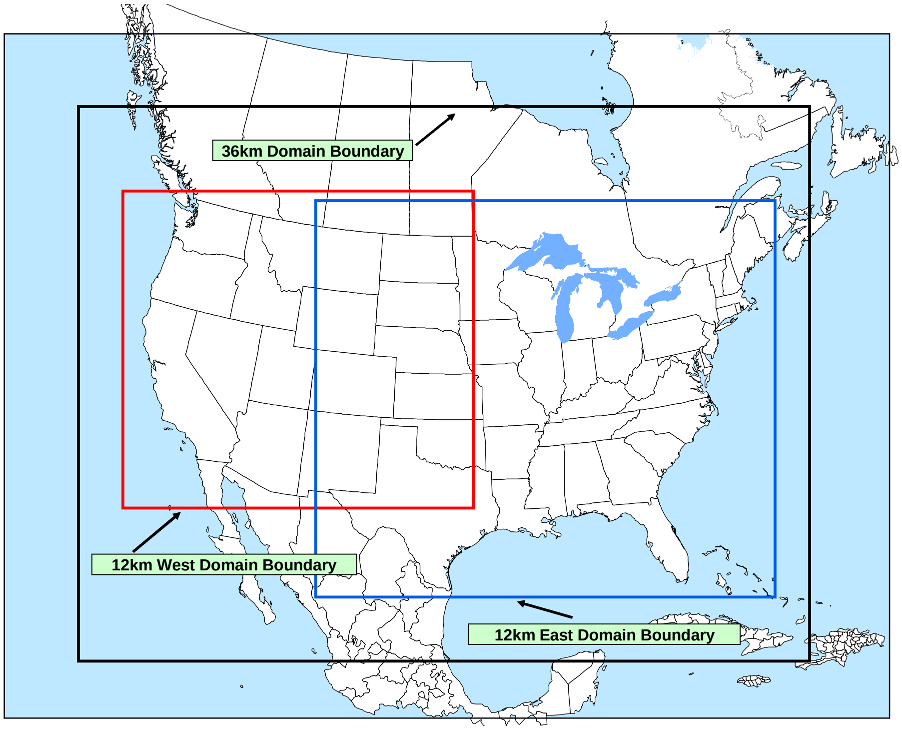

Figure 6.2-1 CMAQ 12-km Eastern and Western US modeling domains

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 are derived from annual simulations of the Pennsylvania State University / National Center for Atmospheric Research Mesoscale Model.[253] 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.[254] The meteorology for the national 36 km grid and the 12 km Eastern and Western U.S. grids are developed by EPA and will be described in more detail within the final RIA and the technical support document for the final rule air quality modeling.[TTTT] The meteorological outputs from MM5 are 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.[255]

The lateral boundary and initial species concentrations are provided by a three-dimensional global atmospheric chemistry model, the GEOS-CHEM model.[256] 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 will be run with a grid resolution of 2 degree x 2.5 degree (latitude-longitude) and 20 vertical layers. The predictions will be used to provide one-way dynamic

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[TTTT] In addition background information can be found in the final RIA and TSD for the 2012-2016 final rule, http://www.epa.gov/otaq/climate/regulations.htm#1-1.

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 will be used as the initial/boundary state for all subsequent 12 km finer grid modeling.

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 proposed 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 proposed standards are also significant sources of mobile source air pollution such as direct PM, NOx, VOCs and air toxics. The proposed standards would affect exhaust emissions of these pollutants from vehicles. They would 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 would result from the proposed 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 proposed standard because a failure to adequately consider these ancillary co-pollutant impacts could lead to an incorrect assessment of their net costs and benefits. 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.

EPA typically quantifies and monetizes the health and environmental impacts related to both PM and ozone exposure in its regulatory impact analyses (RIAs), when possible. To estimate these impacts, EPA conducts full-scale photochemical modeling to provide the needed spatial and temporal detail to estimate the changes in ambient levels of these pollutants and their associated health and welfare impacts. However, we were unable to do so in time for this proposal, as explained above. EPA attempts to make emissions and air quality modeling decisions early in the analytical process so that we can complete the photochemical air quality modeling and use that data to inform the health and environmental impacts analysis. Resource and time constraints precluded the Agency from completing this work in time for the proposal. Instead, EPA is using $PM_{2.5}$-related benefits-per-ton values as an interim approach to estimating the $PM_{2.5}$-related benefits of the proposal. We also provide a complete characterization of the health and environmental impacts that will be quantified and monetized for the final rulemaking.

This section is split into two sub-sections: the first presents the $PM_{2.5}$-related benefits-per-ton values used to monetize the $PM_{2.5}$-related co-benefits associated with the proposal; the second explains what $PM_{2.5}$- and ozone-related health and environmental impacts EPA will quantify and monetize in the analysis for the final rule. EPA bases its analyses on peer-reviewed studies of air quality and health and welfare effects and peer-reviewed studies of the monetary values of public health and welfare improvements, and is generally consistent with benefits analyses performed for the analysis of the final Transport Rule,[257] the final 2012-2016 MY Light-Duty Vehicle Rule, [258] and the final Portland Cement National Emissions Standards for Hazardous Air Pollutants (NESHAP) RIA.[259]

Though EPA is characterizing the changes in emissions associated with toxic pollutants, we will not be able to quantify or monetize the human health effects associated with air toxic pollutants for either the proposal or the final rule analyses. Please refer to Chapter 4.5 of this DRIA for more information about the air toxics emissions impacts associated with the proposed standards.

6.3.1 Economic Value of Reductions in Criteria Pollutants

As described in Chapter 4.5, the proposed standards would reduce emissions of several criteria and toxic pollutants and precursors. In this 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 toxic pollutants, nor does it monetize all of the potential health and welfare effects associated with $PM_{2.5}$.

This analysis uses a "benefit-per-ton" method to estimate a selected suite of $PM_{2.5}$-related health benefits described below. These $PM_{2.5}$ 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 its precursors (such as NOx, SOx, and VOCs), from a specified source. Ideally, the human health benefits would be estimated based on changes in ambient $PM_{2.5}$ as determined by full-scale air quality modeling. However, this modeling was not possible in the timeframe for this proposal, but EPA plans to perform such modeling for the final rulemaking.

The dollar-per-ton estimates used in this analysis are provided in Table 6.3-1. In the summary of costs and benefits, Chapter 7.4 of this RIA, we present the monetized value of PM-related improvements associated with the proposal.

Table 6.3-1 Benefits-per-ton Values (2009$) Derived Using the American Cancer Society Cohort Study for PM-related Premature Mortality (Pope et al., 2002)[a] and a 3% Discount Rate[b]

Year[c]	All Sources[d]		Stationary (Non-EGU) Sources[e]		Mobile Sources	
	SO_X	VOC	NO_X	Direct PM2.5	NO_X	Direct PM2.5
Estimated Using a 3 Percent Discount Rate[b]						
2015	$29,000	$1,200	$4,800	$230,000	$5,000	$280,000
2020	$32,000	$1,300	$5,300	$250,000	$5,500	$300,000
2030	$38,000	$1,600	$6,300	$290,000	$6,600	$360,000
2040	$44,000	$1,900	$7,500	$340,000	$7,900	$430,000
Estimated Using a 7 Percent Discount Rate[b]						
2015	$27,000	$1,100	$4,400	$210,000	$4,600	$250,000
2020	$29,000	$1,200	$4,800	$220,000	$5,000	$280,000
2030	$34,000	$1,400	$5,700	$260,000	$6,000	$330,000
2040	$40,000	$1,700	$6,800	$310,000	$7,200	$390,000

[a] The benefit-per-ton estimates presented in this table are based on an estimate of premature mortality derived from the ACS study (Pope et al., 2002). If the benefit-per-ton estimates were based on the Six-Cities study (Laden et al., 2006), the values would be approximately 245% (nearly two-and-a-half times larger. See below for a description of these studies.

[b] The benefit-per-ton estimates presented in this table assume either a 3 percent or 7 percent discount rate in the valuation of premature mortality to account for a twenty-year segmented cessation lag.
[c] Benefit-per-ton values were estimated for the years 2015, 2020, and 2030. For intermediate years, such as 2017 (the year the standards begin), we interpolated exponentially. For years beyond 2030 (including 2040), EPA and NHTSA extrapolated exponentially based on the growth between 2020 and 2030.
[d] Note that the benefit-per-ton value for SOx is based on the value for Stationary (Non-EGU) sources; no SOx value was estimated for mobile sources. The benefit-per-ton value for VOCs was estimated across all sources.
[e] Non-EGU denotes stationary sources of emissions other than electric generating units (EGUs).

The benefit per-ton technique has been used in previous analyses, including EPA's 2012-2016 Light-Duty Vehicle Greenhouse Gas Rule,[260] and the Portland Cement National Emissions Standards for Hazardous Air Pollutants (NESHAP) RIA.[261] Table 6.3-2 shows the quantified and unquantified $PM_{2.5}$-related co-benefits captured in those benefit-per-ton estimates.

Table 6.3-2 Human Health and Welfare Effects of $PM_{2.5}$

Pollutant / Effect	Quantified and Monetized in Primary Estimates	Unquantified Effects Changes in:
$PM_{2.5}$	Adult premature mortality 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 cost-benefit analysis that accompanied the NO_2 NAAQS,[UUUU,262] the benefits estimates utilize the concentration-response functions as reported in the epidemiology literature. To calculate the total monetized impacts associated with quantified health impacts, EPA applies values derived from a number of sources. For premature mortality, EPA applies a value of a statistical life (VSL) derived from the mortality valuation literature. For certain health impacts, such as chronic bronchitis and a number of respiratory-related ailments, EPA applies willingness-to-pay estimates derived from the valuation literature. For the remaining health impacts, EPA applies values derived from current cost-of-illness and/or wage estimates.

[UUUU] 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. Note that the cost-benefit analysis was prepared solely for purposes of fulfilling analysis requirements under Executive Order 12866 and was not considered, or otherwise played any part, in the decision to revise the NO2 NAAQS.

A more detailed description of the benefit-per-ton estimates is provided in Chapter 4 of the Draft Joint TSD that accompanies this rulemaking. 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)[VVVV,WWWW] accompanying the recent final ozone NAAQS RIA (U.S. EPA, 2008). Readers can also refer to Fann et al. (2009)[XXXX] for a detailed description of the benefit-per-ton methodology.[YYYY]

As described in the documentation for the benefit per-ton estimates cited 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 $PM_{2.5}$ benefits is therefore based on the total direct $PM_{2.5}$ and $PM_{2.5}$-related precursor emissions controlled by sector and multiplied by each per-ton value.

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. EPA will conduct full-scale air quality modeling for the final rulemaking in an effort to capture this variability.
- 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 diesel engines and other industrial sources, but 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

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[VVVV] U.S. Environmental Protection Agency (U.S. EPA). 2008. Technical Support Document: Calculating Benefit Per-Ton estimates, Ozone NAAQS Docket EPA-HQ-OAR-2007-0225-0284. Office of Air Quality Planning and Standards, Research Triangle Park, NC. March. Available on the Internet at <http://www.regulations.gov>.

[WWWW] Note that the cost-benefit analysis was prepared solely for purposes of fulfilling analysis requirements under Executive Order 12866 and was not considered, or otherwise played any part, in the decision to revise the Ozone NAAQS.

[XXXX] Fann, N. et al. (2009). The influence of location, source, and emission type in estimates of the human health benefits of reducing a ton of air pollution. Air Qual Atmos Health. Published online: 09 June, 2009.

[YYYY] 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; 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 health benefits from reducing fine particles in areas with varied 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 benefit categories that EPA was unable to quantify due to limitations associated with using benefits-per-ton estimates, several of which could be substantial. Because the NO_X and VOC emission reductions associated with this proposal are also precursors to ozone, reductions in NO_X and VOC would also reduce ozone formation and the health effects associated with ozone exposure. Unfortunately, ozone-related benefits-per-ton estimates 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 6.3.2 for a description of the agency's plan to quantify and monetize the PM- and ozone-related health impacts planned for the FRM and a description of the unquantified co-pollutant benefits associated with this rulemaking.
- There are many uncertainties associated with the health impact functions used in this modeling effort. These include: within-study variability (the precision with which a given study estimates the relationship between air quality changes and health effects); across-study variation (different published studies of the same pollutant/health effect relationship typically do not report identical findings and in some instances the differences are substantial); the application of concentration-response functions nationwide (does not account for any relationship between region and health effect, to the extent that such a relationship exists); extrapolation of impact functions across population (we assumed that certain health impact functions applied to age ranges broader than that considered in the original epidemiological study); and various uncertainties in the concentration-response function, including causality and thresholds. These uncertainties may under- or over-estimate benefits.
- EPA has investigated methods to characterize uncertainty in the relationship between $PM_{2.5}$ exposure and premature mortality. EPA's final $PM_{2.5}$ NAAQS analysis provides a more complete picture about the overall uncertainty in $PM_{2.5}$ benefits estimates. For more information, please consult the $PM_{2.5}$ NAAQS RIA (Table 5.5).[263]
- The benefit-per-ton estimates used in this analysis incorporate projections of key variables, including atmospheric conditions, source level emissions, population, health baselines and incomes, technology. These projections introduce some uncertainties to the benefit per ton estimates.
- As described above, using the benefit-per-ton value derived from the ACS study (Pope et al., 2002) alone provides an incomplete characterization of $PM_{2.5}$ benefits. When placed in the context of the Expert Elicitation results, this estimate falls toward the lower end of the distribution. By contrast, the estimated $PM_{2.5}$ benefits using the coefficient reported by Laden in that author's reanalysis of the Harvard Six Cities cohort fall toward the upper end of the Expert Elicitation distribution results (Laden et al., 2006).

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 there may be localized impacts associated with the proposed rulemaking. 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. As discussed above, timing and resource constraints precluded EPA from conducting a full-scale photochemical air quality modeling analysis in time for the NPRM. For the final rule, however, a national-scale air quality modeling analysis will be performed to analyze the impacts of the standards on $PM_{2.5}$, ozone, and selected air toxics. The benefits analysis plan for the final rulemaking is discussed in the next section.

6.3.2 Human Health and Environmental Benefits for the Final Rule

6.3.2.1 Human Health and Environmental Impacts

As noted above, to model the ozone and PM air quality benefits for the final rule, EPA plans to use the Community Multiscale Air Quality (CMAQ) model (see Chapter 6.2.2.1 for a description of the CMAQ model). The modeled ambient air quality data will serve as an input to the Environmental Benefits Mapping and Analysis Program (BenMAP).[264] BenMAP is a computer program developed by EPA that integrates a number of the modeling elements used in previous RIAs (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.

Table 6.3-3 lists the PM- and ozone-related health effect exposure-response functions we will use to quantify the non-GHG incidence impacts associated with the final light-duty vehicles standard.

Table 6.3-3: 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	<u>Multi-city</u> Bell et al (2004) (NMMAPS study)[265] – Non-accidental Huang et al (2005)[266] - Cardiopulmonary Schwartz (2005)[267] – Non-accidental <u>Meta-analyses:</u> Bell et al (2005)[268] – All cause Ito et al (2005)[269] – Non-accidental Levy et al (2005)[270] – All cause	All ages
Premature mortality — cohort study, all-cause	$PM_{2.5}$	Pope et al. (2002)[271] Laden et al. (2006)[272]	>29 years >25 years
Premature mortality, total exposures	$PM_{2.5}$	Expert Elicitation (IEc, 2006)[273]	>24 years
Premature mortality — all-cause	$PM_{2.5}$	Woodruff et al. (1997)[274]	Infant (<1 year)
Chronic Illness			
Chronic bronchitis	$PM_{2.5}$	Abbey et al. (1995)[275]	>26 years
Nonfatal heart attacks	$PM_{2.5}$	Peters et al. (2001)[276]	Adults (>18 years)
Hospital Admissions			
Respiratory	O_3	Pooled estimate: Schwartz (1995) - ICD 460-519 (all resp)[277] Schwartz (1994a; 1994b) - ICD 480-486 (pneumonia)[278,279] Moolgavkar et al. (1997) - ICD 480-487 (pneumonia)[280] Schwartz (1994b) - ICD 491-492, 494-496 (COPD) Moolgavkar et al. (1997) – ICD 490-496 (COPD)	>64 years
		Burnett et al. (2001)[281]	<2 years
	$PM_{2.5}$	<u>Pooled estimate:</u> Moolgavkar (2003)—ICD 490-496 (COPD)[282] Ito (2003)—ICD 490-496 (COPD)[283]	>64 years
	$PM_{2.5}$	Moolgavkar (2000)—ICD 490-496 (COPD)[284]	20–64 years
	$PM_{2.5}$	Ito (2003)—ICD 480-486 (pneumonia)	>64 years
	$PM_{2.5}$	Sheppard (2003)—ICD 493 (asthma)[285]	<65 years
Cardiovascular	$PM_{2.5}$	Pooled estimate: Moolgavkar (2003)—ICD 390-429 (all cardiovascular)	>64 years

		Ito (2003)—ICD 410-414, 427-428 (ischemic heart disease, dysrhythmia, heart failure)	
	$PM_{2.5}$	Moolgavkar (2000)—ICD 390-429 (all cardiovascular)	20–64 years
Asthma-related ER visits	O_3	Pooled estimate: Peel et al (2005)[286] Wilson et al (2005)[287]	All ages All ages
Asthma-related ER visits (con't)	$PM_{2.5}$	Norris et al. (1999)[288]	0–18 years
Other Health Endpoints			
Acute bronchitis	$PM_{2.5}$	Dockery et al. (1996)[289]	8–12 years
Upper respiratory symptoms	$PM_{2.5}$	Pope et al. (1991)[290]	Asthmatics, 9–11 years
Lower respiratory symptoms	$PM_{2.5}$	Schwartz and Neas (2000)[291]	7–14 years
Asthma exacerbations	$PM_{2.5}$	Pooled estimate: Ostro et al. (2001)[292] (cough, wheeze and shortness of breath) Vedal et al. (1998)[293] (cough)	6–18 years[a]
Work loss days	$PM_{2.5}$	Ostro (1987)[294]	18–65 years
School absence days	O_3	Pooled estimate: Gilliland et al. (2001)[295] Chen et al. (2000)[296]	5–17 years[b]
Minor Restricted Activity Days (MRADs)	O_3	Ostro and Rothschild (1989)[297]	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.

6.3.2.2 Monetized Estimates of Impacts of Reductions in Co-Pollutants

Table 6.3-4 presents the monetary values we will apply to changes in the incidence of health and welfare effects associated with reductions in non-GHG pollutants that will occur when these GHG control strategies are finalized.

Table 6.3-4: Valuation Metrics Used in BenMAP to Estimate Monetary Co-Benefits

Endpoint	Valuation Method	**Valuation (2009$)**
Premature mortality	Assumed Mean VSL	$7,850,000
Chronic Illness		
Chronic Bronchitis	WTP: Average Severity	$424,193
Myocardial Infarctions, Nonfatal	Medical Costs Over 5 Years. Varies by age and discount rate. Russell (1998)[298]	---
	Medical Costs Over 5 Years. Varies by age and discount rate. Wittels (1990)[299]	---
Hospital Admissions		
Respiratory, Age 65+	COI: Medical Costs + Wage Lost	$26,433
Respiratory, Ages 0-2	COI: Medical Costs	$11,149
Chronic Lung Disease (less Asthma)	COI: Medical Costs + Wage Lost	$17,827
Pneumonia	COI: Medical Costs + Wage Lost	$21,161
Asthma	COI: Medical Costs + Wage Lost	$9,555
Cardiovascular	COI: Medical Costs + Wage Lost (20-64)	$32,806
	COI: Medical Costs + Wage Lost (65-99)	$30,520
ER Visits, Asthma	COI: Smith et al. (1997)[300]	$449
	COI: Standford et al. (1999)[301]	$376
Other Health Endpoints		
Acute Bronchitis	WTP: 6 Day Illness, CV Studies	$444
Upper Respiratory Symptoms	WTP: 1 Day, CV Studies	$31
Lower Respiratory Symptoms	WTP: 1 Day, CV Studies	$20
Asthma Exacerbation	WTP: Bad Asthma Day, Rowe and Chestnut (1986)[302]	$54
Work Loss Days	Median Daily Wage, County-Specific	---
Minor Restricted Activity Days	WTP: 1 Day, CV Studies	$64
School Absence Days	Median Daily Wage, Women 25+	$93
Worker Productivity	Median Daily Wage, Outdoor Workers, County-Specific	---
Environmental Endpoints		
Recreational Visibility	WTP: 86 Class I Areas	---

Source: Dollar amounts for each valuation method were extracted from BenMAP and adjusted to year 2009 dollars (from year 2000 dollars) using the Consumer Price Urban Index (CPI-U). For endpoints valued using measures of VSL, WTP, or are wage-based, we use the CPI-U for "all items": 214.537 (2009) and 172.2 (2000). For endpoints valued using a Cost-of-Illness measure, we use the CPI-U for "medical care": 375.613 (2009) and 260.8 (2000)..

6.3.2.3 Other Unquantified Health and Environmental Impacts

In addition to the co-pollutant health and environmental impacts we plan to quantify for the analysis of the Light-Duty Vehicle GHG standard, there are a number of other health and human welfare endpoints that we will not be able to quantify because of current limitations in the methods or available data. These impacts are associated with emissions of air toxics (including benzene, 1,3-butadiene, formaldehyde, acetaldehyde, acrolein, and ethanol), ambient ozone, and ambient $PM_{2.5}$ exposures. For example, we have not quantified a number of known or suspected health effects linked with ozone and PM for which appropriate health impact functions are not available or which do not provide easily interpretable outcomes (i.e., changes in heart rate variability). In addition, we are currently 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. Table 6.3-5 lists these unquantified health and environmental impacts.

Although there will be impacts associated with air toxic pollutant emission changes that result from this action, 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.[303] 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,[304] 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."[305] 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 this action.[zzzz] We seek public comment to inform how the Agency might do this in the future.

Table 6.3-5: Unquantified and Non-Monetized Potential Effects

POLLUTANT/EFFECTS	EFFECTS NOT INCLUDED IN ANALYSIS - CHANGES IN:
Ozone Health[a]	Chronic respiratory damage Premature aging of the lungs Non-asthma respiratory emergency room visits

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[zzzz] 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.

	Exposure to UVb (+/-)[d]
Ozone Welfare	Yields for -commercial forests -some fruits and vegetables -non-commercial crops Damage to urban ornamental plants Impacts on recreational demand from damaged forest aesthetics Ecosystem functions Exposure to UVb (+/-)
PM Health[b]	Premature mortality - short term exposures[c] Low birth weight Pulmonary function Chronic respiratory diseases other than chronic bronchitis Non-asthma respiratory emergency room visits Exposure to UVb (+/-)
PM Welfare	Residential and recreational visibility in non-Class I areas Soiling and materials damage Damage to ecosystem functions Exposure to UVb (+/-)
Nitrogen and Sulfate Deposition Welfare	Commercial forests due to acidic sulfate and nitrate deposition Commercial freshwater fishing due to acidic deposition Recreation in terrestrial ecosystems due to acidic deposition Existence values for currently healthy ecosystems Commercial fishing, agriculture, and forests due to nitrogen deposition Recreation in estuarine ecosystems due to nitrogen deposition Ecosystem functions Passive fertilization
CO Health	Behavioral effects
Hydrocarbon (HC)/Toxics Health[e]	Cancer (benzene, 1,3-butadiene, formaldehyde, acetaldehyde, ethanol) 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, ethanol) 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[f]	Direct toxic effects to animals Bioaccumulation in the food chain Damage to ecosystem function Odor

[a] In addition to primary economic endpoints, there are a number of biological responses that have been associated with ozone health effects including increased airway responsiveness to stimuli, inflammation in the lung, acute inflammation and respiratory cell damage, and increased susceptibility to respiratory infection. The public health impact of these biological responses may be partly represented by our quantified endpoints.

[b] 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.
[c] While some of the effects of short-term exposures are likely to be captured in the estimates, there may be premature mortality due to short-term exposure to PM not captured in the cohort studies used in this analysis. However, the PM mortality results derived from the expert elicitation do take into account premature mortality effects of short term exposures.
[d] May result in benefits or disbenefits.
[e] Many of the key hydrocarbons related to this rule are also hazardous air pollutants listed in the Clean Air Act. Please refer to Chapter 6.1 for additional information on the health effects of air toxics.
[f] Please refer to Chapter 6.1for additional information on the welfare effects of air toxics.

6.4 Changes in Atmospheric CO_2 Concentrations, Global Mean Temperature, Sea Level Rise, and Ocean pH Associated with the Proposed Rule's GHG Emissions Reductions

6.4.1 Introduction

The impact of GHG emissions on the climate has been reviewed in the 2012-2016 light-duty rulemaking and recent heavy-duty GHG rulemaking. See 75 FR at 25491; 76 FR at 57294. This section briefly discusses again some of the climate impact context for transportation emissions. These previous discussions noted that 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 2009 (27 percent of total emissions).[306]

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") [AAAAA] 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.

[AAAAA] For a complete list of core references from IPCC, USGCRP/CCSP, NRC and others relied upon for development of the TSD for EPA's Endangerment and Cause or Contribute Findings see section 1(b), specifically, Table 1.1 of the TSD. Docket: EPA-HQ-OAR-2009-0171-11645.

Based on these assessments, the Administrator determined, in essence, 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 for which the endangerment finding was made. 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.

More recent assessments have produced 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."[307] 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 20th 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 coral bleaching and erosion will increase due both to warming and ocean acidification, and that sea level will rise 1.6 to 3.3 feet by 2100 in a 3 degree C scenario. 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 proposed 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 proposed 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 DRIA for the estimated net reductions in global emissions over time by GHG.[BBBBB]

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 proposed rule, 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[CCCCC,308] coupled with the MAGICC (Model for the Assessment of Greenhouse-gas Induced Climate Change) simple climate model.[DDDDD,309,310] GCAM was used to create the globally and temporally consistent set of

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[BBBBB] Due to timing constraints, the modeling analysis in this section was conducted with preliminary estimates of the emissions reductions projected from this proposal, which were similar to the final estimates presented in Chapter 4 of this DRIA.

[CCCCC] 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.

[DDDDD] 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 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 the proposal, 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 proposal were evaluated with respect to a baseline reference case. An emissions scenario was developed by applying the estimated emissions reductions from the proposed rule relative to the baseline to the GCAM reference (no climate policy) scenario (used as the basis for the Representative Concentration Pathway RCP4.5).[311] Specifically, the annual CO_2, N_2O, CH_4, HFC-134a, NOx, CO, and SO_2 emissions reductions estimated from this proposal were applied as net reductions to the GCAM global baseline net emissions for each substance.[EEEEE] The emissions reductions past 2050 for all emissions were scaled with total U.S. road transportation fuel consumption from the GCAM reference scenario. This was chosen as a simple scale factor given that both direct and upstream emissions changes are included in the emissions reduction scenario provided. 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[312] 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.

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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.

[EEEEE] Due to timing constraints, the modeling analysis in this section was conducted with preliminary estimates of the emissions reductions projected from this proposal, which were similar to the final estimates presented in Chapter 4 of this DRIA.

The GCAM reference scenario uses non-CO_2 and pollutant 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,[313] 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 proposed 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.[FFFFF] The range as illustrated in Chapter 10, Box 10.2, Figure 2 of the IPCC's Working Group I is approximately consistent with the 10-90% probability distribution of the individual cumulative distributions of climate sensitivity.[314] Other uncertainties, such as uncertainties regarding the carbon cycle, ocean heat uptake, different baseline 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) which were 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

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[FFFFF] 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 "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/.

warming effect and the interaction of black carbon (and other co-emitted aerosol species) with clouds. 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 proposed standards. See generally, EPA, Response to Comments to the Endangerment Finding Vol. 9 section 9.1.6.1 and the discussion of black carbon in the endangerment finding at 74 FR at 66520. Additionally, the magnitude of PM2.5 emissions changes (and therefore, black carbon emission changes) related to these proposed 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 proposal, the difference in emissions between the proposal and the baseline scenario was subtracted from the GCAM reference emissions scenario. As a result of the emissions reductions from the proposed rule relative to the baseline case, the concentration of atmospheric CO_2 is projected to be reduced by approximately 3.3 to 3.7 parts per million by volume (ppmv), the global mean temperature is projected to be reduced by approximately 0.008-0.018°C, and global mean sea level rise is projected to be reduced by approximately 0.07-0.17 cm by 2100. For 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 proposal compared to the baseline case. Figure 6.4-2 provides the estimated change in projected global mean temperatures associated with the proposal. Figure 6.4-3 provides the estimated reductions in global mean sea level rise associated with the proposal. 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.

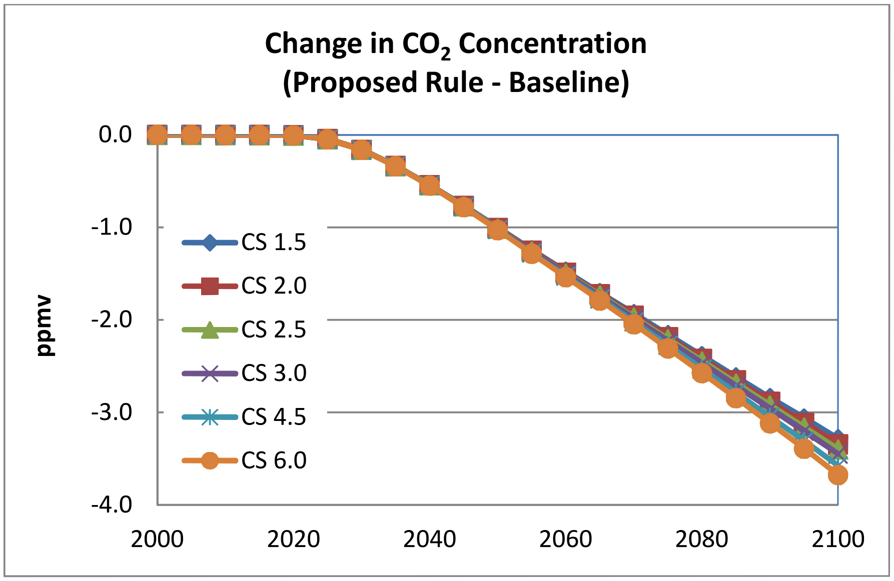

Figure 6.4-1 Projected Reductions in Atmospheric CO_2 Concentrations (parts per million by volume) from the Proposed Rule (climate sensitivity (CS) cases ranging from 1.5-6.0°C)

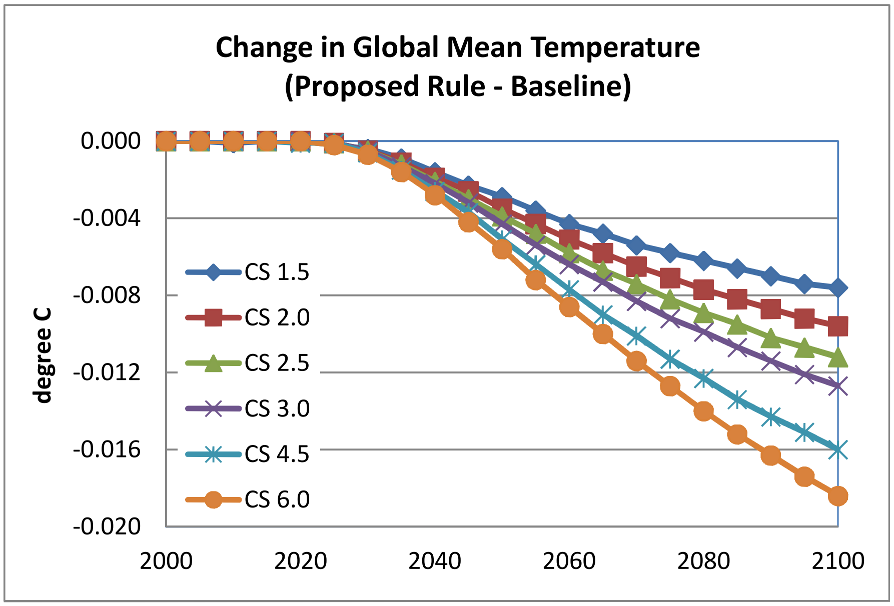

Figure 6.4-2 Projected Reductions in Global Mean Surface Temperatures from the Proposed Rule (climate sensitivity (CS) cases ranging from 1.5-6.0°C)

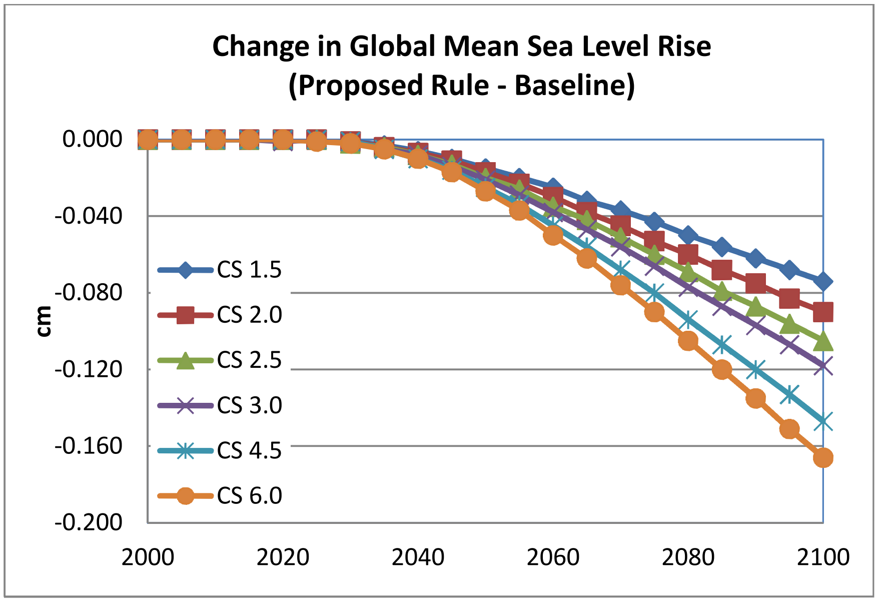

Figure 6.4-3 Projected Reductions in Global Mean Sea Level Rise from the Proposed Rule (climate sensitivity (CS) cases ranging from 1.5-6.0°C)

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 change in temperature (1.8 – 4.8 ºC) and sea level rise (23 – 55 cm) from 1990 to 2100 from the MAGICC simulations for the GCAM reference case. However, this is to be expected given the magnitude of emissions reductions expected from the proposal 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.[315] 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 proposal, 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 proposed rule.[GGGGG] EPA used the proposal developed for CO2 System Calculations CO2SYS,[316] version 1.05, a proposal which performs calculations relating parameters of the carbon dioxide (CO_2) system in seawater. The proposal 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 proposal 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)[317] 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 proposed rule relative to the baseline with a CO_2 concentration of 781.419, 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 proposed emissions standards relative to the baseline scenario pH was +0.0018 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 proposed rule's emissions reduction 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)[318], refit by Dickson and Millero (1987)[319]

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)[320] [Lewis and Wallace (1998)[321] 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).[322] Switching this parameter to Khoo et al. (1977) instead of Dickson (1990) had no effect on the calculated result].

[GGGGG] Due to timing constraints, the modeling analysis in this section was conducted with preliminary estimates of the emissions reductions projected from this proposal, which were highly similar to the final estimates presented in Chapter 4 of this DRIA.

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).[323] Based on the projected atmospheric CO_2 concentration reductions that would result from this proposed rule (784.868 ppmv for a climate sensitivity of 3.0), the modeling program calculates an increase in ocean pH of approximately 0.0018 pH units in 2100. Thus, this analysis indicates the projected decrease in atmospheric CO_2 concentrations from the proposed standards yields an increase in ocean pH. Table 6.4-1 contains the projected changes in ocean pH based the change in atmospheric CO2 concentrations which were derived from the MAGICC modeling.

Table 6.4-1 Impact of the Proposal's GHG Emissions Reductions On Ocean pH[a]

CLIMATE SENSITIVITY	DIFFERENCE IN CO_2[a]	YEAR	PROJECTED CHANGE
3.0	-3.45 ppm	2100	+0.0018

[a] represents the change in atmospheric CO_2 concentrations in 2100 based on the difference from the proposed rule relative to the base case from the GCAM reference scenario used in the MAGICC modeling.

6.4.4 Summary of Climate Analyses

EPA's analysis of the impact of the emissions reductions from this proposal 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 proposal 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 GHG Emissions Reductions On Projected Changes in Global Climate Associated with the Proposal.

These projected reductions are proportionally representative of changes to U.S. GHG emissions in the transportation sector. While not formally estimated for this proposal, 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 proposed rule 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 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 GHG Emissions Reductions On Projected Changes in Global Climate Associated with the Proposal (based on a range of climate sensitivities from 1.5-6°C)

VARIABLE	UNITS	YEAR	PROJECTED CHANGE
Atmospheric CO_2 Concentration	ppmv	2100	-3.29 to -3.68
Global Mean Surface Temperature	ºC	2100	-0.0076 to -0.0184
Sea Level Rise	cm	2100	-0.074 to -0.166
Ocean pH	pH units	2100	+0.0018[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 proposed GHG standards. We 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 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 would require different fuel efficiency improvements. EPA's proposed 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 proposing 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 restrictions on transfer of credits between car and truck fleets), primarily because NHTSA is statutorily prohibited from considering some flexibilities when establishing CAFE standards,[HHHHH] while EPA is not. Also, manufacturers may opt to pay a civil penalty in lieu of actually meeting CAFE standards, but they cannot pay a fine to avoid complying with EPA's proposed 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 harmonized the programs as much as possible, and this proposal to continue the National Program would 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.

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 proposed standard. Note, however, that the values presented in this table are summaries of the inputs used for the agencies' respective models. See draft Joint TSD Chapter 4 for expanded discussion and details on each of these joint economic and other values.

This Chapter includes an expanded description of the agencies' approach to the monetization of CO_2 emission reductions. Though the underlying unit values are consistent with those used in NHTSA's analysis of the proposed CAFE standards, the specific stream of CO_2-

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[HHHHH] *See* 49 U.S.C. 32902(h).

related benefits are unique to each program and EPA's benefits are therefore presented in section 7.1.

Table 7.1-6.4-1 Joint Economic and other Values for Benefits Computations (2009$)

Fuel Economy 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%
Value of refueling time per ($ per vehicle-hour)	$ 22.02
Average tank volume refilled during refueling stop	57%
Annual growth in average vehicle use	1% through 2030, 0.5% thereafter
Fuel Prices (2017-50 average, $/gallon)	
Retail gasoline price	$3.71
Pre-tax gasoline price	$3.35
Economic Benefits from Reducing Oil Imports ($/gallon)	
"Monopsony" Component	$ 0.00
Price Shock Component	$ 0.185 in 2025
Military Security Component	$ 0.00
Total Economic Costs ($/gallon)	$ 0.185 in 2025
Emission Damage Costs (2020, $/short ton)	
Carbon monoxide	$ 0
Volatile organic compounds (VOC)	$ 1,300
Nitrogen oxides (NO_X) – vehicle use	$ 5,500
Nitrogen oxides (NO_X) – fuel production and distribution	$ 5,300
Particulate matter ($PM_{2.5}$) – vehicle use	$ 300,000
Particulate matter ($PM_{2.5}$) – fuel production and distribution	$ 250,000
Sulfur dioxide (SO_2)	$ 32,000
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	$ 0.080
External Costs from Additional Light Truck Use ($/vehicle-mile)	
Congestion	$0.049
Accidents	$0.027
Noise	$0.001
Total External Costs	$0.077
Discount Rates Applied to Future Benefits	3%, 7%

7.1 Monetized CO_2 Estimates

We assigned a dollar value to reductions in carbon dioxide (CO_2) emissions using recent estimates of the "social cost of carbon" (SCC). 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.[324]

The interagency group selected four SCC values for use in regulatory analyses, which we have applied in this analysis: $5, $22, $36, and $67 per metric ton of CO_2 emissions[IIIII,JJJJJ] in the year 2010, and in 2009 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. Treating climate sensitivity probabilistically results in more high temperature outcomes, which in turn 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 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

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[IIIII] The interagency group decided that these estimates apply only to CO_2 emissions. Given that warming profiles and impacts other than temperature change (e.g. ocean acidification) vary across GHGs, the group concluded "transforming gases into CO2-equivalents using GWP, and then multiplying the carbon-equivalents by the SCC, would not result in accurate estimates of the social costs of non-CO2 gases" (SCC TSD, pg 13).

[JJJJJ] The SCC estimates were converted from 2007 dollars to 2008 dollars using a GDP price deflator (1.021) and again to 2009 dollars using a GDP price deflator (1.009) obtained from the Bureau of Economic Analysis, National Income and Product Accounts Table 1.1.4, *Price Indexes for Gross Domestic Product.*

on the physical and biological environment, and (4) the translation of these environmental impacts into economic damages.[325] 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. The interagency group hopes that over time researchers and modelers will work to fill these gaps and that the SCC estimates used for regulatory analysis by the Federal government will continue to evolve with improvements in modeling. Additional details on these limitations are discussed in the SCC TSD.

In light of these limitations, the interagency group has committed to updating the current estimates as the science and economic understanding of climate change and its impacts on society improves over time. Specifically, the interagency group has set a preliminary goal of revisiting the SCC values in the next few years or at such time as substantially updated models become available, and to continue to support research in this area.

Applying the global SCC estimates, shown in Table 7.1-2

Table 7.1-, to the estimated reductions in CO_2 emissions under the proposed standards, we estimate the dollar value of the GHG related benefits for each analysis year. 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%.[KKKKK] The SCC estimates are presented in and the associated CO_2 benefit estimates for each calendar year are shown in Tables 7.1-3.

[KKKKK] It is possible that other benefits or costs of proposed regulations 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] (2009 dollars)

YEAR	DISCOUNT RATE AND STATISTIC			
	5% AVERAGE	3% AVERAGE	2.5% AVERAGE	3% 95TH PERCENTILE
2017	$6.36	$25.59	$40.94	$78.28
2020	$7.01	$27.10	$42.98	$83.17
2025	$8.53	$30.43	$47.28	$93.11
2030	$10.05	$33.75	$51.58	$103.06
2035	$11.57	$37.08	$55.88	$113.00
2040	$13.09	$40.40	$60.19	$122.95
2045	$14.63	$43.34	$63.59	$131.66
2050	$16.18	$46.27	$66.99	$140.37

[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 2009 dollars)

YEAR	5% (AVERAGE SCC = $6 IN 2017)	3% (AVERAGE SCC = $26 IN 2017)	2.5% (AVERAGE SCC = $41 IN 2017)	3% (95TH PERCENTILE = $78 IN 2017)
2017	$13	$53	$85	$162
2018	$45	$179	$286	$549
2019	$97	$378	$602	$1,160
2020	$171	$662	$1,050	$2,030
2021	$289	$1,100	$1,730	$3,360
2022	$443	$1,650	$2,600	$5,060
2023	$635	$2,330	$3,650	$7,150
2024	$866	$3,130	$4,890	$9,600
2025	$1,140	$4,070	$6,320	$12,500
2030	$2,690	$9,040	$13,800	$27,600
2040	$5,490	$17,000	$25,300	$51,600
2050	$8,050	$23,000	$33,300	$69,800
NPV[b]	$32,800	$172,000	$292,000	$522,000

[a] The SCC values are dollar-year and emissions-year specific.

[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, 2.5 percent) is used to calculate net present value of SCC for internal consistency. Refer to SCC TSD for more detail.

We also 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 proposed 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 DRIA. 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 social cost of carbon 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 7.1-4 Undiscounted Annual Upstream and Downstream CO2 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 2009 dollars)

YEAR	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021	MY 2022	MY 2023	MY 2024	MY 2025	SUM
2017	$13	$0	$0	$0	$0	$0	$0	$0	$0	$13
2018	$13	$32	$0	$0	$0	$0	$0	$0	$0	$45
2019	$13	$32	$51	$0	$0	$0	$0	$0	$0	$97
2020	$13	$32	$52	$74	$0	$0	$0	$0	$0	$171
2021	$13	$33	$53	$76	$114	$0	$0	$0	$0	$289
2022	$13	$33	$53	$77	$116	$151	$0	$0	$0	$443
2023	$13	$33	$53	$77	$118	$153	$187	$0	$0	$635
2024	$13	$32	$53	$77	$118	$155	$190	$227	$0	$866
2025	$12	$32	$52	$77	$118	$156	$193	$230	$270	$1,141
2026	$12	$31	$51	$76	$117	$156	$193	$234	$274	$1,143
2027	$11	$29	$49	$74	$115	$154	$192	$233	$276	$1,134
2028	$10	$28	$47	$72	$112	$152	$190	$233	$276	$1,120
2029	$9	$26	$45	$69	$108	$147	$186	$229	$275	$1,094
2030	$8	$23	$42	$66	$105	$142	$182	$226	$273	$1,066
2031	$7	$19	$36	$60	$98	$136	$175	$219	$266	$1,016
2032	$6	$16	$30	$52	$90	$128	$167	$209	$257	$955
2033	$5	$13	$25	$44	$78	$117	$156	$200	$245	$885
2034	$4	$11	$21	$36	$66	$102	$143	$187	$234	$804
2035	$3	$9	$17	$30	$56	$86	$124	$171	$219	$716
2036	$3	$7	$14	$25	$46	$72	$105	$148	$200	$622
2037	$2	$6	$12	$20	$39	$60	$88	$126	$173	$527
2038	$2	$5	$9	$16	$32	$50	$74	$105	$147	$441
2039	$2	$4	$8	$13	$26	$41	$61	$88	$123	$367
2040	$1	$4	$6	$11	$21	$34	$51	$73	$102	$304
2041	$1	$3	$6	$9	$18	$28	$41	$60	$85	$252
2042	$1	$3	$5	$8	$15	$23	$34	$50	$71	$209
2043	$1	$2	$4	$6	$13	$20	$28	$41	$58	$173
2044	$1	$2	$3	$5	$11	$17	$24	$34	$48	$145
2045	$1	$1	$2	$5	$9	$14	$21	$29	$40	$122
2046	$1	$1	$2	$3	$8	$12	$18	$25	$33	$103
2047	$1	$1	$2	$3	$6	$11	$15	$21	$29	$88
2048	$0	$1	$2	$2	$5	$8	$13	$18	$25	$74
2049	$0	$1	$1	$2	$5	$7	$9	$16	$21	$62
2050	$0	$1	$1	$2	$4	$6	$8	$11	$18	$52
NPV, 5%	$142	$344	$552	$802	$1,230	$1,610	$1,980	$2,390	$2,810	$11,900

[a] The SCC values are dollar-year and emissions-year specific. Note that annual data extend to 2052 for the 2017MY and to 2060 for the 2025MY. These data are not shown but are included in the NPV values.

Table 7.1-5 Undiscounted Annual Upstream and Downstream CO2 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 2009 dollars)

YEAR	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021	MY 2022	MY 2023	MY 2024	MY 2025	SUM
2017	$53	$0	$0	$0	$0	$0	$0	$0	$0	$53
2018	$53	$127	$0	$0	$0	$0	$0	$0	$0	$179
2019	$52	$126	$200	$0	$0	$0	$0	$0	$0	$378
2020	$51	$126	$199	$286	$0	$0	$0	$0	$0	$662
2021	$51	$124	$200	$287	$434	$0	$0	$0	$0	$1,096
2022	$50	$123	$197	$287	$433	$563	$0	$0	$0	$1,652
2023	$48	$120	$195	$284	$433	$564	$689	$0	$0	$2,334
2024	$46	$117	$191	$280	$427	$563	$687	$822	$0	$3,134
2025	$44	$113	$186	$275	$422	$556	$688	$822	$964	$4,070
2026	$42	$108	$180	$267	$413	$549	$679	$822	$964	$4,024
2027	$39	$102	$171	$257	$400	$535	$668	$809	$960	$3,942
2028	$36	$96	$163	$246	$386	$520	$654	$799	$948	$3,848
2029	$31	$87	$152	$234	$367	$500	$633	$778	$933	$3,716
2030	$27	$76	$140	$220	$351	$478	$613	$760	$916	$3,580
2031	$22	$64	$120	$200	$327	$453	$580	$728	$885	$3,379
2032	$19	$53	$100	$171	$297	$421	$549	$689	$846	$3,145
2033	$16	$44	$83	$143	$256	$383	$510	$651	$801	$2,885
2034	$13	$36	$68	$118	$214	$329	$462	$603	$755	$2,599
2035	$11	$29	$56	$96	$178	$277	$398	$547	$701	$2,293
2036	$9	$24	$45	$79	$147	$230	$335	$472	$635	$1,976
2037	$7	$19	$36	$64	$122	$190	$279	$396	$547	$1,661
2038	$6	$16	$29	$51	$99	$157	$230	$330	$460	$1,379
2039	$5	$13	$24	$41	$81	$129	$191	$273	$383	$1,139
2040	$5	$12	$20	$34	$66	$105	$156	$226	$316	$938
2041	$4	$10	$17	$28	$54	$85	$127	$185	$262	$771
2042	$3	$8	$14	$24	$45	$70	$104	$150	$214	$633
2043	$2	$7	$12	$20	$39	$59	$85	$123	$174	$521
2044	$2	$5	$10	$16	$33	$51	$72	$101	$142	$432
2045	$2	$4	$7	$14	$27	$43	$63	$85	$117	$361
2046	$2	$4	$6	$9	$23	$36	$52	$74	$98	$304
2047	$2	$3	$5	$8	$17	$31	$44	$62	$86	$256
2048	$1	$3	$5	$7	$15	$22	$38	$52	$71	$213
2049	$1	$3	$4	$6	$13	$19	$27	$45	$60	$178
2050	$1	$2	$4	$5	$11	$17	$24	$32	$52	$149
NPV, 5%	$598	$1,430	$2,260	$3,240	$4,900	$6,350	$7,730	$9,200	$10,700	$46,400

[a] The SCC values are dollar-year and emissions-year specific. Note that annual data extend to 2052 for the 2017MY and to 2060 for the 2025MY. These data are not shown but are included in the NPV values.

Table 7.1-6 Undiscounted Annual Upstream and Downstream CO2 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 2009 dollars)

YEAR	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021	MY 2022	MY 2023	MY 2024	MY 2025	SUM
2017	$85	$0	$0	$0	$0	$0	$0	$0	$0	$85
2018	$84	$202	$0	$0	$0	$0	$0	$0	$0	$286
2019	$83	$201	$318	$0	$0	$0	$0	$0	$0	$602
2020	$81	$199	$316	$453	$0	$0	$0	$0	$0	$1,050
2021	$80	$196	$316	$454	$684	$0	$0	$0	$0	$1,730
2022	$78	$193	$310	$451	$680	$885	$0	$0	$0	$2,597
2023	$76	$188	$306	$445	$679	$882	$1,078	$0	$0	$3,654
2024	$72	$182	$298	$437	$666	$877	$1,072	$1,282	$0	$4,888
2025	$69	$175	$289	$427	$656	$864	$1,068	$1,277	$1,498	$6,324
2026	$65	$167	$278	$414	$640	$850	$1,051	$1,273	$1,492	$6,231
2027	$61	$158	$263	$397	$618	$825	$1,031	$1,248	$1,481	$6,082
2028	$55	$147	$251	$378	$594	$800	$1,005	$1,229	$1,458	$5,918
2029	$48	$134	$233	$358	$562	$766	$971	$1,193	$1,430	$5,696
2030	$41	$116	$213	$337	$537	$731	$936	$1,161	$1,399	$5,472
2031	$34	$97	$183	$305	$498	$691	$884	$1,109	$1,348	$5,149
2032	$28	$80	$152	$260	$451	$640	$834	$1,046	$1,286	$4,779
2033	$24	$66	$126	$217	$388	$580	$773	$986	$1,213	$4,372
2034	$19	$54	$103	$178	$324	$498	$699	$912	$1,141	$3,928
2035	$16	$44	$84	$145	$269	$417	$601	$825	$1,056	$3,457
2036	$13	$36	$68	$119	$221	$346	$504	$709	$955	$2,971
2037	$11	$29	$55	$96	$182	$285	$418	$595	$821	$2,491
2038	$9	$24	$44	$77	$149	$235	$345	$494	$688	$2,064
2039	$8	$20	$36	$62	$120	$192	$285	$407	$571	$1,701
2040	$7	$17	$30	$50	$98	$156	$233	$337	$471	$1,398
2041	$6	$14	$26	$41	$80	$127	$189	$275	$388	$1,145
2042	$5	$12	$21	$35	$67	$104	$154	$222	$317	$936
2043	$4	$10	$17	$29	$58	$87	$126	$181	$257	$769
2044	$3	$7	$15	$24	$48	$76	$106	$149	$209	$636
2045	$3	$6	$10	$20	$40	$62	$92	$125	$172	$530
2046	$2	$5	$9	$13	$34	$52	$76	$109	$144	$445
2047	$2	$5	$8	$12	$24	$45	$64	$90	$125	$374
2048	$2	$4	$7	$10	$21	$32	$55	$75	$104	$310
2049	$2	$4	$6	$9	$19	$28	$39	$65	$87	$258
2050	$2	$3	$5	$8	$17	$25	$35	$47	$75	$216
NPV, 2.5%	$968	$2,310	$3,640	$5,190	$7,820	$10,100	$12,300	$14,600	$16,900	$73,800

[a] The SCC values are dollar-year and emissions-year specific. Note that annual data extend to 2052 for the 2017MY and to 2060 for the 2025MY. These data are not shown but are included in the NPV values.

Table 7.1-7 Undiscounted Annual Upstream and Downstream CO2 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 2009 dollars)

YEAR	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021	MY 2022	MY 2023	MY 2024	MY 2025	SUM
2017	$162	$0	$0	$0	$0	$0	$0	$0	$0	$162
2018	$161	$388	$0	$0	$0	$0	$0	$0	$0	$549
2019	$160	$387	$613	$0	$0	$0	$0	$0	$0	$1,160
2020	$158	$385	$611	$877	$0	$0	$0	$0	$0	$2,031
2021	$156	$382	$613	$881	$1,330	$0	$0	$0	$0	$3,361
2022	$152	$376	$604	$879	$1,326	$1,725	$0	$0	$0	$5,064
2023	$148	$368	$598	$870	$1,328	$1,726	$2,110	$0	$0	$7,149
2024	$142	$358	$584	$858	$1,308	$1,723	$2,104	$2,517	$0	$9,595
2025	$135	$345	$569	$841	$1,293	$1,701	$2,104	$2,516	$2,951	$12,455
2026	$129	$329	$549	$818	$1,264	$1,680	$2,077	$2,515	$2,948	$12,309
2027	$120	$312	$522	$787	$1,224	$1,636	$2,043	$2,473	$2,935	$12,052
2028	$110	$293	$498	$751	$1,180	$1,590	$1,997	$2,442	$2,898	$11,759
2029	$95	$266	$465	$714	$1,121	$1,527	$1,934	$2,377	$2,850	$11,350
2030	$81	$232	$426	$673	$1,072	$1,461	$1,871	$2,320	$2,796	$10,932
2031	$68	$194	$366	$610	$998	$1,383	$1,772	$2,221	$2,701	$10,314
2032	$57	$162	$306	$523	$906	$1,285	$1,675	$2,101	$2,583	$9,597
2033	$48	$133	$253	$436	$780	$1,167	$1,556	$1,985	$2,442	$8,800
2034	$39	$110	$207	$359	$654	$1,004	$1,409	$1,840	$2,302	$7,925
2035	$32	$89	$170	$294	$544	$843	$1,215	$1,668	$2,135	$6,990
2036	$26	$72	$138	$240	$448	$702	$1,021	$1,438	$1,936	$6,021
2037	$22	$59	$111	$194	$370	$579	$849	$1,208	$1,667	$5,059
2038	$19	$48	$90	$156	$303	$479	$701	$1,005	$1,400	$4,200
2039	$16	$40	$73	$126	$245	$392	$581	$830	$1,165	$3,468
2040	$14	$35	$61	$102	$200	$318	$476	$687	$962	$2,855
2041	$12	$29	$52	$84	$164	$260	$386	$562	$796	$2,345
2042	$10	$24	$43	$73	$137	$213	$316	$457	$651	$1,924
2043	$7	$21	$36	$59	$120	$179	$260	$373	$529	$1,584
2044	$7	$14	$30	$49	$99	$156	$218	$307	$432	$1,313
2045	$6	$13	$20	$42	$83	$129	$190	$258	$356	$1,097
2046	$5	$11	$18	$27	$71	$108	$158	$225	$299	$923
2047	$5	$10	$16	$24	$50	$94	$132	$187	$261	$778
2048	$4	$9	$14	$21	$44	$67	$114	$157	$216	$647
2049	$4	$8	$12	$19	$39	$59	$82	$135	$182	$540
2050	$3	$7	$11	$17	$35	$52	$73	$98	$157	$452
NPV, 3%	$1,830	$4,380	$6,920	$9,910	$15,000	$19,400	$23,600	$28,100	$32,700	$142,000

[a] The SCC values are dollar-year and emissions-year specific. Note that annual data extend to 2052 for the 2017MY and to 2060 for the 2025MY. These data are not shown but are included in the NPV values.

7.2 Summary of Costs and Benefits

In this section, EPA presents a summary of costs, benefits, and net benefits of the proposed program. Table 7.2-1 shows the estimated annual monetized costs of the proposed 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.[LLLLL] Table 7.2-2 shows the estimated annual monetized fuel savings of the proposed 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 7.2-3 shows the annual reductions in petroleum-based imports and the monetized energy security benefits of the proposed 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 7.2-1 Undiscounted Annual Costs & Costs of the Proposed Program Discounted Back to 2012 at 3% and 7% Discount Rates (Millions, 2009$) [a]

	2017	2020	2030	2040	2050	NPV, Years 2012-2050, 3% Discount Rate	NPV, Years 2012-2050, 7% Discount Rate
Technology Costs	$2,300	$8,470	$35,700	$39,800	$44,600	$551,000	$243,000

Note:
[a] Technology costs for separate light-duty vehicle segments can be found in Chapter 5 of this DRIA. Annual costs shown are undiscounted values.

Table 7.2-2 Undiscounted Annual Fuel Savings & Proposed Program Fuel Savings Discounted Back to 2012 at 3% and 7% Discount Rates (Millions, 2009$) [a]

	2017	2020	2030	2040	2050	NPV, Years 2012-2050, 3% Discount Rate	NPV, Years 2012-2050, 7% Discount Rate
Fuel Savings (pre-tax)	$570	$7,060	$85,800	$144,000	$187,000	$1,510,000	$579,000

Note:
[a] Fuel savings for separate light-duty vehicle segments can be found in Chapter 5 of this DRIA. Annual costs shown are undiscounted values.

[LLLLL] 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 7.2-3 Undiscounted Annual Energy Security Benefits, & Proposed Program Benefits Discounted back to 2012 at 3% and 7% Discount Rates (Millions, 2009$)[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)	4.4	51.5	579	914	1,083		
Monetized benefits	$30	$366	$4,810	$7,860	$9,310	$81,500	$31,500

Note:

[a] EPA developed estimates of energy security premiums (i.e., $/barrel of imported crude oil and finished petroleum products) as result of the proposed rule for 2020, 2030, 2040 and 2050 using a method developed by the Oak Ridge National Laboratory. 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 from the propose rule. 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 2011 forecasts that end in 2035, EPA assumed that the post-2035 energy security premium did not change through 2050. Annual costs shown are undiscounted values.

Table 7.2-4 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 DRIA, 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 GHG benefits exclude the value of net reductions in non-CO_2 GHG emissions (CH_4, N_2O, HFC) expected under this action. Although EPA has not monetized the benefits of reductions in non-CO_2 GHGs, the value of these reductions should not be interpreted as zero. Rather, the net reductions in non-CO_2 GHGs will contribute to this program's climate benefits, as explained in Chapter 6.4 of this DRIA.

Table 7.2-4 Monetized Undiscounted Annual Benefits & Benefits of the Proposed Program Discounted Back to 2012 at 3% and 7% Discount Rates (Millions, 2009$)

	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)	$13	$171	$2,690	$5,490	$8,050	$32,800	$32,800
3% (avg SCC)	$53	$662	$9,040	$17,000	$23,000	$172,000	$172,000
2.5% (avg SCC)	$85	$1,050	$13,800	$25,300	$33,300	$292,000	$292,000
3% (95th %ile)	$162	$2,030	$27,600	$51,600	$69,800	$522,000	$522,000
Energy Security Benefits	$30	$366	$4,810	$7,860	$9,310	$81,500	$31,500
Accidents, Congestion, Noise Costs[g]	$66	$844	$9,960	$16,900	$22,000	$176,000	$67,700
Increased Travel Benefits	$89	$1,090	$12,900	$23,600	$33,600	$244,000	$92,100
Refueling Time Savings	$25	$301	$3,780	$6,650	$8,800	$68,700	$26,200
$PM_{2.5}$ Related Impacts [c,d,e]	$11	$150	$1,360	$2,190	$2,970	$23,800	$9,280
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)	$101	$1,240	$15,600	$29,000	$40,700	$275,000	$124,000
3% (avg SCC)	$141	$1,730	$22,000	$40,400	$55,600	$413,000	$263,000
2.5% (avg SCC)	$173	$2,120	$26,700	$48,700	$65,900	$534,000	$384,000
3% (95th %ile)	$250	$3,100	$40,500	$75,100	$102,000	$764,000	$614,000

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] DRIA Chapter 7.1 notes that SCC increases over time. For the years 2012-2050, the SCC estimates range as follows: for Average SCC at 5%: $5-$16; for Average SCC at 3%: $23-$46; for Average SCC at 2.5%: $38-$67; and for 95th percentile SCC at 3%: $70-$140.

[c] Note that the co-pollutant impacts associated with the proposed standards presented here do not include the full complement of endpoints that, if quantified and monetized, would change the total monetized estimate of rule-related impacts. Instead, the co-pollutant 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 analysis in time for the proposal. We intend to more fully capture the co-pollutant benefits for the analysis of the final standards.

[d] The $PM_{2.5}$-related 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). See Chapter 6.3.1 of this DRIA. If the benefit-per-ton estimates were based on the Six Cities study (Laden et al., 2006), the values would be nearly two-and-a-half times larger. Id.

[e] The $PM_{2.5}$-related 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] The monetized GHG benefits presented in this analysis exclude the value of changes in non-CO_2 GHG emissions expected under this program as discussed above in section 7.1. Although EPA has not monetized changes in non-

CO_2 GHGs, the value of any increases or reductions should not be interpreted as zero. We seek comment on a method of quantifying non-CO_2 GHG benefits in Section III.H.5 of the preamble.

[g] The values shown for Accidents, Congestion, and Noise are costs and are treated as negative values in the total benefits.

Table 7.2-5 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 2012-2050 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 7.2-5 Undiscounted Annual Monetized Net Benefits & Net Benefits of the Proposed Program Discounted Back to 2012 at 3% and 7% Discount Rates (Millions, 2009$)

	2017	2020	2030	2040	2050	NPV, 3%[a]	NPV, 7%[a]
Technology Costs	$2,300	$8,470	$35,700	$39,800	$44,600	$551,000	$243,000
Fuel Savings	$570	$7,060	$85,800	$144,000	$187,000	$1,510,000	$579,000
Total Annual Benefits at each assumed SCC value [b]							
5% (avg SCC)	$101	$1,240	$15,600	$29,000	$40,700	$275,000	$124,000
3% (avg SCC)	$141	$1,730	$22,000	$40,400	$55,600	$413,000	$263,000
2.5% (avg SCC)	$173	$2,120	$26,700	$48,700	$65,900	$534,000	$384,000
3% (95th %ile)	$250	$3,100	$40,500	$75,100	$102,000	$764,000	$614,000
Monetized Net Benefits at each assumed SCC value [c]							
5% (avg SCC)	-$1,630	-$166	$65,600	$133,000	$183,000	$1,230,000	$460,000
3% (avg SCC)	-$1,590	$325	$72,000	$144,000	$198,000	$1,370,000	$599,000
2.5% (avg SCC)	-$1,560	$712	$76,800	$153,000	$208,000	$1,490,000	$719,000
3% (95th %ile)	-$1,480	$1,690	$90,500	$179,000	$244,000	$1,720,000	$950,000

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] DRIA Chapter 7.1 notes that SCC increases over time. For the years 2012-2050, the SCC estimates range as follows: for Average SCC at 5%: $5-$16; for Average SCC at 3%: $23-$46; for Average SCC at 2.5%: $38-$67; and for 95th percentile SCC at 3%: $70-$140. DRIA 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 7.2-1 through Table 7.2-5, the model year lifetime analysis below shows the impacts of the proposed 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 7.2-6 and Tables 7.2-7 at both 3 percent and 7 percent discount rates, respectively.

Table 7.2-6 Monetized Technology Costs, Fuel Savings, Benefits, and Net Benefits Associated with the Lifetimes of 2017-2025 Model Year Light-Duty Vehicles (Millions, 2009$; 3% Discount Rate)[h]

	2017 MY	2018 MY	2019 MY	2020 MY	2021 MY	2022 MY	2023 MY	2024 MY	2025 MY	Sum
Technology Costs	$2,270	$4,590	$6,410	$8,340	$11,700	$19,100	$24,700	$30,300	$33,100	$140,000
Fuel Savings (pre-tax)	$6,060	$14,300	$22,400	$31,800	$47,300	$61,000	$73,700	$87,000	$100,000	$444,000
Energy Security Benefits	$322	$763	$1,200	$1,710	$2,550	$3,310	$4,030	$4,790	$5,560	$24,200
Accidents, Congestion, Noise Costs [f]	$721	$1,740	$2,740	$3,880	$5,600	$7,150	$8,560	$10,000	$11,500	$52,000
Increased Travel Benefits	$1,040	$2,480	$3,850	$5,380	$7,720	$9,770	$11,600	$13,600	$15,500	$70,900
Refueling Time Savings	$262	$618	$967	$1,370	$2,040	$2,650	$3,230	$3,840	$4,470	$19,500
$PM_{2.5}$ Related Impacts[c,d,e]	$117	$302	$481	$692	$1,090	$1,210	$1,300	$1,380	$1,450	$8,020
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)	$142	$344	$552	$802	$1,230	$1,610	$1,980	$2,390	$2,810	$11,900
3% (avg SCC)	$598	$1,430	$2,260	$3,240	$4,900	$6,350	$7,730	$9,200	$10,700	$46,400
2.5% (avg SCC)	$968	$2,310	$3,640	$5,190	$7,820	$10,100	$12,300	$14,600	$16,900	$73,800
3% (95th %ile)	$1,830	$4,380	$6,920	$9,910	$15,000	$19,400	$23,600	$28,100	$32,700	$142,000
Monetized Net Benefits at each assumed SCC value [a, b]										
5% (avg SCC)	$4,960	$12,500	$20,300	$29,500	$44,600	$53,300	$62,600	$72,600	$85,700	$386,000
3% (avg SCC)	$5,420	$13,600	$22,100	$32,000	$48,300	$58,100	$68,400	$79,400	$93,600	$421,000
2.5% (avg SCC)	$5,790	$14,500	$23,400	$33,900	$51,200	$61,800	$72,900	$84,800	$99,800	$448,000
3% (95th %ile)	$6,650	$16,600	$26,700	$38,600	$58,400	$71,100	$84,300	$98,300	$116,000	$516,000

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] DRIA Chapter 7.1 notes that SCC increases over time. For the years 2012-2050, the SCC estimates range as follows: for Average SCC at 5%: $5-$16; for Average SCC at 3%: $23-$46; for Average SCC at 2.5%: $38-$67; and for 95th percentile SCC at 3%: $70-$140. DRIA Chapter 7.1 also presents these SCC estimates.

[c] Note that the co-pollutant impacts associated with the proposed standards presented here do not include the full complement of endpoints that, if quantified and monetized, would change the total monetized estimate of rule-related impacts. Instead, the co-pollutant 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 analysis in time for the proposal. We intend to more fully capture the co-pollutant benefits for the analysis of the final standards.

[d] The $PM_{2.5}$-related 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). See Chapter 6.3.1 of this DRIA. If the benefit-per-ton estimates were based on the Six Cities study (Laden et al., 2006), the values would be nearly two-and-a-half times larger. Id.

[e] The PM$_{2.5}$-related 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] The values shown for Accidents, Congestion, and Noise are costs and are treated as negative values in the net benefits.

[g] The monetized GHG benefits presented in this analysis exclude the value of changes in non-CO$_2$ GHG emissions expected under this action as discussed above in section 7.1. Although EPA has not monetized changes in non-CO$_2$ GHGs, the value of any increases or reductions should not be interpreted as zero. We seek comment on a method of quantifying non-CO$_2$ GHG benefits in Section III.H.5 of the preamble.

[h] Model year values are discounted to the first year of each model year; the "Sum" represents those discounted values summed across model years.

Table 7.2-7 Monetized Technology Costs, Fuel Savings, Benefits, and Net Benefits Associated with the Lifetimes of 2017-2025 Model Year Light-Duty Vehicles (Millions, 2009$; 7% Discount Rate)[h]

	2017 MY	2018 MY	2019 MY	2020 MY	2021 MY	2022 MY	2023 MY	2024 MY	2025 MY	Sum
Technology Costs	$2,220	$4,500	$6,290	$8,190	$11,500	$18,700	$24,200	$29,700	$32,500	$138,000
Fuel Savings (pre-tax)	$4,720	$11,200	$17,500	$24,900	$37,000	$47,700	$57,700	$68,100	$78,700	$347,000
Energy Security Benefits	$250	$593	$934	$1,330	$1,980	$2,580	$3,150	$3,750	$4,360	$18,900
Accidents, Congestion, Noise Costs [f]	$562	$1,360	$2,140	$3,040	$4,390	$5,600	$6,720	$7,880	$9,060	$40,800
Increased Travel Benefits	$808	$1,930	$3,000	$4,190	$6,010	$7,620	$9,080	$10,600	$12,100	$55,300
Refueling Time Savings	$203	$481	$754	$1,070	$1,590	$2,070	$2,520	$2,990	$3,480	$15,200
PM$_{2.5}$ Related Impacts[c,d,e]	$93	$240	$382	$551	$864	$964	$1,030	$1,100	$1,160	$6,390
Non-CO$_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)	$142	$344	$552	$802	$1,230	$1,610	$1,980	$2,390	$2,810	$11,900
3% (avg SCC)	$598	$1,430	$2,260	$3,240	$4,900	$6,350	$7,730	$9,200	$10,700	$46,400
2.5% (avg SCC)	$968	$2,310	$3,640	$5,190	$7,820	$10,100	$12,300	$14,600	$16,900	$73,800
3% (95th %ile)	$1,830	$4,380	$6,920	$9,910	$15,000	$19,400	$23,600	$28,100	$32,700	$142,000
Monetized Net Benefits at each assumed SCC value [a, b]										
5% (avg SCC)	$3,420	$8,920	$14,700	$21,600	$32,800	$38,200	$44,500	$51,300	$61,100	$277,000
3% (avg SCC)	$3,880	$10,000	$16,400	$24,000	$36,400	$43,000	$50,200	$58,100	$69,000	$311,000
2.5% (avg SCC)	$4,250	$10,900	$17,800	$26,000	$39,400	$46,700	$54,800	$63,500	$75,200	$338,000
3% (95th %ile)	$5,110	$13,000	$21,100	$30,700	$46,500	$56,000	$66,100	$77,000	$91,000	$406,000

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] DRIA Chapter 7.1 notes that SCC increases over time. For the years 2012-2050, the SCC estimates range as follows: for Average SCC at 5%: \$5-\$16; for Average SCC at 3%: \$23-\$46; for Average SCC at 2.5%: \$38-\$67; and for 95th percentile SCC at 3%: \$70-\$140. DRIA Chapter 7.1 also presents these SCC estimates.
[c] Note that the co-pollutant impacts associated with the proposed standards presented here do not include the full complement of endpoints that, if quantified and monetized, would change the total monetized estimate of rule-related impacts. Instead, the co-pollutant 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 analysis in time for the proposal. We intend to more fully capture the co-pollutant benefits for the analysis of the final standards.
[d] The $PM_{2.5}$-related 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). See Chapter 6.3.1 of this DRIA. If the benefit-per-ton estimates were based on the Six Cities study (Laden et al., 2006), the values would be nearly two-and-a-half times larger. Id
[e] The $PM_{2.5}$-related 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] The values shown for Accidents, Congestion, and Noise are costs and are treated as negative values in the net benefits.
[g] The monetized GHG benefits presented in this analysis exclude the value of changes in non-CO_2 GHG emissions expected under this action as discussed above in section 7.1. Although EPA has not monetized changes in non-CO_2 GHGs, the value of any increases or reductions should not be interpreted as zero. We seek comment on a method of quantifying non-CO_2 GHG benefits in Section III.H.5 of the preamble.
[h] Model year values are discounted to the first year of each model year; the "Sum" represents those discounted values summed across model years.

References

[324] Docket ID EPA-HQ-OAR-2010-0799, Technical Support Document: Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866, Interagency Working Group on Social Cost of Carbon, with participation by Council of Economic Advisers, Council on Environmental Quality, Department of Agriculture, Department of Commerce, Department of Energy, Department of Transportation, Environmental Protection Agency, National Economic Council, Office of Energy and Climate Change, Office of Management and Budget, Office of Science and Technology Policy, and Department of Treasury (February 2010). Also available at http://epa.gov/otaq/climate/regulations.htm

[325] National Research Council (2009). Hidden Costs of Energy: Unpriced Consequences of Energy Production and Use. National Academies Press. See docket ID EPA-HQ-OAR-2010-0799.

8 Vehicle Sales and Employment Impacts

8.1 Vehicle Sales Impacts

8.1.1 Vehicle Sales Impacts and Payback Period

Predicting the effects of this rule on vehicles 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, be expected to discourage sales. On the other hand, the vehicles will have improved fuel economy and thus lower operating costs, producing lower total costs over the life of vehicles, which makes them more attractive to consumers. Which of these effects dominates for potential vehicle buyers when they are considering a purchase will determine the effect on sales. However, assessing the net effect of these two competing effects is complex and uncertain, as it rests on how consumers value fuel savings at the time of purchase and the extent to which manufacturers and dealers reflect them in the purchase price. The empirical literature does not provide clear evidence on whether consumers fully consider the value of fuel savings at the time of purchase. It also generally does not speak to the efficiency of manufacturing and dealer pricing decisions. Thus, for the proposal we do not provide quantified estimates of potential sales impacts. Rather, we solicit comment on the issues raised here and on methods for estimating the effect of this rule on vehicle sales.

For years, consumers have been gaining experience with the benefits that accrue to them from owning and operating vehicles with greater fuel efficiency. Many households already own vehicles with a fairly wide range of fuel economy, and thus already have an opportunity to learn about the value of fuel economy on their own. Among two-vehicle households, for example, the least fuel-efficient vehicle averages just over 22 mpg (EPA test rating), and the range between this and the fuel economy of their other vehicle averages nearly 7 mpg. Among households that own 3 or more vehicles, the typical range of the fuel economy they offer is much wider. Consumer demand may have shifted towards such vehicles, not only because of higher fuel prices but also if many consumers are learning about the value of purchases based not only on initial costs but also on the total cost of owning and operating a vehicle over its lifetime. This type of learning should continue before and during the model years affected by this rule, particularly given the new fuel economy labels that clarify potential economic effects and should therefore reinforce that learning..

Today's proposed rule, combined with the new and easier-to-understand fuel economy label required to be on all new vehicles beginning in 2012, may increase sales above baseline levels by hastening this very type of consumer learning. As more consumers experience, as a result of the rule, the savings in time and expense from owning more fuel efficient vehicles, demand may shift yet further in the direction of the vehicles mandated under the rule. This social learning can take place both within and across households, as consumers learn from one another.

First and most directly, the time and fuel savings associated with operating more fuel efficient vehicles may be more salient to individuals who own them, which might cause their subsequent purchase decisions to shift closer to minimizing the total cost of ownership over the lifetime of the vehicle.

Second, this appreciation may spread across households through word of mouth and other forms of communications.

Third, as more motorists experience the time and fuel savings associated with greater fuel efficiency, the price of used cars will better reflect such efficiency, further reducing the cost of owning more efficient vehicles for the buyers of new vehicles (since the resale price will increase).

If these induced learning effects are strong, the rule could potentially increase total vehicle sales over time. It is not possible to quantify these learning effects years in advance and that effect may be speeded or slowed by other factors that enter into a consumer's valuation of fuel efficiency in selecting vehicles. The possibility that the rule will (after a lag for consumer learning) increase sales need not rest on the assumption that automobile manufacturers are failing to pursue profitable opportunities to supply the vehicles that consumers demand. In the absence of the rule, no individual automobile manufacturer would find it profitable to move toward the more efficient vehicles mandated under the rule. In particular, no individual company can fully internalize the future boost to demand resulting from the rule. If one company were to make more efficient vehicles, counting on consumer learning to enhance demand in the future, that company would capture only a fraction of the extra sales so generated, because the learning at issue is not specific to any one company's fleet. Many of the extra sales would accrue to that company's competitors.

In other words, consumer learning about the benefits of fuel efficient vehicles involves positive externalities (spillovers) from one company to the others[MMMMM]. These positive externalities may lead to benefits for manufacturers as a whole. We emphasize that this discussion has been tentative and qualified. To be sure, social learning of related kinds has been identified in a number of contexts.[326] Comments are invited on the discussion offered here, with particular reference to any relevant empirical findings.

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

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[MMMMM] Industrywide positive spillovers of this type are hardly unique to this situation. In many industries, companies form trade associations to promote industry-wide public goods. For example, merchants in a given locale may band together to promote tourism in that locale. Antitrust law recognizes that this type of coordination can increase output.

similar to the average time that a new vehicle purchaser holds onto the vehicle.[NNNNN] 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.[OOOOO] 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, we present 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. The calculation of the payback period is discussed in DRIA Chapter 5.3. Table 8.1-1 shows the estimated payback period for MY 2021 and 2025. We present MY 2021 because it is the last year before the mid-term review impacts, if any, will take place, and MY 2025 because it is the last year of the program. The payback period in 2021 is shorter than that in 2025, because the technologies required to meet the proposed MY 2021 standards are more cost-effective than those for MY 2025. In all cases, the payback periods are less than 4 years.

Table 8.1-1 Estimated Payback Period for Model Years 2021 and 2025 (Years)

Model Year	Estimated Payback Period for Cash Purchase, 3% Discount Rate	Estimated Payback Period for Cash Purchase, 7% Discount Rate	Estimated Payback Period for Purchase on Credit, 3% Discount Rate	Estimated Payback Period for Purchase on Credit, 7% Discount Rate
2021	2.7	2.9	2.9	2.8
2025	3.7	3.9	3.9	3.9

We welcome comments on all aspects of this discussion, including the full range of considerations and assumptions which influence market behavior and outcomes; and associated uncertainties. We welcome comments on the methodology described here for quantitative estimates of the effects of this proposal on sales and its appropriateness for this rulemaking; we also welcome proposals for other methods.

[NNNNN] In this proposal, 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, model year, and car vs. truck).

[OOOOO] 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.

We here provide further detail on some of the assumptions included in the payback analysis. We seek comment on all these factors as well. The analysis starts with the increase in costs estimated by the OMEGA model. We assume that these costs are fully passed along to consumers. This assumption is appropriate for cost increases in perfectly competitive markets. In less than perfectly competitive markets, though, it is possible that the cost increase is split between consumers and automakers, and possibly suppliers, and the price may not increase as much as costs.[327] Thus, the assumption of full cost pass-through is possibly an overestimate.

The next step in the analysis is to adjust this cost increase for other effects on the consumer. The higher vehicle price is likely to lead to an increase in sales tax, insurance, and vehicle financing costs.

The increase in insurance costs is estimated from the average value of collision plus comprehensive insurance as a proportion of average new vehicle price. Collision plus comprehensive insurance is the portion of insurance costs that depend on vehicle value. The Insurance Information Institute[328] provides the average value of collision plus comprehensive insurance in 2008 as $432. The average value of a new vehicle in 2008, according to the U.S. Department of Energy, was $23,334.[329] Dividing the insurance cost by the average price of a new vehicle gives the proportion of comprehensive plus collision insurance as 1.85 percent of the price of a vehicle. If this same proportion holds for the increase in price of a vehicle, then insurance costs should go up by 1.85 percent of the increase in vehicle cost. We use information on depreciation of vehicle value from the same U.S. Department of Energy report to estimate a reduction in insurance costs, due to reduction in the estimated value of the vehicle, over 9 years.

Calculating the average increase in sales tax starts with the vehicle sales tax for each state in 2006, the most recent source identified.[330] The sales tax per state was then multiplied by the 2010 population of the state;[331] those values were summed and divided by total U.S. population, to give a population-weighted sales tax. That estimate of the state sales taxes for vehicles in the U.S. is 5.3 percent. This value is assumed to be a one-time cost incurred when the vehicle is purchased.

As of July, 2011, the national average interest rate for a 5 year new car loan was 5.51 percent.[332] We use this loan rate to calculate the increase in vehicle costs due to financing a loan.

8.1.2 Consumer Vehicle Choice Modeling[PPPPP]

An alternative to the vehicle sales analysis 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

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[PPPPP] 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.

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 may be limited. 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, but, given the known limitations and uncertainties of vehicle choice models, EPA has not conducted an analysis using these models for this proposal.

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.

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 compliance costs compared to models that hold fleet mix constant, since it predicts changes in the fleet mix that can affect 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 is 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.[QQQQQ] 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,[333] Greene et al.,[334] and McManus.[335]

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 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,[336] Bento et al.,[337] and Train and Winston.[338]

While discrete choice modeling appears to be the primary method for consumer choice modeling, others (such as Kleit[339] and Austin and Dinan[340]) 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.[341] Because they draw on

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[QQQQQ] 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).

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.[342]

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[343] and the New Vehicle Market Model developed by NERA Economic Consulting[344] 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;[345] others consider the choice between new vehicles and an outside good (possibly including a used vehicle);[346] others explicitly consider the relationship between the new and used vehicle markets.[347] Some models include consideration of vehicle miles traveled,[348] 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;[349] others include varying numbers and kinds of vehicle and consumer attributes.

Some models include only the consumer side of the vehicle market;[350] others seek to represent both consumer and producer decisions.[351] 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.[352] 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.[353] 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.[354]

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,[355] 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,[356] the market acceptability of alternative-fuel vehicles,[357] the effects of introduction and exit of vehicles from markets,[358] causes of the decline in market shares of U.S. automakers,[359] and the effects of gasoline taxes[360] and "feebates"[361] (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. It can appear in various forms.

Some models[362] 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. Turrentine and Kurani[363] 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:[364] since consumers pay for gallons of fuel, then this measure can assess fuel savings relatively directly.[365] Yet other models multiply fuel consumption per mile by the cost of fuel to get the cost of driving a mile,[366] or they divide fuel economy by fuel cost to get miles per dollar.[367] 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.[RRRRR] 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[368] presents results that higher fuel prices play a major role in that decision.

Greene and Liu,[369] 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

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[RRRRR] 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 4.2.5.2 of the TSD).

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[370] 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[371] includes both 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[372] 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[373] 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[374] 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 which 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,[375] 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.[376] 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 put little weight on benefits from fuel economy in the future and show high discount rates;
- Consumers do not find the benefits from fuel economy to be sufficiently salient at the time of purchase, even if it would be in consumers' economic interest to take account of those benefits;
- Consumers consider other attributes more important than fuel economy at the time of vehicle purchase, especially if fuel economy is a relatively "shrouded" attribute;
- Consumers have difficulty in calculating expected fuel savings;
- Consumers may use imprecise rules of thumb when deciding how much fuel economy to purchase;
- Consumers might associate higher fuel economy with inexpensive, less well designed vehicles;
- Fuel savings in the future are uncertain, while at the time of purchase the increased costs of fuel-saving technologies are certain and immediate;
- Consumers may not be able to find the vehicles they want with improved fuel economy;
- The level of cost savings may be affected by the underlying reasons for the gap: factors such as transactions costs and differences in quality may not be adequately measured;[377]
- There is likely to be variation among consumers in the benefits they get from improved fuel economy, due to different miles driven and driving styles;
- Consumers may give particular weight to the losses associated with upfront costs, and less so to the costs over time (a version of the phenomenon of "myopic loss aversion").

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 underlying causes, and their potential significance for assessing the potential incremental effects of pollution control standards. We welcome comments on any aspect of this discussion.

8.1.2.7 Modeling 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.[SSSSS] They may have different 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.[378] 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, 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 8.1-2 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.

[SSSSS] 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 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 8.1-2 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 2009$[a]
Bunch et al. (1993)[b]	$7,600 (1991$)	$11,100
Kavelek (1996) for California Energy Commission[c]	$2600 - $41,900 (1993$)	$3700 - $58,700
Resource Systems Group (2009) for California Energy Commission[d]	$2900 - $7500 (2009$)	$2900 - $7500
Hess et al. (2009), using the same data as Resource Systems Group (2009)[e]	$2400 - $8500 (2009$)	$2400 - $8500
Hidrue et al. (2011)[f]	$3776 - $10,399 (2009$)	$3776 - $10,399

[a] Values adjusted to 2009$ 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 8.1-2, 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 in the process of developing a vehicle choice model. 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 draft 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) are being 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,[TTTTT] assist in

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[TTTTT] 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.

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 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 will take 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.[UUUUU] 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 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.

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 proposed standards, because the mix and volume of vehicles sold changed from the initial levels. To correct this problem, it would be necessary to feed the new fleet mix into OMEGA (which calculates costs and compliance) and get a new set of output, which could then be fed back into the vehicle choice model. OMEGA would increase 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 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.

[UUUUU] As explained in Section III.D of the preamble, as part of the technology cost analysis for the proposed rule, the agencies have estimated the cost of maintaining all vehicle utility, with minor exceptions.

The model is still undergoing development; EPA will seek peer review on it before it is utilized. In addition, concerns remain over the ability of any vehicle choice model to make reasonable predictions of the response of the vehicle fleet to changes in prices and vehicle characteristics. EPA seeks comments on the use of vehicle choice modeling for predicting changes in fleet mix due to policies, and on methods to test the ability of a vehicle choice model to produce reasonable estimates of changes in fleet mix.

8.1.2.9 Summary and Additional Considerations

Consumer vehicle choice modeling in principle can 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.

The modeling may 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 compliance costs: because the model allows consumers to choose among accepting the new vehicle, buying a different vehicle, or not buying a vehicle, 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. 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 proposal 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,[VVVVV] the price increase measures the loss to the buyer.[WWWWW] Assuming that the full technology cost gets passed along to the 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 proposal 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 exploration of a vehicle choice model for use in the future.

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."[379,XXXXX] The recently issued Executive Order 13563, "Improving Regulation and Regulatory Review"

[VVVVV] 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.

[WWWWW] 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 welfare, unless there are other changes to the vehicle due to the fuel economy improvements that make the vehicle less desirable to buyers.

[XXXXX] 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."

(January 18, 2011), states, "Our regulatory system must protect public health, welfare, safety, and our environment while promoting economic growth, innovation, competitiveness, and job creation" (emphasis added). EPA is accordingly providing partial estimates of the effects of this proposal on domestic employment in the auto manufacturing and parts sectors, while qualitatively discussing how it may affect employment in other sectors more generally.

This proposal 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 proposed standards.[380] 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 proposed 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 the RIA, this proposal 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 proposal 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.[YYYYY] 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.[381] 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 the regulatory

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[YYYYY] Masur and Posner, available at http://papers.ssrn.com/sol3/papers.cfm?abstract_id=1920441 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.[zzzzz] 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, 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). 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[382] 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

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[zzzzz] 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.

regulatory change on the regulated sector in the medium to longer 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,[AAAAAA] 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

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[AAAAAA] As will be discussed below, the demand effect in this proposal 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?

pollution control standards on industrial facilities that were considered in 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.[383]

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.[384] 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 proposal

As mentioned above, this program is expected to affect employment in the regulated sector (auto manufacturing) and other sectors directly affected by the proposal: auto parts suppliers, auto dealers, 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), and consumers (who will face higher vehicle costs and lower fuel expenditures). 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 proposal on the regulated sector (the auto industry; for reasons discussed below, we include some quantitative assessment of effects on suppliers to the industry although they are not regulated directly). It also includes qualitative discussion of the effects of the proposal 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 proposal. Secondly, 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 proposal 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. The agencies seek comment on other sectors that are likely to be significantly affected and thus warrant further analysis in the final rulemaking analysis.

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 proposal 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 unambiguously decreased employment, there are countervailing effects in the vehicle market due to the fuel savings resulting from this program. On one hand, this proposal will increase vehicle costs; by itself, this effect would reduce vehicle sales. On the other hand, this proposal 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 proposal, we do not quantify the demand effect.

8.2.3.1.2 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 new or additional technologies needed for vehicles to comply with the proposed 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 proposal 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 public sources for estimates of employment per $1 million expenditures. The U.S. Bureau of Labor Statistics (BLS) provides its Employment Requirements Matrix (ERM),[385] which provides direct estimates of the employment per $1 million in sales of goods in 202 sectors. The most recent estimates, used here, are from 2008 (adjusted to 2009$). The tables used here are adjusted to remove the employment effects of imports through use of the ratio of domestic production to domestic sales, described above, of 0.667. The values reported are for Motor Vehicle Manufacturing (NAICS 3361) and Motor Vehicle Parts Manufacturing (NAICS 3363).

The Annual Survey of Manufactures[386] (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 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 2009. 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 2009$), 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 8.2-1 provides the values, either given (BLS) or calculated (ASM, Economic Census) for employment per $1 million of expenditures, all based on 2009 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 8.2-1 Employment per $1 Million Expenditures (2009$) 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	0.834	0.556
ASM	Motor Vehicle Mfg	0.824	0.549
ASM	Light Duty Vehicle Mfg	0.757	0.505
Economic Census	Motor Vehicle Mfg	0.674	0.449
Economic Census	Light Duty Vehicle Mfg	0.610	0.407
BLS ERM	Motor Vehicle Parts Mfg	3.073	2.049
ASM	Motor Vehicle Parts Mfg	3.093	2.063
Economic Census	Motor Vehicle Parts Mfg	2.749	1.833

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, 1.52 workers were needed per $1 million of 2000$, but only 0.83 workers by 2008 (in 2000$).[387] Because the ERM is available annually for 1993-2008, we used these data to estimate productivity improvements over time. We regressed logged ERM values on year (to estimate percent change per year) for both the Motor Vehicle Manufacturing and Motor Vehicle Parts Manufacturing sectors. The results suggest a 4.4 percent per year productivity improvement in the Motor Vehicle Manufacturing Sector, and a 3.6 percent per year improvement in the Motor Vehicle Parts Manufacturing Sector. We then used the regression relationship to project the ERM through 2025. In the results presented below, these projected values (adjusted to 2009$) 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 2009 (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). As noted above, we adjusted the estimate of workers per vehicle for the demand effect in Chapter 8.2.3.1.1, above, using the productivity improvement for the Motor Vehicle Manufacturing sector; because the estimate of workers per vehicle for the demand effect was based on data from 2001 to 2010, we used the projected value of the ERM in 2005 as the denominator of the ratio. This is a simple way to examine the relationship between labor required and expenditure and we seek comment on refining this method.

Table 8.2-2 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 2.049 in 2009 if all the additional costs are in the parts sector; the minimum value is 0.407 in 2009, 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 2009. The results in Table 8.2-2 include the productivity adjustment described above.

While we estimate employment impacts beginning with the first year of the standard (2017), some of these job gains may occur earlier as auto manufacturers and parts suppliers hire staff in anticipation of compliance with the standard.

Table 8.2-2 Employment due to Cost Effect in the Motor Vehicle Manufacturing Sector

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	$ 2,300	600	3,600
2018	$ 4,656	1,200	7,000
2019	$ 6,507	1,600	9,400
2020	$ 8,467	1,900	11,800
2021	$ 11,878	2,600	15,900
2022	$ 19,340	4,100	25,000
2023	$ 25,036	5,000	31,200
2024	$ 30,738	5,900	37,000
2025	$ 33,561	6,200	39,000

8.2.3.1.3 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 proposed 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.[388] 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 proposed 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 proposed 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 8.2-3 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 proposal, 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 proposed 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 proposal.

Table 8.2-3 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

8.2.3.1.4 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 proposed standards on employment for auto dealers depend principally on the effects of the standards on light duty vehicle sales. 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.

Although this proposal predicts very small penetration of advanced technology 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 proposed 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 proposed 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 proposed 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 Chapter 5.3. 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 Chapter 5.3. This new fuel may require additional infrastructure, such as electricity charging locations. Providing this infrastructure 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 proposed 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.10.b); 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 proposal are expected to be found throughout several key sectors: auto manufacturers, auto dealers, auto parts manufacturing, fuel production and supply, and consumers.

These proposed 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 600 – 3,600 workers 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 is ambiguous and depends on changes in vehicle sales, which are not quantified for this proposal. 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 fuel production implies less employment in the petroleum sectors. 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 proposing to certify that this proposed rule would 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 would not be subject to this proposed rule. We are proposing to exempt small business entities from the proposed 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 model year certification database. 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 21 entities that appear to fit the Small Business Administration (SBA) criterion of a small business. EPA estimates there are about 4 small vehicle manufacturers, including three electric vehicle manufacturers, 8 independent commercial importers (ICIs), and 9 alternative fuel vehicle converters in the light-duty vehicle market which may qualify as small businesses.[389] 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 proposing to exempt from the proposed 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.[390] 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 proposing to exempt small businesses from the GHG standards, we are proposing to certify that the rule would 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.

Based on input we have heard from at least one small business vehicle manufacturer, EPA is proposing to allow small businesses to voluntarily waive their small entity exemption and optionally certify to the GHG standards. This would allow small entity manufacturers to earn CO_2 credits under the GHG program, if their actual fleetwide CO_2 performance was better than their fleetwide CO_2 target standard. EPA is proposing to make the GHG program opt-in available starting in MY 2014, as the MY 2012, and potentially the MY 2013, certification process will have already occurred by the time this rulemaking is finalized. EPA is also proposing that manufacturers certifying to the GHG standards for MY 2014 would be eligible to generate early credits for vehicles sold in MY 2012 and MY 2013. EPA is proposing that manufacturers waiving their small entity exemption would be required to meet all aspects of the GHG standards and program requirements across their entire product line. However, the exemption waiver would be 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 proposed standards would impose no significant adverse impact on small entities.

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