APPENDIX E

EPA Draft Regulatory Impact Assessment

EPA-420-D-09-003

September 2009

Draft Regulatory Impact Analysis:

Proposed Rulemaking to Establish Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards

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

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List of Acronyms

2-mode: 2-mode hybrid electric vehicle
2V: 2-valves per cylinder
4V: 4-valves per cylinder
12V: 12 Volts
42V: 42 Volts
A/C: Air conditioner/conditioning
AERO: Improved aerodynamics
ASL: Aggressive Shift Logic
AT: Automatic transmission
CAFE: Corporate Average Fuel Economy
CCP: Couple Cam Phasing
CO2: carbon dioxide
CVA: Camless Valve Actuation (full)
CVT: Continuously Variable Transmission
CVVL: Continuous Variable Valve Lift
Deac: Cylinder Deactivation
DICE: Dynamic Integrated Model of Climate and the Economy
DCP: Dual (independent) Cam Phasing
DCT: 6-speed Dual Clutch Transmission
DOHC: Dual Overhead Camshafts
DOT: Department of Transportation
DVVL: Discrete (two-step) Variable Valve Lift
EFR: Engine Friction Reduction
EIS: Environmental Impact Statement
EPS: Electric Power Steering
FUND:Climate Framework for Uncertainty, Negotiation, and Distribution
GDI: Gasoline Direct Injection
GHG: Greenhouse gas
HCCI: Homogenous Charge Compression Ignition (gasoline)
HEV: Hybrid Electric Vehicle
I3: In-line 3-cylinder engine
I4: In-line 4-cylinder engine
IACC: Improved Accessories
IAM: Integrated Assessment Model
IMA: Integrated Motor Assist
IPCC: Intergovernmental Panel on Climate Change
L4: Lock-up 4-speed automatic transmission
L5: Lock-up 5-speed automatic transmission
L6: Lock-up 6-speed automatic transmission
LDB: Low drag brakes
LRR: Low Rolling Resistance
LUB: Low-friction engine lubricants
MPV: Multi-Purpose Vehicle
MY: Model Year

NESCCAF: Northeast States Center for a Clean Air Future
NHTSA: National Highway Transportation Safety Administration
OECD: Organization for Economic Cooperation and Development
OHV: Overhead Valve (pushrod)
OMB: Office of Management and Budget
ORNL: Oak Ridge National Laboratory
PAGE: Policy Analysis for the Greenhouse Effect
PHEV: Plug-in Hybrid Electric Vehicle
PRTP: Pure Rate of Time Preference
S&P: Standard and Poor's
SCC: Social Cost of Carbon
SCR: Selective Catalytic Reduction
SOHC: Single Overhead Camshaft
SRES: Special Report on Emissions Scenarios
S-S: Stop-start hybrid system
THC: Thermohaline circulation
TORQ: Early torque converter lockup
Turbo: Turbocharger/Turbocharging
V6: 6-cylinder engine in a "V" configuration
V8: 8-cylinder engine in a "V" configuration
WGII: Working group II

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Executive Summary

The Environmental Protection Agency (EPA) and the National Highway Traffic Safety Administration (NHTSA) are issuing a joint proposal to establish new standards for light-duty highway vehicles that will reduce greenhouse gas emissions and improve fuel economy. The joint proposed rulemaking is consistent with the National Fuel Efficiency Policy announced by President Obama on May 19, 2009, responding to the country's critical need to address global climate change and to reduce oil consumption. 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, as amended. These standards apply to passenger cars, light-duty trucks, and medium-duty passenger vehicles, covering model years 2012 through 2016. They would require these vehicles to meet an estimated combined average emissions level of 250 grams of CO2 per mile in MY 2016 under EPA's GHG program, and 34.1 mpg in MY 2016 under NHTSA's CAFE program and represent a harmonized and consistent national program (National Program). These standards are designed such that compliance can be achieved with a single national vehicle fleet whose emissions and fuel economy performance improves year over year. The proposed National Program would result in approximately 950 million metric tons of CO2 emission reductions and approximately 1.8 billion barrels of oil savings over the lifetime of vehicles sold in model years 2012 through 2016.

The vehicle categories covered by the rulemaking are responsible for almost 60 percent of all U.S. transportation-related greenhouse gas emissions and include cars, sport utility vehicles, minivans, and pickup trucks used for personal transportation. Transportation related emissions are responsible for approximately 30 percent of total U.S. greenhouse gas emissions. Under the National Program, automobile manufacturers would be able to build a single light-duty national fleet that satisfies all requirements under both programs while ensuring that consumers still have a full range of vehicle choices.

This draft regulatory impact analysis (DRIA) contains supporting documentation to the EPA proposal. NHTSA has prepared their own Proposed RIA (PRIA) in support of their proposal (this can be found in NHTSA's docket for their proposal, NHTSA-2009-0059). While the two proposals 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 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, which can be found in EPA's docket EPA-HQ-OAR-2009-0472). 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 proposal.

Specifically, this document contains, in Chapter 1, a description of EPA's use of technology packages in the OMEGA model. This discussion builds on the discussion contained in Chapter 3 of the draft joint TSD which provides details of technology costs and effectiveness but only an overview of how technologies are put together into packages for the OMEGA model. Chapter 1 also contains a discussion of the lumped parameter model which is a major part of our determination of the effectiveness of these packages.

In Chapter 2, we present a detailed discussion of our AC credit program and the technology costs and effectiveness associated with new AC systems. This discussion is unique to this DRIA as the AC-related proposal is unique to EPA.

In Chapter 3, we present the technical basis of EPA's proposed standards and an analysis of the "footprint" approach EPA is proposing for establishing standards. In Chapter 4, we present an overview of the OMEGA model and the modeling results (actual OMEGA model inputs and outputs) in support of the proposed program and the alternative standards that were considered. Chapter 5 presents the emission reductions expected from the proposal. Chapter 6 presents the program costs and fuel savings associated with EPA's proposal. Chapter 7 presents the environmental and health impacts, including EPA's discussion of the social cost of carbon, and Chapter 8 presents other economic and social impacts—e.g., less time spent refueling due to higher fuel efficiency—of the proposal. Chapter 9 presents our analysis of the small business impacts due to EPA's proposal. All of these discussions—Chapters 3 through 9—are unique to this DRIA since, even though many of the metrics are common between EPA and DOT, we have different results due to our use of different models (EPA's OMEGA model versus DOT's CAFE Compliance and Effects Modeling System (often referred to as "the CAFE model" or "the Volpe model")) and the differences in our programs (e.g., AC credits versus no AC credits, plus many other program flexibilities).

Greenhouse Emission Impacts of EPA's Proposal

Table 1 shows reductions estimated from EPA's proposed GHG standards assuming a pre-control case of 2011 MY CAFE standards continuing indefinitely beyond 2011, and a post-control case in which 2016 MY standards continue indefinitely beyond 2016. These reductions are broken down by upstream and downstream components, including air conditioning improvements, and also account for the offset from a 10 percent "rebound" effect in vehicle miles travelled as discussed in Chapter 4 of the joint draft TSD.[A] Including the reductions from upstream emissions, total reductions are estimated to reach 325 MMTCO$_2$eq (million metric tons of CO$_2$ equivalent emissions) annually by 2030 (a 21 percent reduction in U.S. car and light truck emissions), and grow to over 500 MMTCO$_2$eq in 2050 as cleaner vehicles continue to come into the fleet (a 23 percent reduction in U.S. car and light truck emissions).

[A] "Rebound VMT" is the term used to describe the increase in driving that might occur as vehicle fuel consumption decreases (i.e., the fuel economy improves) since the cost per mile of operating the vehicle decreases. As a result of this rebound effect, the benefits of the proposed rule are offset slightly since owners of compliant vehicles drive more miles resulting in slightly more GHG emissions. Importantly, the adverse effects, or disbenefits, of rebound VMT are far outweighed by the overall benefits of the proposal.

Table 1. Projected Net GHG Reductions (MMT CO_2 Equivalent per year)

CALENDAR YEAR	2020	2030	2040	2050
Net reduction to tailpipe standards*	165.2	324.6	417.5	518.5
Tailpipe standards	*107.7*	*211.4*	*274.1*	*344.0*
A/C – indirect CO2	*11.0*	*21.1*	*27.3*	*34.2*
A/C – direct HFCs	*13.5*	*27.2*	*32.1*	*34.9*
Upstream	*33.1*	*64.9*	*84.1*	*105.5*
Percent reduction relative to U.S. reference (cars + light trucks)	12.4%	2.14%	22.8%	22.9%
Percent reduction relative to U.S. reference (all sectors)	2.2%	4.2%	5.2%	6.2%
Percent reduction relative to worldwide reference	0.3%	0.6%	0.7%	0.9%

* includes impacts of 10% VMT rebound rate presented in Table III.F.1-3

Criteria Pollutant Impacts of EPA's Proposal

As shown in Table 2, EPA estimates that the proposed program would result in reductions of oxides of nitrogen (NOx), volatile organic compounds (VOC), particulate matter (PM) and oxides of sulfur (SOx), but would increase carbon monoxide (CO) emissions. The CO increase is because gasoline fueled passenger cars and light trucks contribute over 50 percent of the total CO emissions in the US, whereas for other pollutants the contribution is less than 40 percent. Thus, for CO the increase from VMT rebound outweighs the upstream CO reductions. For all pollutants the overall impact of the program would be relatively small compared to total U.S. inventories across all sectors. In the year 2030, EPA estimates the proposed program would reduce these total NOx, PM and SOx inventories by 0.2 to 0.3 percent and reduce the VOC inventory by 1.2 percent, while increasing the total national CO inventory by 0.4 percent.

As shown in Table 3, EPA estimates that the proposed program would result in small changes for toxic emissions compared to total U.S. inventories across all sectors. In 2030, EPA estimates the program would reduce total benzene and formaldehyde by 0.04 percent. Total acrolein, acetaldehyde, and 1,3-butadiene would increase by 0.03 to 0.2 percent.

Other factors which may impact criteria, or non-GHG, emissions but are not estimated in this analysis include:

- Vehicle technologies used to reduce tailpipe CO2 emissions; because the regulatory standards for non-GHG emissions are the primary driver for these emissions, EPA expects the impact of today's program to be negligible on non-GHG emission rates per mile.
- The potential for increased market penetration of diesel vehicles; because these vehicles would be held to the same certification and in-use standards for criteria pollutants as their gasoline counterparts, EPA expects their impact to be negligible on criteria pollutants and other non-GHG emissions.
- Early introduction of electric vehicles and plug-in hybrid electric vehicles, which would reduce criteria emissions in cases where they are able to certify to lower certification standards. It would also likely reduce gaseous air toxics.
- Reduced refueling emissions due to less frequent refueling events and reduced annual refueling volumes resulting from the GHG standards.
- Increased hot soak evaporative emissions due to the likely increase in number of trips associated with VMT rebound modeled in this proposal.
- Increased market share of E10 relative to E0, due to the decreased overall gasoline consumption of today's proposal combined with an unchanged fuel ethanol volume.

Table 2. Annual Criteria Emission Impacts of Program (short tons)

	TOTAL IMPACTS		UPSTREAM IMPACATS		DOWNSTREAM IMPACTS	
	2020	2030	2020	2030	2020	2030
VOC	-73,739	-142,347	-75,437	-147,841	1,698	5,494
% of total inventory	-0.60%	-1.20%	-0.61%	-1.20%	0.01%	0.05%
CO	70,614	227,832	-7,209	-14,107	77,823	241,939
% of total inventory	0.13%	0.38%	-0.01%	-0.02%	0.14%	0.40%
NO_X	-17,206	-27,726	-22,560	-43,286	5,354	15,560
% of total inventory	-0.14%	-0.20%	-0.18%	-0.36%	0.04%	0.13%
PM2.5	-2,856	-5,431	-3,075	-6,003	218	572
% of total inventory	-0.08%	-0.16%	-0.09%	-0.18%	0.01%	0.02%
SOx	-16,307	-31,965	-13,804	-27,060	-2,503	-4,906
% of total inventory	-0.18%	-0.34%	-0.16%	-0.29%	-0.03%	-0.05%

Table 3. Annual Air Toxic Emission Impacts of Program (short tons)

	TOTAL IMPACTS		UPSTREAM IMPACATS		DOWNSTREAM IMPACTS	
	2020	2030	2020	2030	2020	2030
1,3-Butadiene	11	37	-1.8	-3.4	13.2	40.2
% of total inventory	0.07%	0.22%	-0.01%	-0.02%	0.08%	0.24%
Acetaldehyde	17	61	-8	-15	24.8	75.5
% of total inventory	0.04%	0.13%	-0.02%	-0.03%	0.05%	0.17%
Acrolein	0	2	-1.1	-2	1.3	3.9
% of total inventory	0.00%	0.03%	0.00%	0.00%	0.02%	0.06%
Benzene	-84	-77	-163	-320	79.6	242.2
% of total inventory	-0.04%	-0.04%	-0.08%	-0.15%	0.04%	0.11%
Formaldehyde	-28	-16	-60	-112	31.8	96.3
% of total inventory	-0.03%	-0.02%	-0.07%	-0.10%	0.04%	0.11%

Costs and Benefits of EPA's Proposal

Table 4 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 a 3 percent and a 7 percent discount rate. The table includes the benefits of reduced GHG emissions—and consequently the annual net benefits—for each of five interim SCC values considered by EPA (please refer to Chapter 7 of this DRIA for a discussion of the five interim SCC values). As noted in Chapter 7, there is a very high probability (very likely according to the IPCC) that the benefit estimates from GHG reductions are underestimates because, in part, models used to calculate SCC values do not include information about impacts that have not been quantified. Note that the quantified annual costs shown in Table 4 are negative because fuel savings are included. Fuel savings are considered as negative costs (i.e., positive benefits) of the proposed vehicle program. The fuel savings outweigh the costs associated with the addition of new technology and, therefore, the vehicle program costs are negative.

Table 4 Quantified Net Benefits Associated with the Proposed Light-Duty Vehicle GHG Program[a, b]

(Millions of 2007 dollars)

	2020	2030	2040	2050	NPV, 3%	NPV, 7%
Quantified Annual Costs	-$25,100	-$72,500	-$105,700	-$146,100	-$1,287,600	-$529,500
Quantified Annual Benefits at each assumed SCC value						
SCC 5%	$9,900	$21,100	$30,200	$42,100	$400,900	$177,200
SCC 5% Newell-Pizer	$11,200	$24,400	$35,500	$51,600	$470,100	$205,700
SCC from 3% and 5%	$13,400	$29,800	$46,500	$68,600	$594,700	$257,100
SCC 3%	$16,900	$39,800	$62,500	$95,600	$788,600	$337,100
SCC 3% Newell-Pizer	$22,700	$53,800	$87,500	$132,600	$1,093,100	$462,800
Quantified Net Benefits at each assumed SCC value						
SCC 5%	$35,000	$93,600	$135,900	$188,200	$1,688,500	$706,700
SCC 5% Newell-Pizer	$36,300	$96,900	$141,200	$197,700	$1,757,700	$735,200
SCC from 3% and 5%	$38,500	$102,300	$152,200	$214,700	$1,882,300	$786,600
SCC 3%	$42,000	$112,300	$168,200	$241,700	$2,076,200	$866,600
SCC 3% Newell-Pizer	$47,800	$126,300	$193,200	$278,700	$2,380,700	$992,300

[a] Note that the co-pollutant impacts associated with the 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 PM2.5 exposure. Ideally, human health and environmental co-benefits would be based on changes in ambient PM2.5 and ozone as determined by full-scale air quality modeling. However, we were 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.

[b] Quantified annual costs are shown as negative here because fuel savings are included. Fuel savings are considered as negative costs (i.e., positive benefits) of the proposed vehicle program. The fuel savings outweigh the costs associated with the addition of new technology and, therefore, the vehicle program costs are negative. The fuel impacts included here were calculated using pre-tax fuel prices.

CHAPTER 1: Technology Packages, Cost and Effectiveness

1.1 Overview of Technology

The proposed GHG program is based on the need to obtain significant GHG emissions reductions from the transportation sector, and the recognition that there are cost effective technologies to achieve such reductions in the 2012-2016 time frame. 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.

At the same time, the technological problems and solutions involved in this rulemaking differ in many ways from prior mobile source rulemakings. In the past the assessment of exhaust emissions control technology has focused on how to reduce the amount of various unwanted chemical compounds that are generated when fuel is combusted. The emissions are often the result of incomplete combustion, such as emissions of HC, CO, and PM. In some cases the combustion products are the result of the specific conditions under which combustion occurs, such as the relationship between emissions of NOx and the temperature of combustion. Technology to control exhaust emissions has focused, in part, on changing the fuel delivery and engine systems so there is more complete combustion of the fuel which generates less HC, CO, and PM in the engine exhaust but, by design, generates more CO_2. (CO_2 is one of ultimate combustion products of any carbon containing fuel, such as gasoline and diesel fuel.) Other changes to the fuel delivery and engine systems have been designed to change the combustion process to reduce the amount of NOx and PM generated by the engine. Very large reductions have been achieved by installing and optimizing aftertreatment (post-combustion, post- engine generated pollution) devices, such as catalytic converters and catalyzed diesel particulate filters (DPF), that reduce the amount of emissions of HC, CO, and PM by oxidizing or combusting these compounds in the aftertreatment device, again generating CO_2 in the process. In the case of NOx, aftertreatment devices have focused on the chemical process of reduction, or removal of oxygen from the compound. Therefore the exhaust emissions control technologies of the past have focused almost exclusively on (1) upgrading the fuel delivery and engine systems to control the combustion process to reduce the amount of unwanted emissions from the engine and in the process increase the amount of CO_2 emitted, and on (2) aftertreatment devices that either continue this oxidation process and increase emissions of CO_2, or otherwise change the compounds emitted by the engine. Since CO_2 is a stable compound produced by the complete combustion of the fuel – indeed serving as a marker of how efficiently fuel has been combusted, these two methods employed to address HC, CO, PM, and NOx are not available to address CO_2. Instead, the focus of the CO2 emissions control technology must be entirely different—reducing the amount of fuel that is combusted.

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 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. The braking system the aerodynamics 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. Finally, there are other advanced technologies under development, such as lean burn gasoline engines, which offer the potential of improved energy generation through improvements in the basic combustion process.

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 proposed 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 typically plan on a major redesign for the models approximately every 5 years. 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 often 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. 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 thus occur at the vehicle redesign stage and not in the time period between redesigns.

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 five model years at issue in this rulemaking, 2012-2016, EPA projects that almost the entire fleet of light-duty vehicles (i.e., 85 percent) will have gone through a redesign cycle. If the technology to control greenhouse gas emissions is efficiently folded into this redesign process, then by 2016 almost 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 HFCs from the air conditioner.

In determining the requisite technology and cost of these first ever GHG emissions standards for light-duty vehicles, EPA proposes to use 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 required by the GHG proposal is commercially available and already being employed to a limited extent across the fleet. The vast majority of the emission reductions which would result from the proposed rule would result from the increased the use of these technologies. EPA also believes the proposed rule would encourage the development and limited use of more advanced technologies, such as PHEVs and EVs.

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 through 1.6 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 CO2 emission reducing technologies from a wide range of sources. The primary sources of information were NHTSA's 2011 CAFE FRM and EPA's 2008 Staff Technical Report. In those analyses, piece costs and effectiveness were estimated based on a number of sources. The objective was to use those sources of information considered to be most credible. Those sources included: the 2002 NAS report on the effectiveness and impact of CAFE standards; the 2004 study done by the Northeast States Center for a Clean Air Future (NESCCAF); the California Air Resources Board (CARB) Initial Statement of Reasons in support of their carbon rulemaking; a 2006 study done by Energy and Environmental Analysis (EEA) for the Department of Energy; a study done by the Martec Group for the Alliance of Automobile Manufacturers, and an update by the Martec Group to that study; and vehicle fuel economy certification data. In addition, confidential data submitted by vehicle manufacturers in response to NHTSA's request for product plans were considered, as was confidential information shared by automotive industry component suppliers in meetings with EPA and NHTSA staff held during the second half of the 2007 calendar year. 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. EPA also has a contracted study ongoing with FEV (an engineering services firm) that consists of complete system tear-downs to evaluate technologies down to the nuts and bolts to arrive at very detailed estimates of the costs associated with manufacturing them. Lastly, cost and effectiveness estimates have been adjusted slightly as a result of further meetings between EPA and NHTSA staff in the first half of 2009 where both piece costs and fuel consumption efficiencies were discussed in detail. EPA also reviewed the published technical literature which addressed the issue of CO2 emission control, such as papers published by the Society of Automotive Engineers and the American Society of Mechanical Engineers. The results of all of the research and discussions are summarized in Chapter 3 of the draft Joint Technical Support Document.

EPA reviewed all this information in order to develop the best estimates of the cost and effectiveness of CO2 reducing technologies. These estimates were developed for five vehicle classes: small car, large car, minivan, small truck and large truck. All vehicle types were mapped into one of these five classes in EPA's analysis (see Chapter 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., electronic power steering), or vehicle-related (e.g., low rolling resistance tires). Table 1-1 through Table 1-5 show estimates of the near term cost associated with various technologies for the five vehicle classes used in this analysis. These estimates shown in Table 1-1 through Table 1-5 are relative to a baseline vehicle having a multi-point, port fuel injected gasoline engine operating at a stoichiometric air-fuel ratio with fixed valve timing and lift and without any turbo or super charging and equipped with a 4-speed automatic transmission. This configuration was chosen as the baseline vehicle because it is the predominant technology package sold in the United States. Costs are presented in terms of their hardware incremental compliance cost. This means that they include all potential 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 CO2 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 1-1 EPA's Incremental Piece Costs for Engine Technologies Marked up to include both Direct and Indirect Costs in 2016 (2007 Dollars per Vehicle)

	Technology	Incremental to	Vehicle Class				
			Small Car	Large Car	Minivan	Small Truck	Large Truck
	Low friction lubricants	Base engine	$3	$3	$3	$3	$3
	Engine friction reduction	Base engine	$50	$75	$75	$75	$100
OHC Engines	VVT – intake cam phasing	Base engine	$40	$80	$80	$80	$80
	VVT – coupled cam phasing	Base engine	$40	$80	$80	$80	$80
	VVT – dual cam phasing	Base engine	$73	$157	$157	$157	$157
	Cylinder deactivation	Base engine	n/a	$150	$150	$150	$169
	Discrete VVLT	Base engine	$125	$181	$181	$181	$259
	Continuous VVLT	Base engine	$245	$449	$449	$449	$489
OHV Engines	Cylinder deactivation	Base engine	n/a	$150	$150	$150	$169
	VVT – coupled cam phasing	Base engine	$40	$40	$40	$40	$40
	Discrete VVLT	Base engine	$141	$204	$204	$204	$291
	Continuous VVLT (includes conversion to Overhead Cam)	Base engine w/ VVT-coupled	$497	$1,048	$1,048	$1,048	$1,146
	Camless valvetrain (electromagnetic)	Base engine	$501	$501	$501	$501	$501
	GDI – stoichiometric	Base engine	$222	$287	$287	$287	$312
	GDI – lean burn	GDI - stoich	$623	$623	$623	$623	$623
Turbo w/o downsize Downsize w/o turbo	Turbocharge (single)	Base engine	$366	$366	$366	$366	$366
	Turbocharge (twin)	Base engine	$663	$663	$663	$663	$663
	Downsize to I4 DOHC	V6 DOHC	-$337	-$337	-$337	-$337	-$337
	Downsize to I4 DOHC	V6 SOHC	-$53	-$53	-$53	-$53	-$53
	Downsize to I4 DOHC	V6 OHV	$265	$265	$265	$265	$265
	Downsize to I4 DOHC	I4 DOHC (larger)	-$47	-$47	-$47	-$47	-$47
	Downsize to I3 DOHC	I4 DOHC	-$80	n/a	n/a	n/a	n/a
	Downsize to V6 DOHC	V8 DOHC	n/a	-$160	-$160	-$160	-$160
	Downsize to V6 DOHC	V8 SOHC 2V	n/a	$199	$199	$199	$199
	Downsize to V6 DOHC	V8 SOHC 3V	n/a	$111	$111	$111	$111
	Downsize to V6 DOHC	V8 OHV	n/a	$310	$310	$310	$310
Turbo with downsize	Downsize to I4 DOHC & add turbo	V6 DOHC w/o turbo	$214	$214	$214	$214	$214
	Downsize to I4 DOHC & add turbo	V6 SOHC w/o turbo	$453	$453	$453	$453	$453
	Downsize to I4 DOHC & add turbo	V6 OHV w/o turbo	$797	$797	$797	$797	$797
	Downsize to I4 DOHC & add turbo	I4 DOHC (larger) w/o turbo	$372	$372	$372	$372	$372
	Downsize to I3 DOHC & add turbo	I4 DOHC w/o turbo	$344	n/a	n/a	n/a	n/a
	Downsize to V6 DOHC & add twin turbo	V8 DOHC w/o turbo	n/a	$613	$613	$613	$613
	Downsize to V6 DOHC & add twin turbo	V8 SOHC 2V w/o turbo	n/a	$971	$971	$971	$971
	Downsize to V6 DOHC & add twin turbo	V8 SOHC 3V w/o turbo	n/a	$872	$872	$872	$872
	Downsize to V6 DOHC	V8 OHV w/o turbo	n/a	$1,096	$1,096	$1,096	$1,096

	& add twin turbo						
	Convert to V6 DOHC	V6 SOHC	n/a	$354	$354	$354	$354
	Convert to V6 DOHC	V6 OHV	n/a	$464	$464	$464	$464
	Convert to V8 DOHC	V8 SOHC 2V	n/a	$398	$398	$398	$398
	Convert to V8 DOHC	V8 SOHC 3V	n/a	$310	$310	$310	$310
	Convert to V8 DOHC	V8 OHV	n/a	$509	$509	$509	$509
	Gasoline HCCI dual-mode	GDI - stoich	$253	$375	$375	$375	$659
	Diesel – Lean NOx trap	Base gasoline engine					
	Diesel – urea SCR	Base gasoline engine		$2,655	$2,164	$2,164	$2,961

Table 1-2 EPA's Incremental Piece Costs for Transmission Technologies Marked up to include both Direct and Indirect Costs in 2016 (2007 Dollars per Vehicle)

Technology	Incremental to	Vehicle Class				
		Small Car	Large Car	Minivan	Small Truck	Large Truck
Aggressive shift logic	Base trans	$28	$28	$28	$28	$28
Early torque converter lockup	Base trans	$25	$25	$25	$25	$25
5-speed automatic	4-speed auto trans	$90	$90	$90	$90	$90
6-speed automatic	4-speed auto trans	$150	$150	$150	$150	$150
6-speed DCT – dry clutch	6-speed auto trans	$65	$65	$65	$65	$65
6-speed DCT – wet clutch	6-speed auto trans	$139	$139	$139	$139	$139
6-speed manual	5-speed manual trans	$79	$79	$79	$79	$79
CVT	4-speed auto trans	$192	$224	$224	n/a	n/a

Table 1-3 EPA's Incremental Piece Costs for Hybrid Technologies Marked up to include both Direct and Indirect Costs in 2016 (2007 Dollars per Vehicle)

Technology	Incremental to	Vehicle Class				
		Small Car	Large Car	Minivan	Small Truck	Large Truck
Stop-Start	Base engine & trans	$351	$398	$398	$398	$437
IMA/ISA/BSG (includes engine downsize)	Base engine & trans	$2,854	$3,612	$3,627	$3,423	$4,431
2-Mode hybrid electric vehicle	Base engine & trans	$4,232	$5,469	$5,451	$4,943	$7,236
Power-split hybrid electric vehicle	Base engine & trans	$3,967	$5,377	$5,378	$4,856	$7,210
Full-Series hydraulic hybrid	Base engine & trans	$750	$825	$825	$900	$1200
Plug-in hybrid electric vehicle	IMA/ISA/BSG hybrid	$6,922	$9,519	$9,598	$9,083	$12,467
Plug-in hybrid electric vehicle	Power-split hybrid	$5,423	$7,431	$7,351	$7,128	$9,643
Full electric vehicle	Base engine & trans	$27,628	n/a	n/a	n/a	n/a

Table 1-4 EPA's Incremental Piece Costs for Accessory Technologies Marked up to include both Direct and Indirect Costs in 2016 (2007 Dollars per Vehicle)

Technology	Incremental to	Vehicle Class				
		Small Car	Large Car	Minivan	Small Truck	Large Truck
Improved high efficiency alternator & electrification of accessories	Base accessories	$76	$76	$76	$76	$76
Upgrade to 42 volt electrical system	12 volt electrical system	$86	$86	$86	$86	$86
Electric power steering (12 or 42 volt)	Base power steering	$94	$94	$94	$94	$94

Table 1-5 EPA's Incremental Piece Costs for Vehicle Technologies Marked up to include both Direct and Indirect Costs in 2016 (2007 Dollars per Vehicle)

Technology	Incremental to	Vehicle Class				
		Small Car	Large Car	Minivan	Small Truck	Large Truck
Aero drag reduction (20% on cars, 10% on trucks)	Base vehicle	$42	$42	$42	$42	$42
Low rolling resistance tires	Base tires	$6	$6	$6	$6	$6
Low drag brakes (ladder frame only)	Base brakes	n/a	n/a	n/a	$63	$63
Secondary axle disconnect (unibody only)	Base vehicle	$514	$514	$514	$514	n/a
Front axle disconnect (ladder frame only)	Base vehicle	n/a	n/a	n/a	$84	$84

Table 1-6 through Table 1-10 summarize the CO_2 reduction estimates of various technologies which can be applied to cars and light-duty trucks. A similar summary of costs is provided in Chapter 3 of the draft joint TSD and each of these estimates is discussed in more detail there.

Table 1-6 Engine Technology Effectiveness

Technology	Absolute CO_2 Reduction (% from baseline vehicle)				
	Small Car	Large Car	Minivan	Small Truck	Large Truck
Low friction lubricants – incremental to base engine	0.5	0.5	0.5	0.5	0.5
Engine friction reduction – incremental to base engine	1-3	1-3	1-3	1-3	1-3
Overhead Cam Branch					
VVT – intake cam phasing	2	1	1	1	2
VVT – coupled cam phasing	3	4	2	3	4
VVT – dual cam phasing	3	4	2	2	4
Cylinder deactivation (includes imp. oil pump, if applicable)	n.a.	6	6	6	6
Discrete VVLT	4	3	3	4	4
Continuous VVLT	5	6	4	5	5
Overhead Valve Branch					
Cylinder deactivation (includes imp. oil pump, if applicable)	n.a.	6	6	6	6
VVT – coupled cam phasing	3	4	2	3	4
Discrete VVLT	4	4	3	4	4
Continuous VVLT (includes conversion to Overhead Cam)	5	6	4	5	5
Camless valvetrain (electromagnetic) **	5-15	5-15	5-15	5-15	5-15
Gasoline Direct Injection–stoichiometric (GDI-S)	1-2	1-2	1-2	1-2	1-2
Gasoline Direct Injection–lean burn (incremental to GDI-S) **	8-10	9-12	9-12	9-12	10-14
Gasoline HCCI dual-mode (incremental to GDI-S) **	10-12	10-12	10-12	10-12	10-12
Turbo+downsize (incremental to GDI-S)	5-7	5-7	5-7	5-7	5-7
Diesel – Lean NOx trap[ ]*	15-26 [25-35]	21-32 [30-40]	21-32 [30-40]	21-32 [30-40]	21-32 [30-40]
Diesel – urea SCR [ ]*	15-26 [25-35]	21-32 [30-40]	21-32 [30-40]	21-32 [30-40]	21-32 [30-40]

* Note: estimates for % reduction in fuel consumption are presented in brackets.

** Note: for reference only, not used in this rulemaking

Table 1-7 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)	2.5	2.5	2.5	2.5	2.5
Aggressive shift logic	1-2	1-2	1-2	1-2	1-2
Early torque converter lockup	0.5	0.5	0.5	0.5	0.5
6-speed automatic (from 4-speed auto)	4.5-6.5	4.5-6.5	4.5-6.5	4.5-6.5	4.5-6.5
6-speed AMT (from 4-speed auto)	9.5-14.5	9.5-14.5	9.5-14.5	9.5-14.5	9.5-14.5
6-speed manual (from 5-speed manual)	0.5	0.5	0.5	0.5	0.5
CVT (from 4-speed auto)	6	6	6	n.a.	n.a.

Table 1-8 Hybrid Technology Effectiveness

Technology	Absolute CO_2 Reduction (% from baseline vehicle)				
	Small Car	Large Car	Minivan	Small Truck	Large Truck
Stop-Start with 42 volt system	7.5	7.5	7.5	7.5	7.5
IMA/ISA/BSG (includes engine downsize)	30	25	20	20	20
2-Mode hybrid electric vehicle	n.a.	40	40	40	25
Power-split hybrid electric vehicle	35	35	35	35	n.a.
Full-Series hydraulic hybrid	40	40	40	40	30
Plug-in hybrid electric vehicle	58	58	58	58	47
Full electric vehicle (EV)	100	100	n.a.	n.a.	n.a.

Table 1-9 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)	1-2	1-2	1-2	1-2	1-2
Electric power steering (12 or 42 volt)	1.5	1.5-2	2	2	2
Improved high efficiency alternator & electrification of accessories (42 volt)	2-4	2-4	2-4	2-4	2-4

Table 1-10 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)	3	3	3	2	2
Low rolling resistance tires (10%)	1-2	1-2	1-2	1-2	n.a.
Low drag brakes (ladder frame only)	n.a.	n.a.	n.a.	1	1
Secondary axle disconnect (unibody only)	1	1	1	1	n.a.
Front axle disconnect (ladder frame only)	n.a.	n.a.	n.a.	1.5	1.5

1.3 Package Cost and Effectiveness

1.3.1 Explanation of Technology Packages

Individual technologies can be used by manufactures to achieve incremental CO2 reductions. However, as mentioned in Section 1.1, EPA believes that manufacturers are more likely to bundle technologies into “packages” to capture synergistic aspects and reflect progressively larger CO2 reductions with additions or changes to any given package. In addition, manufacturers typically apply new technologies in packages during model redesigns—which occur once roughly 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 here is to group technologies into packages of increasing cost and effectiveness. EPA determined that 19 different vehicle types provided adequate resolution required to accurately model the entire fleet. 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, and finally by the number of valves per cylinder. Note that each of these 19 vehicle types was mapped into one of the five classes of vehicles mentioned in Figure 1-1. While the five classes provide adequate resolution for the cost basis associated with technology application, they do not adequately account for all vehicle attributes such as base vehicle powertrain configuration and mass reduction. For example, costs and effectiveness estimates for the small car class were used to represent costs for three vehicle types: subcompact cars, compact cars, and small multi-purpose vehicles (MPV) equipped with a 4-cylinder engine, however the mass reduction associated for each of these vehicle types was based on the vehicle type sales weighted average. Note also that these 19 vehicle types span the range of vehicle footprints—smaller footprints for smaller vehicles and larger footprints for larger vehicles—which serve as the basis for the proposed GHG standards.

Within each of the 19 vehicle types multiple technology packages were created in increasing technology content and, hence, increasing effectiveness. Important to note is that the effort in creating the packages attempted to maintain a constant utility 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. The initial packages represent what a manufacturer will most likely implement on all vehicles, including low rolling resistance tires, low friction lubricants, engine friction reduction, aggressive shift logic, early torque converter lock-up, improved electrical accessories, and low drag brakes. Subsequent packages include advanced gasoline engine and transmission technologies such as turbo/downsizing, GDI, mass reduction and dual-clutch transmission. The most technologically advanced packages within a segment included HEV, PHEV and EV designs. The end result being a list of several packages for each of 19 different vehicle types from which a manufacturer could choose in order to modify its fleet such that compliance could be achieved.

The final step in creating the vehicle packages was to evaluate each package within the 19 vehicle types for cost-effectiveness. This was accomplished by dividing the incremental cost of the technology package by its incremental effectiveness and assessing the overall step in cost-effectiveness. Technology packages that demonstrated little to no increase in effectiveness and a significant increase in cost were eliminated as a choice for the model. This process provided several positive aspects in the package creation:

(1) Vehicle packages were not limited by any preconceived assumptions of which technologies should be more prominent. An example of this is turbo-downsizing a V6 engine. In some cases the GDI V6 with advanced valvetrain technology was just as effective as a turbo charge I4, thus excluding the additional cost of turbo charging;

(2) The OMEGA model was allowed to apply packages in an increasing order of both effectiveness and cost.

Some of the intermediate packages were not cost-effective. As a result, the model might be blocked from choosing a subsequent package that was cost-effective. Most of the diesel packages and some of the hybrid packages exhibited this condition. Due to the high cost of these packages, and effectiveness on par with advanced gas, the model would not move through these packages and choose a more cost effective package, thus blocking the model's logical progression. This is the reason for the absence of diesel and hybrid packages in some of the 19 vehicle types available for the OMEGA model. The specific criteria used to remove certain packages from use the model inputs is discussed further below. It is important to note that the burning of diesel fuel generates approximately 15% more CO2 than gasoline. As this rule is based on the reduction of CO2 emissions and not on fuel economy, this creates an additional effectiveness disadvantage for the diesel packages as compared to the advanced gas and gas hybrid packages.

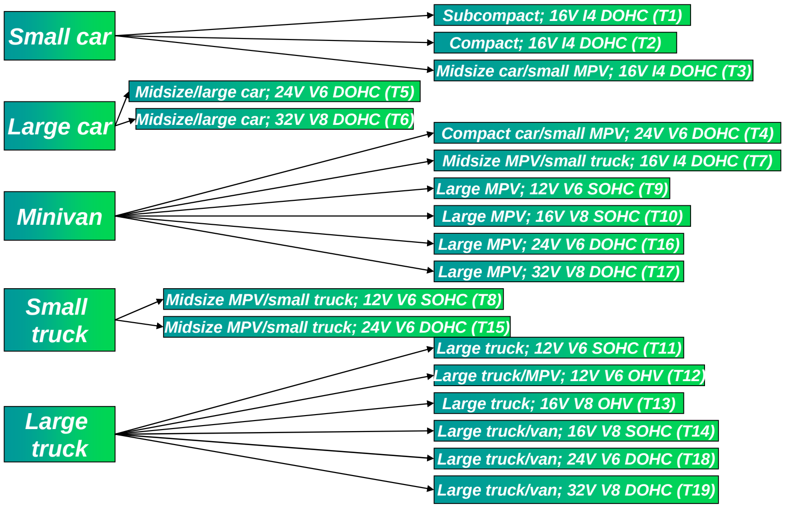


Figure 1-1 Scaling classes to Vehicle Type Mapping

1.3.2 Technology Package Costs & Effectiveness

As described above, technology packages were created for each of 19 different vehicle types. These packages are described in Table 1-11 and the 2016 MY costs for each package are also presented. Note that Table 1-11 includes all the packages created and considered by EPA. Only a subset of these packages was actually used as inputs to the OMEGA model because some of the packages were not desirable from a cost effectiveness standpoint (in other words, some packages would be skipped over if the next package provide more attractive cost effectiveness). Table 1-12 shows the package costs for the packages that were actually used as inputs to the OMEGA model (note that all packages are listed but only those for which costs are shown were actually used in the OMEGA model). This table shows the package costs for each model year 2012 through 2022 and later. This shows the impact of both learning effects and short-term versus long-term indirect cost markups on the package costs. For details of the learning effects and indirect cost markups used in this analysis refer to Chapter 3 of the draft joint TSD. By taking a simple average of the technology package costs for each year shown in Table 1-12 and then normalizing the averages to the 2016 model year average, the package costs for each year can be expressed as a percentage relative to 2016. These results are shown in Table 1-13. This table shows that package costs are, on average, 117% of the costs for 2016. This higher cost is due to backing out the learning effects that are built into the 2016 model year estimates. For 2014, the costs are 108% of those for 2016 as learning has occurred between 2012 and 2014. The costs for 2022 are 92% of those for 2016. This is the result of the long-term ICM kicking in as some indirect costs are no longer attributable to the proposed program. Table 1-12 also shows the effectiveness of each package used in the OMEGA model (note that the effectiveness of packages does not change with model year).

Table 1-11 Package Descriptions and 2016MY Costs for 19 Vehicle Types (T1-T19), All Packages Considered, Costs in 2007 dollars

Vehicle	Technology Package	Engine	Transmission	System Voltage	Camshaft changes (excluding those for downsized engines)	Lubes	Friction Rdxn	Downsize	Aftertreatment	Aggressive shift	Early torque lock	Alternator & electrificatio	Power steering	Aero	Low RR tires	Low drag brakes	Axle disconnect	Weight rdxn	2016 MY Cost
Subcomp I4 (T1)	baseline	1.5L - 4V DOHC I4	AT 4 spd	12 V															
	1	1.5L - 4V I4	AT 4 spd	12 V		LUB	EFR			ASL	TORQ	IACC 12V			LRR				$189
	2	1.5L - 4V I4 CCP	DCT 6 spd	12 V		LUB	EFR					IACC 12V	EPS	AERO 1	LRR			3%	$716
	3	1.2L I3 DVVL + CCP + GDI	dry DCT 6 spd	42 S-S		LUB	EFR	I4 to I3				IACC 42V	EPS	AERO 1	LRR			5%	$1,422
	4	0.7L I3 (small) Turbo DCP + GDI	dry DCT 6 spd	42 S-S		LUB	EFR	I4 to I3				IACC 42V	EPS	AERO 1	LRR			10%	$1,946
	5	150kW/lithium ion (range of FTP 150 miles)	N/A	HEV										AERO 1	LRR				$27,675
Compact Car I4 (T2)	baseline	2.4L-4V DOHC I4	AT 4 spd	12 V															
	1	2.4L 4V I4	AT 4 spd	12 V		LUB	EFR			ASL	TORQ	IACC 12V			LRR				$189
	2	2.0L I4 CCP + GDI	AT 6 spd	12 V		LUB	EFR	I4 to I4		ASL	TORQ	IACC 12V	EPS	AERO 1	LRR			3%	$814
	3	2.4L -4V I4 CCP + GDI	DCT 6 spd	12 V		LUB	EFR	I4 to I4				IACC 12V	EPS	AERO 1	LRR			3%	$1,025
	4	2.0L I4 DVVL + CCP + GDI	dry DCT 6 spd	42 S-S		LUB	EFR	I4 to I4				IACC 42V	EPS	AERO 1	LRR			10%	$1,675
	5	1.5L I4 Turbo DCP + GDI	dry DCT 6 spd	42 S-S		LUB	EFR	I4 to I4				IACC 42V	EPS	AERO 1	LRR			10%	$2,003
	6	1.2L I4 HEV (IMA) + GDI	dry DCT 6 spd	HEV		LUB	EFR	I4 to I4						AERO 1	LRR				$3,345
	7	1.2L I4 HEV Plug-in IMA + GDI	dry DCT 6 spd	HEV		LUB	EFR	I4 to I4						AERO 1	LRR				$10,267
Midsize Car/Small MPV (unibody) I4 (T3)	baseline	2.4L-4V DOHC I4	AT 4 spd	12 V															
	1	2.4L - 4V I4	AT 4 spd	12 V		LUB	EFR			ASL	TORQ	IACC 12V			LRR				$189
	2	2.2L I4 CCP + GDI	AT 6 spd	12 V		LUB	EFR	I4 to I4		ASL	TORQ	IACC 12V	EPS	AERO 1	LRR			3%	$833
	3	2.2L I4 DVVL + CCP + GDI	DCT 6 spd	12 V		LUB	EFR	I4 to I4				IACC 12V	EPS	AERO 1	LRR			5%	$1,014
	4	2.2L I4 DVVL + CCP + GDI	dry DCT 6 spd	42 S-S		LUB	EFR	I4 to I4				IACC 42V	EPS	AERO 1	LRR			10%	$1,739
	5	1.6L I4 Turbo DCP + GDI	dry DCT 6 spd	42 S-S		LUB	EFR	I4 to I4				IACC 42V	EPS	AERO 1	LRR			10%	$2,066
	6	1.6L Turbo DCP + GDI lean burn	dry DCT 6 spd	42 S-S		LUB	EFR	I4 to I4	GDI-LB			IACC 42V	EPS	AERO 1	LRR			30%	$4,075
	7	1.4L I4 Turbo HEV (IMA) + GDI	dry DCT 6 spd	HEV		LUB	EFR	I4 to I4						AERO 1	LRR				$3,764
	8	1.8L I4 HEV (Power Split) + GDI	N/A	HEV		LUB	EFR	I4 to I4						AERO 1	LRR				$4,243
	9	1.8L I4 HEV Plug-in Power Split + GDI	N/A	HEV		LUB	EFR	I4 to I4						AERO 1	LRR				$9,666
Compact Car/Small MPV (unibody) V6 (T4)	baseline	3.0L-4V DOHC V6	AT 4 spd	12 V															
	1	3.0L - 4V V6	AT 4 spd	12 V		LUB	EFR			ASL	TORQ	IACC 12V			LRR				$214
	2	2.0L I4 Turbo DCP + GDI	AT 6 spd	12 V		LUB	EFR	V6 DOHC to I4		ASL	TORQ	IACC 12V	EPS	AERO 1	LRR			3%	$1,306
	3	2.0L I4 Turbo DCP + GDI	DCT 6 spd	12 V		LUB	EFR	V6 DOHC to I4				IACC 12V	EPS	AERO 1	LRR			3%	$1,392
	4	2.0L I4 Turbo DCP + GDI	DCT 6 spd	42 S-S		LUB	EFR	V6 DOHC to I4				IACC 42V	EPS	AERO 1	LRR			5%	$1,974
	5	2.0L Turbo DCP + GDI lean burn	DCT 6 spd	42 S-S		LUB	EFR	V6 DOHC to I4	GDI-LB			IACC 42V	EPS	AERO 1	LRR			30%	$4,273
	6	2.4L I4 Turbo Diesel	DCT 6 spd			LUB	EFR		Diesel-SCR				EPS	AERO 1	LRR			5%	$2,920
	7	1.5L I4 Turbo HEV (IMA) + GDI	DCT 6 spd	HEV		LUB	EFR	V6 DOHC to I4						AERO 1	LRR				$4,530
	8	2.8L V6 w/ Deac GDI + CCP HEV (2-mode)	N/A	HEV		LUB	EFR							AERO 1	LRR				$6,095

Table 1-11 Continued

Midsize/Large Car V6 (T5)	baseline	3.3L-4V DOHC V6	AT 4 spd	12 V													
	1	3.3L - 4V V6	AT 4 spd	12 V		LUB	EFR			ASL	TORQ	IACC 12V			LRR		$214
	2	3.0L V6 GDI + CCP	AT 6 spd	12 V		LUB	EFR			ASL	TORQ	IACC 12V	EPS	AERO 1	LRR	3%	$1,022
	3	3.0L V6 w/ Deac GDI + CCP	AT 6 spd	12 V		LUB	EFR			ASL	TORQ	IACC 12V	EPS	AERO 1	LRR	5%	$1,275
	4	3.0L V6 w/ Deac GDI + CCP	DCT 6 spd	42 S-S		LUB	EFR					IACC 42V	EPS	AERO 1	LRR	10%	$2,103
	5	2.2L I4 Turbo DCP + GDI	DCT 6spd	42 S-S		LUB	EFR	V6 DOHC to I4				IACC 42V	EPS	AERO 1	LRR	10%	$2,245
	6	3.0L V6 HCCI GDI	DCT 6spd	42 S-S		LUB	EFR					IACC 42V	EPS	AERO 1	LRR	30%	$3,754
	7	2.2L Turbo DCP + GDI lean burn	DCT 6spd	42 S-S		LUB	EFR	V6 DOHC to I4	GDI-LB			IACC 42V	EPS	AERO 1	LRR	30%	$4,373
	8	2.5L I4 HEV (Power Split) + GDI	N/A	HEV		LUB	EFR	V6 DOHC to I4						AERO 1	LRR		$6,005
Midsize Car/Large Car V8 (T6)	baseline	4.5L-4V DOHC V8	AT 4 spd	12 V													
	1	4.5L - 4V V8	AT 4 spd	12 V		LUB	EFR			ASL	TORQ	IACC 12V			LRR		$214
	2	4.0L V6 GDI + CCP	AT 6 spd	12 V		LUB	EFR	V8 DOHC to V6 DOHC		ASL	TORQ	IACC 12V	EPS	AERO 1	LRR	3%	$883
	3	4.0L V6 w/ Deac GDI + CCP	AT 6 spd	42 S-S		LUB	EFR	V8 DOHC to V6 DOHC		ASL	TORQ	IACC 42V	EPS	AERO 1	LRR	5%	$1,633
	4	4.0L V6 w/ Deac GDI + CCP	DCT 6 spd	42 S-S		LUB	EFR	V8 DOHC to V6 DOHC				IACC 42V	EPS	AERO 1	LRR	5%	$1,719
	5	3.0L V6 Turbo DCP + GDI	AT 6 spd	42 S-S		LUB	EFR	V8 DOHC to V6 DOHC		ASL	TORQ	IACC 42V	EPS	AERO 1	LRR	5%	$2,333
	6	3.0L V6 Turbo DCP + GDI	DCT 6 spd	42 S-S		LUB	EFR	V8 DOHC to V6 DOHC				IACC 42V	EPS	AERO 1	LRR	5%	$2,419
	7	4.0L V6 HCCI GDI	DCT 6 spd	42 S-S		LUB	EFR	V8 DOHC to V6 DOHC				IACC 42V	EPS	AERO 1	LRR	30%	$3,853
	8	3.0L V6 Turbo Diesel	DCT 6 spd	12		LUB	EFR		Diesel-SCR				EPS	AERO 1	LRR	5%	$3,456
	9	3.0L V6 w/ Deac GDI + CCP HEV (2-mode)	N/A	HEV		LUB	EFR	V8 DOHC to V6 DOHC						AERO 1	LRR		$5,953
Mid-sized MPV (unibody)/Small Truck I4 (T7)	baseline	2.6L-4V DOHC I4 (I5)	AT 4 spd	12 V													
	1	2.6 L - 4V I4	AT 4 spd	12 V		LUB	EFR			ASL	TORQ	IACC 12V			LRR		$214
	2	2.4L I4 CCP + GDI	AT 6 spd	12 V		LUB	EFR	I4 to I4		ASL	TORQ	IACC 12V	EPS	AERO 1	LRR	3%	$987
	3	2.4L I4 DVVL + CCP + GDI	DCT 6 spd	12 V		LUB	EFR	I4 to I4				IACC 12V	EPS	AERO 1	LRR	3%	$1,255
	4	2.4L I4 DVVL + CCP + GDI	dry DCT 6 spd	42 S-S		LUB	EFR	I4 to I4				IACC 42V	EPS	AERO 1	LRR	10%	$2,054
	5	2.0L I4 Turbo DCP + GDI	dry DCT 6 spd	42 S-S		LUB	EFR	I4 to I4				IACC 42V	EPS	AERO 1	LRR	10%	$2,369
	6	1.8L Turbo DCP + GDI lean burn	DCT 6 spd	42 S-S		LUB	EFR	I4 to I4	GDI-LB			IACC 42V	EPS	AERO 1	LRR	30%	$4,691
	7	1.8L I4 Turbo HEV (IMA) + GDI	dry DCT 6 spd	HEV		LUB	EFR	I4 to I4						AERO 1	LRR		$4,628
	8	1.8L I4 Turbo HEV (Power Split) + GDI	N/A	HEV		LUB	EFR	I4 to I4						AERO 1	LRR		$6,164
	9	1.8L I4 Turbo HEV Plug-in IMA + GDI	dry DCT 6 spd	HEV		LUB	EFR	I4 to I4						AERO 1	LRR		$14,226
Midsize MPV (unibody)/Small Truck V6/V8 (T8)	baseline	3.7L-2V SOHC V6	AT 4 spd	12V													
	1	3.7L 2V SOHC V6	AT 4 spd	12V		LUB	EFR			ASL	TORQ	IACC 12V			LRR		$214
	2	3.2L 2V SOHC V6 GDI + CCP	AT 6 spd	12V		LUB	EFR			ASL	TORQ	IACC 12V	EPS	AERO 1	LRR	3%	$1,044
	3	3.2L 2V SOHC V6 w/Deac GDI + CCP	AT 6 spd	12V		LUB	EFR			ASL	TORQ	IACC 12V	EPS	AERO 1	LRR	3%	$1,194
	4	2.8L 4V V6 GDI + CCP	AT 6 spd	12V	V6 SOHC to V6 DOHC	LUB	EFR			ASL	TORQ	IACC 12V	EPS	AERO 1	LRR	3%	$1,398
	5	2.8L 4V V6 GDI + CCP + DVVL	AT 6 spd	12V	V6 SOHC to V6 DOHC	LUB	EFR			ASL	TORQ	IACC 12V	EPS	AERO 1	LRR	5%	$1,696
	6	2.8L 4V V6 w/ Deac GDI + CCP	AT 6 spd	12V	V6 SOHC to V6 DOHC	LUB	EFR			ASL	TORQ	IACC 12V	EPS	AERO 1	LRR	5%	$1,665
	7	2.8L 4V V6 w/ Deac GDI + CCP	DCT 6 spd	42 S-S	V6 SOHC to V6 DOHC	LUB	EFR					IACC 42V	EPS	AERO 1	LRR	10%	$2,528
	8	2.4L I4 Turbo DCP + GDI	DCT 6spd	42 S-S		LUB	EFR	V6 SOHC to I4				IACC 42V	EPS	AERO 1	LRR	10%	$2,555
	9	2.8L 4V V6 HCCI GDI	DCT 6spd	42 S-S	V6 SOHC to V6 DOHC	LUB	EFR					IACC 42V	EPS	AERO 1	LRR	30%	$4,387
	10	2.4L I4 Turbo DCP + GDI lean burn	DCT 6spd	42 S-S		LUB	EFR	V6 SOHC to I4	GDI-LB			IACC 42V	EPS	AERO 1	LRR	30%	$4,890
	11	2.8L I4 Turbo Diesel	DCT 6 spd	12		LUB	EFR		Diesel-SCR				EPS	AERO 1	LRR	5%	$2,968
	12	3.0L 4V V6 w/ Deac GDI + CCP HEV (IMA)	DCT 6 spd	HEV	V6 SOHC to V6 DOHC	LUB	EFR							AERO 1	LRR		$4,710
	13	3.0L 4V V6 w/ Deac GDI + CCP HEV (2-mode)	N/A	HEV	V6 SOHC to V6 DOHC	LUB	EFR							AERO 1	LRR		$5,940

Table 1-11 Continued

Large MPV (unibody) V6 (T9)	baseline	4.0L-2V SOHC V6	AT 4 spd	12V														
	1	4.0L 2V SOHC V6	AT 4 spd	12V		LUB	EFR			ASL	TORQ	IACC 12V			LRR			$214
	2	3.6L 2V SOHC V6 GDI + CCP	AT 6 spd	12V		LUB	EFR			ASL	TORQ	IACC 12V	EPS	AERO 1	LRR		3%	$1,064
	3	3.6L 2V SOHC V6 w/Deac GDI + CCP	AT 6 spd	12V		LUB	EFR			ASL	TORQ	IACC 12V	EPS	AERO 1	LRR		3%	$1,214
	4	3.2L 4V V6 GDI + CCP	AT 6 spd	12V	V6 SOHC to V6 DOHC	LUB	EFR			ASL	TORQ	IACC 12V	EPS	AERO 1	LRR		3%	$1,418
	5	3.2L 4V V6 w/ Deac GDI + CCP	AT 6 spd	12V	V6 SOHC to V6 DOHC	LUB	EFR			ASL	TORQ	IACC 12V	EPS	AERO 1	LRR		5%	$1,699
	6	3.2L 4V V6 w/ Deac GDI + CCP	DCT 6 spd	42 S-S	V6 SOHC to V6 DOHC	LUB	EFR					IACC 42V	EPS	AERO 1	LRR		10%	$2,596
	7	2.4L I4 Turbo DCP + GDI	DCT 6spd	42 S-S		LUB	EFR	V6 SOHC to I4				IACC 42V	EPS	AERO 1	LRR		10%	$2,623
	8	3.2L 4V V6 HCCI GDI	DCT 6spd	42 S-S	V6 SOHC to V6 DOHC	LUB	EFR					IACC 42V	EPS	AERO 1	LRR		30%	$4,654
	9	2.4L I4 Turbo DCP + GDI lean burn	DCT 6spd	42 S-S		LUB	EFR	V6 SOHC to I4	GDI-LB			IACC 42V	EPS	AERO 1	LRR		30%	$5,158
	10	2.0L I4 Turbo HEV (IMA) + GDI	DCT 6 spd	HEV		LUB	EFR	V6 SOHC to I4						AERO 1	LRR			$4,814
	11	3.2L 4V V6 w/ Deac GDI + CCP HEV (2-mode)	N/A	HEV	V6 SOHC to V6 DOHC	LUB	EFR							AERO 1	LRR			$6,449
Large MPV (unibody) V8 (T10)	baseline	4.7L-2V SOHC V8	AT 4 spd	12V														
	1	4.7L 2V SOHC V8	AT 4 spd	12V		LUB	EFR			ASL	TORQ	IACC 12V			LRR			$214
	2	4.4L 2V SOHC V8 GDI + CCP	AT 6 spd	12V		LUB	EFR			ASL	TORQ	IACC 12V	EPS	AERO 1	LRR		3%	$1,085
	3	4.4L 2V SOHC V8 w/Deac GDI + CCP	AT 6 spd	12V		LUB	EFR			ASL	TORQ	IACC 12V	EPS	AERO 1	LRR		3%	$1,235
	4	4.2L 4V V6 GDI + CCP	AT 6 spd	12V		LUB	EFR	V8 SOHC to V6 DOHC		ASL	TORQ	IACC 12V	EPS	AERO 1	LRR		3%	$1,284
	5	4.2L 4V V6 w/ Deac GDI + CCP	AT 6 spd	12V		LUB	EFR	V8 SOHC to V6 DOHC		ASL	TORQ	IACC 12V	EPS	AERO 1	LRR		5%	$1,579
	6	4.2L 4V V6 w/ Deac GDI + CCP	DCT 6 spd	42 S-S		LUB	EFR	V8 SOHC to V6 DOHC				IACC 42V	EPS	AERO 1	LRR		10%	$2,512
	7	2.8L 4V V6 Turbo CP + GDI	DCT 6spd	42 S-S		LUB	EFR	V8 SOHC to V6 DOHC				IACC 42V	EPS	AERO 1	LRR		10%	$3,211
	8	4.2L 4V V6 HCCI GDI	DCT 6spd	42 S-S		LUB	EFR	V8 SOHC to V6 DOHC				IACC 42V	EPS	AERO 1	LRR		30%	$4,774
	9	2.8L 4V V6 Turbo DCP + GDI lean burn	DCT 6spd	42 S-S		LUB	EFR	V8 SOHC to V6 DOHC	GDI-LB			IACC 42V	EPS	AERO 1	LRR		30%	$5,951
	10	3.0L V6 Turbo Diesel	DCT 6 spd	12		LUB	EFR		Diesel-SCR				EPS	AERO 1	LRR		5%	$3,037
	11	4.2L 4V V6 w/ Deac GDI + CCP HEV (2-mode)	N/A	HEV		LUB	EFR	V8 SOHC to V6 DOHC						AERO 1	LRR			$6,294
Large Truck (+ Van) V6 (T11)	baseline	4.2L-2V SOHC V6	AT 4 spd	12V														
	1	4.2L 2V SOHC V6	AT 4 spd	12V		LUB	EFR			ASL	TORQ	IACC 12V			LRR			$239
	2	3.9L 2V SOHC V6 GDI + CCP	AT 6 spd	12V		LUB	EFR			ASL	TORQ	IACC 12V	EPS	AERO 1	LRR		3%	$1,104
	3	3.9L 2V SOHC V6 w/Deac GDI + CCP	AT 6 spd	12V		LUB	EFR			ASL	TORQ	IACC 12V	EPS	AERO 1	LRR		3%	$1,273
	4	3.6L 4V V6 GDI + CCP	AT 6 spd	12V	V6 SOHC to V6 DOHC	LUB	EFR			ASL	TORQ	IACC 12V	EPS	AERO 1	LRR		3%	$1,458
	5	3.6L 4V V6 GDI + CCP + DVVL	AT 6 spd	12V	V6 SOHC to V6 DOHC	LUB	EFR			ASL	TORQ	IACC 12V	EPS	AERO 1	LRR		5%	$1,842
	6	3.6L 4V V6 w/ Deac GDI + CCP	AT 6 spd	12V	V6 SOHC to V6 DOHC	LUB	EFR			ASL	TORQ	IACC 12V	EPS	AERO 1	LRR		5%	$1,751
	7	3.6L 4V V6 w/ Deac GDI + CCP	DCT 6 spd	42 S-S	V6 SOHC to V6 DOHC	LUB	EFR					IACC 42V	EPS	AERO 1	LRR	LDB	10%	$2,735
	8	2.5L I4 Turbo DCP + GDI	DCT 6spd	42 S-S		LUB	EFR	V6 SOHC to I4				IACC 42V	EPS	AERO 1	LRR	LDB	10%	$2,743
	9	4.0L 4V V6 HCCI GDI	DCT 6spd	42 S-S	V6 SOHC to V6 DOHC	LUB	EFR					IACC 42V	EPS	AERO 1	LRR	LDB	30%	$4,967
	10	2.5L I4 Turbo DCP + GDI lean burn	DCT 6spd	42 S-S		LUB	EFR	V6 SOHC to I4	GDI-LB			IACC 42V	EPS	AERO 1	LRR	LDB	30%	$5,186
	11	2.8L I4 Turbo Diesel	DCT 6 spd	12		LUB	EFR		Diesel-SCR				EPS	AERO 1	LRR	LDB	5%	$3,871
	12	3.6L 4V V6 w/ Deac GDI + CCP HEV (IMA)	DCT 6 spd	HEV	V6 SOHC to V6 DOHC	LUB	EFR							AERO 1	LRR	LDB		$5,849
	13	3.6L 4V V6 w/ Deac GDI + CCP HEV (2-mode)	N/A	HEV	V6 SOHC to V6 DOHC	LUB	EFR							AERO 1	LRR	LDB		$8,364
Large Truck + Large MPV V6 (T12)	baseline	3.8L 2V OHV V6	AT 4 sp	12 V														
	1	3.8L-2V OHV V6	AT 4 spd	12V		LUB	EFR			ASL	TORQ	IACC 12V			LRR			$239
	2	3.2L 4V DOHC V6 GDI + CCP	AT 6 spd	12V	V6 OHV to V6 DOHC	LUB	EFR			ASL	TORQ	IACC 12V		AERO 1	LRR		3%	$1,324
	3	3.2L 4V DOHC V6 w/Deac GDI + CCP	AT 6 spd	12V	V6 OHV to V6 DOHC	LUB	EFR			ASL	TORQ	IACC 12V		AERO 1	LRR		3%	$1,493
	4	3.2L 4V DOHC V6 w/ Deac GDI + CCP	DCT 6 spd	42 S-S	V6 OHV to V6 DOHC	LUB	EFR					IACC 42V	EPS	AERO 1	LRR	LDB	10%	$2,845
	5	2.5L I4 Turbo DCP + GDI	DCT 6spd	42 S-S		LUB	EFR	V6 OHV to I4 DOHC				IACC 42V	EPS	AERO 1	LRR	LDB	10%	$3,087

Table 1-11 Continued

Large Truck (+ Van) V8 (T13)	baseline	5.7L 2V OHV V8	AT 4 spd	12V														
	1	5.7L 2V OHV V8	AT 4 spd	12V		LUB	EFR			ASL	TORQ	IACC 12V			LRR			$239
	2	5.2L 2V OHV V8 GDI + CCP	AT 6 spd	12V		LUB	EFR			ASL	TORQ	IACC 12V		AERO 1	LRR		3%	$1,051
	3	5.2L 2V OHV V8 w/Deac GDI + CCP	AT 6 spd	12V		LUB	EFR			ASL	TORQ	IACC 12V		AERO 1	LRR		3%	$1,219
	4	4.6L 4V V8 GDI + CCP	AT 6 spd	12V	V8 OHV to V8 DOHC	LUB	EFR			ASL	TORQ	IACC 12V		AERO 1	LRR		3%	$1,559
	5	4.6L 4V V8 w/ Deac GDI + CCP	AT 6 spd	12V	V8 OHV to V8 DOHC	LUB	EFR			ASL	TORQ	IACC 12V		AERO 1	LRR		5%	$1,879
	6	4.6L 4V V8 w/ Deac GDI + CCP	DCT 6 spd	42 S-S	V8 SOHC to V8 DOHC	LUB	EFR					IACC 42V	EPS	AERO 1	LRR	LDB	10%	$2,913
	7	3.5L 4V V6 Turbo DCP + GDI	DCT 6spd	42 S-S		LUB	EFR	V8 OHV to V6 DOHC				IACC 42V	EPS	AERO 1	LRR	LDB	10%	$3,520
	8	4.6L 4V V8 HCCI GDI	DCT 6spd	42 S-S	V8 OHV to V8 DOHC	LUB	EFR					IACC 42V	EPS	AERO 1	LRR	LDB	30%	$5,647
	9	3.5L V6 Turbo DCP + GDI lean burn	DCT 6spd	42 S-S		LUB	EFR	V8 OHV to V6 DOHC	GDI-LB			IACC 42V	EPS	AERO 1	LRR	LDB	30%	$6,355
	10	3.5L V6 Turbo Diesel	DCT 6 spd	12		LUB	EFR		Diesel-SCR					AERO 1	LRR	LDB	5%	$3,844
	11	4.6L 4V V8 w/ Deac GDI + CCP HEV (2-mode)	N/A	HEV	V8 OHV to V8 DOHC	LUB	EFR							AERO 1	LRR	LDB		$8,519
Large Truck (+Van) V8 (T14)	baseline	5.4L 3V SOHC V8	AT 4 sp	12 V														
	1	5.4L 3V SOHC - V8	AT 4 spd	12 V		LUB	EFR			ASL	TORQ	IACC 12V			LRR			$239
	2	4.6L 4V DOHC V8 GDI + CCP	AT 6 spd	12V	'8 SOHC 3V to V8 DOH	LUB	EFR			ASL	TORQ	IACC 12V		AERO 1	LRR		3%	$1,210
	3	4.6L 4V DOHC V8 w/ Deac GDI + CCP	AT 6 spd	12V	'8 SOHC 3V to V8 DOH	LUB	EFR			ASL	TORQ	IACC 12V		AERO 1	LRR		5%	$1,530
	4	4.6L 4V DOHC V8 w/ Deac GDI + CCP	DCT 6 spd	42 S-S	'8 SOHC 3V to V8 DOH	LUB	EFR					IACC 42V	EPS	AERO 1	LRR	LDB	10%	$2,825
	5	3.5L V6 Turbo DCP + GDI	DCT 6spd	42 S-S		LUB	EFR	V8 SOHC 3V to V6 DOHC				IACC 42V	EPS	AERO 1	LRR	LDB	10%	$3,295
Midsize MPV (unibody)/Small Truck V6/V8 (T15)	baseline	3.2L-4V DOHC V6	AT 4 spd	12V														
	1	3.2 L - 4V V6	AT 4 spd	12 V		LUB	EFR			ASL	TORQ	IACC 12V			LRR			$214
	2	2.8L V6 GDI + CCP	AT 6 spd	12 V		LUB	EFR			ASL	TORQ	IACC 12V	EPS	AERO 1	LRR		3%	$1,044
	3	2.8L V6 GDI + CCP + DVVL	AT 6 spd	12 V		LUB	EFR			ASL	TORQ	IACC 12V	EPS	AERO 1	LRR		5%	$1,342
	4	2.8L V6 w/ Deac GDI + CCP	AT 6 spd	12 V		LUB	EFR			ASL	TORQ	IACC 12V	EPS	AERO 1	LRR		5%	$1,311
	5	2.8L V6 w/ Deac GDI + CCP	DCT 6 spd	42 S-S		LUB	EFR					IACC 42V	EPS	AERO 1	LRR		5%	$1,881
	6	2.4L I4 Turbo DCP + GDI	DCT 6 spd	42 S-S		LUB	EFR	V6 DOHC to I4				IACC 42V	EPS	AERO 1	LRR		5%	$2,023
	7	2.8L V6 HCCI GDI	DCT 6spd	42 S-S		LUB	EFR					IACC 42V	EPS	AERO 1	LRR		30%	$4,033
	8	2.4L I4 Turbo DCP + GDI lean burn	DCT 6 spd	42 S-S		LUB	EFR	V6 DOHC to I4	GDI-LB			IACC 42V	EPS	AERO 1	LRR		30%	$4,494
	9	2.8L I4 Turbo Diesel	DCT 6 spd	12		LUB	EFR		Diesel-SCR				EPS	AERO 1	LRR		5%	$2,968
	10	3.0L V6 w/ Deac GDI + CCP HEV (IMA)	DCT 6 spd	HEV		LUB	EFR							AERO 1	LRR			$4,356
	11	3.0L V6 w/ Deac GDI + CCP HEV (2-mode)	N/A	HEV		LUB	EFR							AERO 1	LRR			$5,586
Large MPV (unibody) V6 (T16)	baseline	3.5L-4V DOHC V6	AT 4 spd	12V														
	1	3.5L - 4V V6	AT 4 spd	12 V		LUB	EFR			ASL	TORQ	IACC 12V			LRR			$214
	2	3.2L V6 GDI + CCP	AT 6 spd	12 V		LUB	EFR			ASL	TORQ	IACC 12V	EPS	AERO 1	LRR		3%	$1,064
	3	3.2L V6 w/ Deac GDI + CCP	AT 6 spd	12 V		LUB	EFR			ASL	TORQ	IACC 12V	EPS	AERO 1	LRR		5%	$1,345
	4	3.2L V6 w/ Deac GDI + CCP	DCT 6 spd	42 S-S		LUB	EFR					IACC 42V	EPS	AERO 1	LRR		10%	$2,243
	5	2.4L I4 Turbo DCP + GDI	DCT 6spd	42 S-S		LUB	EFR	V6 DOHC to I4				IACC 42V	EPS	AERO 1	LRR		5%	$2,057
	6	3.2L V6 HCCI GDI	DCT 6spd	42 S-S		LUB	EFR					IACC 42V	EPS	AERO 1	LRR		30%	$4,300
	7	2.4L I4 Turbo DCP + GDI lean burn	DCT 6spd	42 S-S		LUB	EFR	V6 DOHC to I4	GDI-LB			IACC 42V	EPS	AERO 1	LRR		30%	$4,919
	8	2.0L I4 Turbo HEV (IMA) + GDI	DCT 6 spd	HEV		LUB	EFR	V6 DOHC to I4						AERO 1	LRR			$4,530
	9	3.2L V6 w/ Deac GDI + CCP HEV (2-mode)	N/A	HEV		LUB	EFR							AERO 1	LRR			$6,095

Table 1-11 Continued

Large MPV (unibody) V8 (T17)	baseline	4.6L-4V DOHC V8	AT 4 spd	12V													
	1	4.6L - 4V V8	AT 4 spd	12 V	LUB	EFR			ASL	TORQ	IACC 12V			LRR			$214
	2	4.2L V6 GDI + CCP	AT 8 spd	12 V	LUB	EFR	V8 DOHC to V6 DOHC		ASL	TORQ	IACC 12V	EPS	AERO 1	LRR		3%	$926
	3	4.2L V6 w/ Deac GDI + CCP	AT 8 spd	12 V	LUB	EFR	V8 DOHC to V6 DOHC		ASL	TORQ	IACC 12V	EPS	AERO 1	LRR		5%	$1,221
	4	4.2L V6 w/ Deac GDI + CCP	DCT 6 spd	42 S-S	LUB	EFR	V8 DOHC to V6 DOHC				IACC 42V	EPS	AERO 1	LRR		10%	$2,153
	5	2.8L V6 Turbo DCP + GDI	DCT 6spd	42 S-S	LUB	EFR	V8 DOHC to V6 DOHC				IACC 42V	EPS	AERO 1	LRR		10%	$2,853
	6	4.2L V6 HCCI GDI	DCT 6spd	42 S-S	LUB	EFR	V8 DOHC to V6 DOHC				IACC 42V	EPS	AERO 1	LRR		30%	$4,415
	7	2.8L V6 Turbo DCP + GDI lean burn	DCT 6spd	42 S-S	LUB	EFR	V8 DOHC to V6 DOHC	GDI-LB			IACC 42V	EPS	AERO 1	LRR		30%	$5,592
	8	3.0L V6 Turbo Diesel	DCT 6 spd	12	LUB	EFR		Diesel-SCR				EPS	AERO 1	LRR		5%	$3,037
	9	4.2L V6 w/ Deac GDI + CCP HEV (2-mode)	N/A	HEV	LUB	EFR	V8 DOHC to V6 DOHC						AERO 1	LRR			$5,935
Large Truck (+ Van) V6 (T18)	baseline	4.0L-4V DOHC V6	AT 4 spd	12V													
	1	4.0L - 4V V6	AT 4 spd	12 V	LUB	EFR			ASL	TORQ	IACC 12V			LRR			$239
	2	3.6L V6 GDI + CCP	AT 6 spd	12 V	LUB	EFR			ASL	TORQ	IACC 12V	EPS	AERO 1	LRR		3%	$1,104
	3	3.6L V6 GDI + CCP + DVVL	AT 6 spd	12 V	LUB	EFR			ASL	TORQ	IACC 12V	EPS	AERO 1	LRR		5%	$1,488
	4	3.6L V6 w/ Deac GDI + CCP	AT 6 spd	12 V	LUB	EFR			ASL	TORQ	IACC 12V	EPS	AERO 1	LRR		5%	$1,398
	5	3.6L V6 w/ Deac GDI + CCP	DCT 6 spd	42 S-S	LUB	EFR					IACC 42V	EPS	AERO 1	LRR	LDB	10%	$2,381
	6	2.5L I4 Turbo DCP + GDI	DCT 6spd	42 S-S	LUB	EFR	V6 DOHC to I4				IACC 42V	EPS	AERO 1	LRR	LDB	10%	$2,504
	7	4.0L V6 HCCI GDI	DCT 6spd	42 S-S	LUB	EFR					IACC 42V	EPS	AERO 1	LRR	LDB	30%	$4,613
	8	2.5L I4 Turbo DCP + GDI lean burn	DCT 6spd	42 S-S	LUB	EFR	V6 DOHC to I4	GDI-LB			IACC 42V	EPS	AERO 1	LRR	LDB	30%	$4,947
	9	2.8L I4 Turbo Diesel	DCT 6 spd	12	LUB	EFR		Diesel-SCR				EPS	AERO 1	LRR	LDB	5%	$3,871
	10	3.6L V6 w/ Deac GDI + CCP HEV (IMA)	DCT 6 spd	HEV	LUB	EFR							AERO 1	LRR	LDB		$5,495
	11	3.6L V6 w/ Deac GDI + CCP HEV (2-mode)	N/A	HEV	LUB	EFR							AERO 1	LRR	LDB		$8,010
Large Truck (+ Van) V8 (T19)	baseline	5.6L 4V DOHC V8	AT 4 spd	12V													
	1	5.6L 4V V8	AT 4 spd	12 V	LUB	EFR			ASL	TORQ	IACC 12V			LRR			$239
	2	4.6L V8 GDI + CCP	AT 6 spd	12 V	LUB	EFR			ASL	TORQ	IACC 12V		AERO 1	LRR		3%	$1,051
	3	4.6L V8 w/ Deac GDI + CCP	AT 6 spd	12 V	LUB	EFR			ASL	TORQ	IACC 12V		AERO 1	LRR		5%	$1,371
	4	4.6L V8 w/ Deac GDI + CCP	DCT 6 spd	42 S-S	LUB	EFR					IACC 42V	EPS	AERO 1	LRR	LDB	10%	$2,515
	5	3.5L V6 Turbo DCP + GDI	DCT 6spd	42 S-S	LUB	EFR	V8 DOHC to V6 DOHC				IACC 42V	EPS	AERO 1	LRR	LDB	10%	$3,036
	6	4.6L V8 HCCI GDI	DCT 6spd	42 S-S	LUB	EFR					IACC 42V	EPS	AERO 1	LRR	LDB	30%	$5,139
	7	3.5L V6 Turbo DCP + GDI lean burn	DCT 6spd	42 S-S	LUB	EFR	V8 DOHC to V6 DOHC	GDI-LB			IACC 42V	EPS	AERO 1	LRR	LDB	30%	$5,872
	8	3.5L V6 Turbo Diesel	DCT 6 spd	12	LUB	EFR		Diesel-SCR					AERO 1	LRR	LDB	5%	$3,844
	9	4.6L V8 w/ Deac GDI + CCP HEV (2-mode)	N/A	HEV	LUB	EFR							AERO 1	LRR	LDB		$8,010

Notes to Table 1-11:

DOHC=dual overhead cam; SOHC=single overhead cam; OHV=overhead valve; AT=automatic transmission; DCT=dual clutch transmission; LUB=low friction lubes; EFR=engine friction reduction; ASL=aggressive shift logic; TORQ=early torque converter lockup; IACC=improved accessories; EPS=electric power steering; AERO 1=improved aerodynamics; LRR=low rolling resistance tires.

Table 1-12 Package Costs & Effectiveness for 2012-2022+MY for 19 Vehicle Types (T1-T19), Packages Used as Inputs to the OMEGA Model, Costs in 2007 dollars

Vehicle	Technology Package	Engine	Transmission	System Voltage	Camshaft changes (excluding those for downsized engines)	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	CO2 % Reduction
Subcomp I4 (T1)	baseline	1.5L - 4V DOHC I4	AT 4 spd	12 V													
	1	1.5L - 4V I4	AT 4 spd	12 V		$206	$202	$197	$193	$189	$189	$189	$189	$189	$189	$182	7.6%
	2	1.5L - 4V I4 CCP	DCT 6 spd	12 V		$801	$779	$757	$736	$716	$716	$716	$716	$716	$716	$685	18.9%
	3	1.2L I3 DVVL + CCP + GDI	dry DCT 6 spd	42 S-S		$1,751	$1,717	$1,574	$1,454	$1,422	$1,422	$1,422	$1,422	$1,422	$1,422	$1,340	33.2%
	4	0.7L I3 (small) Turbo DCP + GDI	dry DCT 6 spd	42 S-S		$2,343	$2,291	$2,130	$1,994	$1,946	$1,946	$1,946	$1,946	$1,946	$1,946	$1,820	36.4%
	5	150kW/lithium ion (range of FTP 150 miles)	N/A	HEV													
Compact Car I4 (T2)	baseline	2.4L-4V DOHC I4	AT 4 spd	12 V													
	1	2.4L 4V I4	AT 4 spd	12 V		$206	$202	$197	$193	$189	$189	$189	$189	$189	$189	$182	7.6%
	2	2.0L I4 CCP + GDI	AT 6 spd	12 V		$911	$886	$861	$837	$814	$814	$814	$814	$814	$814	$784	17.5%
	3	2.4L -4V I4 CCP + GDI	DCT 6 spd	12 V													
	4	2.0L I4 DVVL + CCP + GDI	dry DCT 6 spd	42 S-S		$2,037	$1,994	$1,843	$1,715	$1,675	$1,675	$1,675	$1,675	$1,675	$1,675	$1,593	35.4%
	5	1.5L I4 Turbo DCP + GDI	dry DCT 6 spd	42 S-S													
	6	1.2L I4 HEV (IMA) + GDI	dry DCT 6 spd	HEV													
	7	1.2L I4 HEV Plug-in IMA + GDI	dry DCT 6 spd	HEV													
Midsize Car/Small MPV (unibody) I4 (T3)	baseline	2.4L-4V DOHC I4	AT 4 spd	12 V													
	1	2.4L - 4V I4	AT 4 spd	12 V		$206	$202	$197	$193	$189	$189	$189	$189	$189	$189	$182	7.6%
	2	2.2L I4 CCP + GDI	AT 6 spd	12 V													
	3	2.2L I4 DVVL + CCP + GDI	DCT 6 spd	12 V		$1,137	$1,105	$1,074	$1,043	$1,014	$1,014	$1,014	$1,014	$1,014	$1,014	$972	23.2%
	4	2.2L I4 DVVL + CCP + GDI	dry DCT 6 spd	42 S-S		$2,108	$2,063	$1,910	$1,780	$1,739	$1,739	$1,739	$1,739	$1,739	$1,739	$1,656	35.4%
	5	1.6L I4 Turbo DCP + GDI	dry DCT 6 spd	42 S-S													
	6	1.6L Turbo DCP + GDI lean burn	dry DCT 6 spd	42 S-S													
	7	1.4L I4 Turbo HEV (IMA) + GDI	dry DCT 6 spd	HEV													
	8	1.8L I4 HEV (Power Split) + GDI	N/A	HEV		$4,785	$4,644	$4,506	$4,373	$4,243	$4,243	$4,243	$4,243	$4,243	$4,243	$3,710	35.9%
	9	1.8L I4 HEV Plug-in Power Split + GDI	N/A	HEV													
Compact Car/Small MPV (unibody) V6 (T4)	baseline	3.0L-4V DOHC V6	AT 4 spd	12 V													
	1	3.0L - 4V V6	AT 4 spd	12 V		$231	$227	$222	$218	$214	$214	$214	$214	$214	$214	$207	7.6%
	2	2.0L I4 Turbo DCP + GDI	AT 6 spd	12 V													
	3	2.0L I4 Turbo DCP + GDI	DCT 6 spd	12 V		$1,562	$1,518	$1,475	$1,433	$1,392	$1,392	$1,392	$1,392	$1,392	$1,392	$1,190	23.4%
	4	2.0L I4 Turbo DCP + GDI	DCT 6 spd	42 S-S		$2,392	$2,341	$2,168	$2,021	$1,974	$1,974	$1,974	$1,974	$1,974	$1,974	$1,725	31.6%
	5	2.0L Turbo DCP + GDI lean burn	DCT 6 spd	42 S-S													
	6	2.4L I4 Turbo Diesel	DCT 6 spd														
	7	1.5L I4 Turbo HEV (IMA) + GDI	DCT 6 spd	HEV													
	8	2.8L V6 w/ Deac GDI + CCP HEV (2-mode)	N/A	HEV		$9,234	$9,215	$7,493	$6,112	$6,095	$6,095	$6,095	$6,095	$6,095	$6,095	$5,310	36.5%

Table 1-12 Continued

Midsize/Large Car V6 (T5)	baseline	3.3L-4V DOHC V6	AT 4 spd	12 V													
	1	3.3L - 4V V6	AT 4 spd	12 V		$231	$227	$222	$218	$214	$214	$214	$214	$214	$214	$207	7.6%
	2	3.0L V6 GDI + CCP	AT 6 spd	12 V		$1,144	$1,112	$1,081	$1,051	$1,022	$1,022	$1,022	$1,022	$1,022	$1,022	$927	17.9%
	3	3.0L V6 w/ Deac GDI + CCP	AT 6 spd	12 V													
	4	3.0L V6 w/ Deac GDI + CCP	DCT 6 spd	42 S-S		$2,537	$2,482	$2,305	$2,153	$2,103	$2,103	$2,103	$2,103	$2,103	$2,103	$1,942	34.2%
	5	2.2L I4 Turbo DCP + GDI	DCT 6spd	42 S-S													
	6	3.0L V6 HCCI GDI	DCT 6spd	42 S-S													
	7	2.2L Turbo DCP + GDI lean burn	DCT 6spd	42 S-S													
	8	2.5L I4 HEV (Power Split) + GDI	N/A	HEV		$6,772	$6,572	$6,377	$6,188	$6,005	$6,005	$6,005	$6,005	$6,005	$6,005	$5,129	37.5%
Midsize Car/Large Car V8 (T6)	baseline	4.5L-4V DOHC V8	AT 4 spd	12 V													
	1	4.5L - 4V V8	AT 4 spd	12 V		$231	$227	$222	$218	$214	$214	$214	$214	$214	$214	$207	7.6%
	2	4.0L V6 GDI + CCP	AT 6 spd	12 V		$986	$959	$933	$907	$883	$883	$883	$883	$883	$883	$780	17.9%
	3	4.0L V6 w/ Deac GDI + CCP	AT 6 spd	42 S-S													
	4	4.0L V6 w/ Deac GDI + CCP	DCT 6 spd	42 S-S		$2,103	$2,061	$1,896	$1,757	$1,719	$1,719	$1,719	$1,719	$1,719	$1,719	$1,552	31.9%
	5	3.0L V6 Turbo DCP + GDI	AT 6 spd	42 S-S													
	6	3.0L V6 Turbo DCP + GDI	DCT 6 spd	42 S-S													
	7	4.0L V6 HCCI GDI	DCT 6 spd	42 S-S													
	8	3.0L V6 Turbo Diesel	DCT 6 spd	12													
	9	3.0L V6 w/ Deac GDI + CCP HEV (2-mode)	N/A	HEV		$9,082	$9,068	$7,346	$5,966	$5,953	$5,953	$5,953	$5,953	$5,953	$5,953	$5,143	44.4%
Mid-sized MPV (unibody)/Small Truck I4 (T7)	baseline	2.6L-4V DOHC I4 (I5)	AT 4 spd	12 V													
	1	2.6 L - 4V I4	AT 4 spd	12 V		$231	$227	$222	$218	$214	$214	$214	$214	$214	$214	$207	7.6%
	2	2.4L I4 CCP + GDI	AT 6 spd	12 V		$1,104	$1,074	$1,044	$1,015	$987	$987	$987	$987	$987	$987	$890	17.4%
	3	2.4L I4 DVVL + CCP + GDI	DCT 6 spd	12 V		$1,406	$1,367	$1,328	$1,291	$1,255	$1,255	$1,255	$1,255	$1,255	$1,255	$1,139	21.4%
	4	2.4L I4 DVVL + CCP + GDI	dry DCT 6 spd	42 S-S		$2,481	$2,428	$2,252	$2,102	$2,054	$2,054	$2,054	$2,054	$2,054	$2,054	$1,896	34.7%
	5	2.0L I4 Turbo DCP + GDI	dry DCT 6 spd	42 S-S		$2,837	$2,773	$2,587	$2,427	$2,369	$2,369	$2,369	$2,369	$2,369	$2,369	$2,172	36.3%
	6	1.8L Turbo DCP + GDI lean burn	DCT 6 spd	42 S-S													
	7	1.8L I4 Turbo HEV (IMA) + GDI	dry DCT 6 spd	HEV													
	8	1.8L I4 Turbo HEV (Power Split) + GDI	N/A	HEV		$6,951	$6,745	$6,545	$6,352	$6,164	$6,164	$6,164	$6,164	$6,164	$6,164	$5,335	39.6%
	9	1.8L I4 Turbo HEV Plug-in IMA + GDI	dry DCT 6 spd	HEV													
Midsize MPV (unibody)/Small Truck V6/V8 (T8)	baseline	3.7L-2V SOHC V6	AT 4 spd	12V													
	1	3.7L 2V SOHC V6	AT 4 spd	12V		$231	$227	$222	$218	$214	$214	$214	$214	$214	$214	$207	7.6%
	2	3.2L 2V SOHC V6 GDI + CCP	AT 6 spd	12V		$1,168	$1,136	$1,104	$1,073	$1,044	$1,044	$1,044	$1,044	$1,044	$1,044	$948	17.8%
	3	3.2L 2V SOHC V6 w/Deac GDI + CCP	AT 6 spd	12V		$1,337	$1,300	$1,263	$1,228	$1,194	$1,194	$1,194	$1,194	$1,194	$1,194	$1,093	19.6%
	4	2.8L 4V V6 GDI + CCP	AT 6 spd	12V	V6 SOHC to V6 DOHC												
	5	2.8L 4V V6 GDI + CCP + DVVL	AT 6 spd	12V	V6 SOHC to V6 DOHC												
	6	2.8L 4V V6 w/ Deac GDI + CCP	AT 6 spd	12V	V6 SOHC to V6 DOHC												
	7	2.8L 4V V6 w/ Deac GDI + CCP	DCT 6 spd	42 S-S	V6 SOHC to V6 DOHC	$3,017	$2,948	$2,756	$2,591	$2,528	$2,528	$2,528	$2,528	$2,528	$2,528	$2,354	32.4%
	8	2.4L I4 Turbo DCP + GDI	DCT 6spd	42 S-S													
	9	2.8L 4V V6 HCCI GDI	DCT 6spd	42 S-S	V6 SOHC to V6 DOHC												
	10	2.4L I4 Turbo DCP + GDI lean burn	DCT 6spd	42 S-S													
	11	2.8L I4 Turbo Diesel	DCT 6 spd	12													
	12	3.0L 4V V6 w/ Deac GDI + CCP HEV (IMA)	DCT 6 spd	HEV	V6 SOHC to V6 DOHC												
	13	3.0L 4V V6 w/ Deac GDI + CCP HEV (2-mode)	N/A	HEV	V6 SOHC to V6 DOHC	$8,838	$8,807	$7,233	$5,968	$5,940	$5,940	$5,940	$5,940	$5,940	$5,940	$5,193	36.3%

Table 1-12 Continued

Large MPV (unibody) V6 (T9)	baseline	4.0L-2V SOHC V6	AT 4 spd	12V													
	1	4.0L 2V SOHC V6	AT 4 spd	12V		$231	$227	$222	$218	$214	$214	$214	$214	$214	$214	$207	7.6%
	2	3.6L 2V SOHC V6 GDI + CCP	AT 6 spd	12V		$1,191	$1,158	$1,126	$1,095	$1,064	$1,064	$1,064	$1,064	$1,064	$1,064	$969	17.4%
	3	3.6L 2V SOHC V6 w/Deac GDI + CCP	AT 6 spd	12V		$1,360	$1,322	$1,285	$1,249	$1,214	$1,214	$1,214	$1,214	$1,214	$1,214	$1,113	19.4%
	4	3.2L 4V V6 GDI + CCP	AT 6 spd	12V	V6 SOHC to V6 DOHC												
	5	3.2L 4V V6 w/ Deac GDI + CCP	AT 6 spd	12V	V6 SOHC to V6 DOHC												
	6	3.2L 4V V6 w/ Deac GDI + CCP	DCT 6 spd	42 S-S	V6 SOHC to V6 DOHC												
	7	2.4L I4 Turbo DCP + GDI	DCT 6spd	42 S-S		$3,125	$3,052	$2,857	$2,690	$2,623	$2,623	$2,623	$2,623	$2,623	$2,623	$2,409	32.3%
	8	3.2L 4V V6 HCCI GDI	DCT 6spd	42 S-S	V6 SOHC to V6 DOHC												
	9	2.4L I4 Turbo DCP + GDI lean burn	DCT 6spd	42 S-S													
	10	2.0L I4 Turbo HEV (IMA) + GDI	DCT 6 spd	HEV													
	11	3.2L 4V V6 w/ Deac GDI + CCP HEV (2-mode)	N/A	HEV	V6 SOHC to V6 DOHC	$9,633	$9,602	$7,869	$6,477	$6,449	$6,449	$6,449	$6,449	$6,449	$6,449	$5,651	36.5%
Large MPV (unibody) V8 (T10)	baseline	4.7L-2V SOHC V8	AT 4 spd	12V													
	1	4.7L 2V SOHC V8	AT 4 spd	12V		$231	$227	$222	$218	$214	$214	$214	$214	$214	$214	$207	7.6%
	2	4.4L 2V SOHC V8 GDI + CCP	AT 6 spd	12V		$1,215	$1,181	$1,148	$1,116	$1,085	$1,085	$1,085	$1,085	$1,085	$1,085	$990	17.4%
	3	4.4L 2V SOHC V8 w/Deac GDI + CCP	AT 6 spd	12V		$1,384	$1,345	$1,307	$1,271	$1,235	$1,235	$1,235	$1,235	$1,235	$1,235	$1,134	19.4%
	4	4.2L 4V V6 GDI + CCP	AT 6 spd	12V													
	5	4.2L 4V V6 w/ Deac GDI + CCP	AT 6 spd	12V													
	6	4.2L 4V V6 w/ Deac GDI + CCP	DCT 6 spd	42 S-S		$2,999	$2,930	$2,739	$2,575	$2,512	$2,512	$2,512	$2,512	$2,512	$2,512	$2,342	34.3%
	7	2.8L 4V V6 Turbo DCP + GDI	DCT 6spd	42 S-S													
	8	4.2L 4V V6 HCCI GDI	DCT 6spd	42 S-S													
	9	2.8L 4V V6 Turbo DCP + GDI lean burn	DCT 6spd	42 S-S													
	10	3.0L V6 Turbo Diesel	DCT 6 spd	12													
	11	4.2L 4V V6 w/ Deac GDI + CCP HEV (2-mode)	N/A	HEV		$9,458	$9,433	$7,704	$6,317	$6,294	$6,294	$6,294	$6,294	$6,294	$6,294	$5,486	36.5%
Large Truck (+ Van) V6 (T11)	baseline	4.2L-2V SOHC V6	AT 4 spd	12V													
	1	4.2L 2V SOHC V6	AT 4 spd	12V		$256	$252	$247	$243	$239	$239	$239	$239	$239	$239	$231	7.6%
	2	3.9L 2V SOHC V6 GDI + CCP	AT 6 spd	12V		$1,233	$1,199	$1,167	$1,135	$1,104	$1,104	$1,104	$1,104	$1,104	$1,104	$984	18.3%
	3	3.9L 2V SOHC V6 w/Deac GDI + CCP	AT 6 spd	12V		$1,424	$1,384	$1,346	$1,309	$1,273	$1,273	$1,273	$1,273	$1,273	$1,273	$1,146	19.9%
	4	3.6L 4V V6 GDI + CCP	AT 6 spd	12V	V6 SOHC to V6 DOHC												
	5	3.6L 4V V6 GDI + CCP + DVVL	AT 6 spd	12V	V6 SOHC to V6 DOHC												
	6	3.6L 4V V6 w/ Deac GDI + CCP	AT 6 spd	12V	V6 SOHC to V6 DOHC												
	7	3.6L 4V V6 w/ Deac GDI + CCP	DCT 6 spd	42 S-S	V6 SOHC to V6 DOHC	$3,256	$3,184	$2,977	$2,800	$2,735	$2,735	$2,735	$2,735	$2,735	$2,735	$2,529	34.9%
	8	2.5L I4 Turbo DCP + GDI	DCT 6spd	42 S-S													
	9	4.0L 4V V6 HCCI GDI	DCT 6spd	42 S-S	V6 SOHC to V6 DOHC												
	10	2.5L I4 Turbo DCP + GDI lean burn	DCT 6spd	42 S-S													
	11	2.8L I4 Turbo Diesel	DCT 6 spd	12													
	12	3.6L 4V V6 w/ Deac GDI + CCP HEV (IMA)	DCT 6 spd	HEV	V6 SOHC to V6 DOHC												
	13	3.6L 4V V6 w/ Deac GDI + CCP HEV (2-mode)	N/A	HEV	V6 SOHC to V6 DOHC												
Large Truck + Large MPV V6 (T12)	baseline	3.8L 2V OHV V6	AT 4 sp	12 V													
	1	3.8L-2V OHV V6	AT 4 spd	12V		$256	$252	$247	$243	$239	$239	$239	$239	$239	$239	$231	7.6%
	2	3.2L 4V DOHC V6 GDI + CCP	AT 6 spd	12V	V6 OHV to V6 DOHC	$1,482	$1,441	$1,401	$1,362	$1,324	$1,324	$1,324	$1,324	$1,324	$1,324	$1,196	18.9%
	3	3.2L 4V DOHC V6 w/Deac GDI + CCP	AT 6 spd	12V	V6 OHV to V6 DOHC	$1,672	$1,625	$1,580	$1,536	$1,493	$1,493	$1,493	$1,493	$1,493	$1,493	$1,358	20.1%
	4	3.2L 4V DOHC V6 w/ Deac GDI + CCP	DCT 6 spd	42 S-S	V6 OHV to V6 DOHC	$3,381	$3,305	$3,095	$2,914	$2,845	$2,845	$2,845	$2,845	$2,845	$2,845	$2,635	34.9%
	5	2.5L I4 Turbo DCP + GDI	DCT 6spd	42 S-S		$3,653	$3,569	$3,351	$3,163	$3,087	$3,087	$3,087	$3,087	$3,087	$3,087	$2,820	35.1%

Table 1-12 Continued

Large Truck (+ Van) V8 (T13)	baseline	5.7L 2V OHV V8	AT 4 spd	12V													
	1	5.7L 2V OHV V8	AT 4 spd	12V		$256	$252	$247	$243	$239	$239	$239	$239	$239	$239	$231	7.6%
	2	5.2L 2V OHV V8 GDI + CCP	AT 6 spd	12V		$1,172	$1,141	$1,110	$1,080	$1,051	$1,051	$1,051	$1,051	$1,051	$1,051	$933	18.3%
	3	5.2L 2V OHV V8 w/Deac GDI + CCP	AT 6 spd	12V		$1,363	$1,325	$1,289	$1,253	$1,219	$1,219	$1,219	$1,219	$1,219	$1,219	$1,096	19.9%
	4	4.6L 4V V8 GDI + CCP	AT 6 spd	12V	V8 OHV to V8 DOHC												
	5	4.6L 4V V8 w/ Deac GDI + CCP	AT 6 spd	12V	V8 OHV to V8 DOHC												
	6	4.6L 4V V8 w/ Deac GDI + CCP	DCT 6 spd	42 S-S	V8 SOHC to V8 DOHC	$3,457	$3,379	$3,167	$2,984	$2,913	$2,913	$2,913	$2,913	$2,913	$2,913	$2,705	34.9%
	7	3.5L 4V V6 Turbo DCP + GDI	DCT 6spd	42 S-S		$4,142	$4,044	$3,812	$3,610	$3,520	$3,520	$3,520	$3,520	$3,520	$3,520	$3,223	35.1%
	8	4.6L 4V V8 HCCI GDI	DCT 6spd	42 S-S	V8 OHV to V8 DOHC												
	9	3.5L V6 Turbo DCP + GDI lean burn	DCT 6spd	42 S-S													
	10	3.5L V6 Turbo Diesel	DCT 6 spd	12													
	11	4.6L 4V V8 w/ Deac GDI + CCP HEV (2-mode)	N/A	HEV	V8 OHV to V8 DOHC												
Large Truck (+Van) V8 (T14)	baseline	5.4L 3V SOHC V8	AT 4 sp	12 V													
	1	5.4L 3V SOHC - V8	AT 4 spd	12 V		$256	$252	$247	$243	$239	$239	$239	$239	$239	$239	$239	7.6%
	2	4.6L 4V DOHC V8 GDI + CCP	AT 6 spd	12V	V8 SOHC 3V to V8 DOHC	$1,352	$1,315	$1,279	$1,244	$1,210	$1,210	$1,210	$1,210	$1,210	$1,210	$1,161	18.9%
	3	4.6L 4V DOHC V8 w/ Deac GDI + CCP	AT 6 spd	12V	V8 SOHC 3V to V8 DOHC	$1,714	$1,666	$1,619	$1,574	$1,530	$1,530	$1,530	$1,530	$1,530	$1,530	$1,456	21.2%
	4	4.6L 4V DOHC V8 w/ Deac GDI + CCP	DCT 6 spd	42 S-S	V8 SOHC 3V to V8 DOHC	$3,357	$3,282	$3,073	$2,893	$2,825	$2,825	$2,825	$2,825	$2,825	$2,825	$2,687	34.9%
	5	3.5L V6 Turbo DCP + GDI	DCT 6spd	42 S-S		$3,889	$3,798	$3,573	$3,379	$3,295	$3,295	$3,295	$3,295	$3,295	$3,295	$3,085	35.1%
Midsize MPV (unibody)/Small Truck V6/V8 (T15)	baseline	3.2L-4V DOHC V6	AT 4 spd	12V													
	1	3.2 L - 4V V6	AT 4 spd	12 V		$231	$227	$222	$218	$214	$214	$214	$214	$214	$214	$207	7.6%
	2	2.8L V6 GDI + CCP	AT 6 spd	12 V		$1,168	$1,136	$1,104	$1,073	$1,044	$1,044	$1,044	$1,044	$1,044	$1,044	$948	17.8%
	3	2.8L V6 GDI + CCP + DVVL	AT 6 spd	12 V													
	4	2.8L V6 w/ Deac GDI + CCP	AT 6 spd	12 V													
	5	2.8L V6 w/ Deac GDI + CCP	DCT 6 spd	42 S-S		$2,286	$2,239	$2,068	$1,924	$1,881	$1,881	$1,881	$1,881	$1,881	$1,881	$1,722	31.8%
	6	2.4L I4 Turbo DCP + GDI	DCT 6 spd	42 S-S													
	7	2.8L V6 HCCI GDI	DCT 6spd	42 S-S													
	8	2.4L I4 Turbo DCP + GDI lean burn	DCT 6 spd	42 S-S													
	9	2.8L I4 Turbo Diesel	DCT 6 spd	12		$3,342	$3,244	$3,149	$3,057	$2,968	$2,968	$2,968	$2,968	$2,968	$2,968	$2,732	32.6%
	10	3.0L V6 w/ Deac GDI + CCP HEV (IMA)	DCT 6 spd	HEV													
	11	3.0L V6 w/ Deac GDI + CCP HEV (2-mode)	N/A	HEV		$8,439	$8,420	$6,857	$5,603	$5,586	$5,586	$5,586	$5,586	$5,586	$5,586	$4,852	35.8%
Large MPV (unibody) V6 (T16)	baseline	3.5L-4V DOHC V6	AT 4 spd	12V													
	1	3.5L - 4V V6	AT 4 spd	12 V		$231	$227	$222	$218	$214	$214	$214	$214	$214	$214	$207	7.6%
	2	3.2L V6 GDI + CCP	AT 6 spd	12 V		$1,191	$1,158	$1,126	$1,095	$1,064	$1,064	$1,064	$1,064	$1,064	$1,064	$969	17.4%
	3	3.2L V6 w/ Deac GDI + CCP	AT 6 spd	12 V													
	4	3.2L V6 w/ Deac GDI + CCP	DCT 6 spd	42 S-S													
	5	2.4L I4 Turbo DCP + GDI	DCT 6spd	42 S-S		$2,485	$2,431	$2,255	$2,105	$2,057	$2,057	$2,057	$2,057	$2,057	$2,057	$1,806	31.6%
	6	3.2L V6 HCCI GDI	DCT 6spd	42 S-S													
	7	2.4L I4 Turbo DCP + GDI lean burn	DCT 6spd	42 S-S													
	8	2.0L I4 Turbo HEV (IMA) + GDI	DCT 6 spd	HEV													
	9	3.2L V6 w/ Deac GDI + CCP HEV (2-mode)	N/A	HEV		$9,234	$9,215	$7,493	$6,112	$6,095	$6,095	$6,095	$6,095	$6,095	$6,095	$5,310	36.5%

Table 1-12 Continued

Large MPV (unibody) V8 (T17)	baseline	4.6L-4V DOHC V8	AT 4 spd	12V												
	1	4.6L - 4V V8	AT 4 spd	12 V	$231	$227	$222	$218	$214	$214	$214	$214	$214	$214	$207	7.6%
	2	4.2L V6 GDI + CCP	AT 8 spd	12 V	$1,035	$1,006	$979	$952	$926	$926	$926	$926	$926	$926	$823	17.4%
	3	4.2L V6 w/ Deac GDI + CCP	AT 8 spd	12 V	$1,368	$1,329	$1,292	$1,256	$1,221	$1,221	$1,221	$1,221	$1,221	$1,221	$1,111	20.5%
	4	4.2L V6 w/ Deac GDI + CCP	DCT 6 spd	42 S-S	$2,593	$2,537	$2,358	$2,205	$2,153	$2,153	$2,153	$2,153	$2,153	$2,153	$1,984	33.7%
	5	2.8L V6 Turbo DCP + GDI	DCT 6spd	42 S-S												
	6	4.2L V6 HCCI GDI	DCT 6spd	42 S-S												
	7	2.8L V6 Turbo DCP + GDI lean burn	DCT 6spd	42 S-S												
	8	3.0L V6 Turbo Diesel	DCT 6 spd	12												
	9	4.2L V6 w/ Deac GDI + CCP HEV (2-mode)	N/A	HEV	$9,053	$9,040	$7,323	$5,948	$5,935	$5,935	$5,935	$5,935	$5,935	$5,935	$5,127	36.5%
Large Truck (+ Van) V6 (T18)	baseline	4.0L-4V DOHC V6	AT 4 spd	12V												
	1	4.0L - 4V V6	AT 4 spd	12 V	$256	$252	$247	$243	$239	$239	$239	$239	$239	$239	$231	7.6%
	2	3.6L V6 GDI + CCP	AT 6 spd	12 V	$1,233	$1,199	$1,167	$1,135	$1,104	$1,104	$1,104	$1,104	$1,104	$1,104	$984	18.3%
	3	3.6L V6 GDI + CCP + DVVL	AT 6 spd	12 V												
	4	3.6L V6 w/ Deac GDI + CCP	AT 6 spd	12 V	$1,565	$1,521	$1,479	$1,437	$1,398	$1,398	$1,398	$1,398	$1,398	$1,398	$1,270	21.0%
	5	3.6L V6 w/ Deac GDI + CCP	DCT 6 spd	42 S-S	$2,856	$2,796	$2,601	$2,436	$2,381	$2,381	$2,381	$2,381	$2,381	$2,381	$2,187	34.4%
	6	2.5L I4 Turbo DCP + GDI	DCT 6spd	42 S-S	$2,995	$2,931	$2,732	$2,562	$2,504	$2,504	$2,504	$2,504	$2,504	$2,504	$2,220	34.5%
	7	4.0L V6 HCCI GDI	DCT 6spd	42 S-S												
	8	2.5L I4 Turbo DCP + GDI lean burn	DCT 6spd	42 S-S												
	9	2.8L I4 Turbo Diesel	DCT 6 spd	12												
	10	3.6L V6 w/ Deac GDI + CCP HEV (IMA)	DCT 6 spd	HEV												
	11	3.6L V6 w/ Deac GDI + CCP HEV (2-mode)	N/A	HEV												
Large Truck (+ Van) V8 (T19)	baseline	5.6L 4V DOHC V8	AT 4 spd	12V												
	1	5.6L 4V V8	AT 4 spd	12 V	$256	$252	$247	$243	$239	$239	$239	$239	$239	$239	$231	7.6%
	2	4.6L V8 GDI + CCP	AT 6 spd	12 V	$1,172	$1,141	$1,110	$1,080	$1,051	$1,051	$1,051	$1,051	$1,051	$1,051	$933	18.3%
	3	4.6L V8 w/ Deac GDI + CCP	AT 6 spd	12 V	$1,363	$1,325	$1,289	$1,253	$1,219	$1,219	$1,219	$1,219	$1,219	$1,219	$1,096	21.0%
	4	4.6L V8 w/ Deac GDI + CCP	DCT 6 spd	42 S-S	$1,556	$1,515	$1,475	$1,435	$1,398	$1,398	$1,398	$1,398	$1,398	$1,398	$1,272	34.4%
	5	3.5L V6 Turbo DCP + GDI	DCT 6spd	42 S-S	$2,145	$2,086	$2,029	$1,973	$1,919	$1,919	$1,919	$1,919	$1,919	$1,919	$1,703	34.5%
	6	4.6L V8 HCCI GDI	DCT 6spd	42 S-S												
	7	3.5L V6 Turbo DCP + GDI lean burn	DCT 6spd	42 S-S												
	8	3.5L V6 Turbo Diesel	DCT 6 spd	12												
	9	4.6L V8 w/ Deac GDI + CCP HEV (2-mode)	N/A	HEV												

Table 1-13 Package Costs Measured Relative to the Package Costs for the 2016MY

YEAR	PACKAGE COSTS RELATIVE TO 2016
2012	117%
2013	115%
2014	108%
2015	102%
2016	100%
2017	100%
2018	100%
2019	100%
2020	100%
2021	100%
2022+	92%

We do not show cost and effectiveness estimates for a number of the technology listed in Table 1-12, as we determined that these packages were not cost effective relative to other packages available for a specific vehicle type. The process used to make these determinations is discussed below.

As discussed in detail in Chapter 4 of this DRIA, the order of technology which will be applied to any specific vehicle by the OMEGA model is set in the Technology input file. Since the goal of adding technology is to move the manufacturer closer to compliance with the GHG standard, the available technology packages should be placed in order of their total GHG effectiveness. Otherwise, the model is adding technology which moves the manufacturer further from compliance. At the same time, the cost of each successive package should be greater than that of the prior package. In this case, a greater degree of GHG reduction is available at a lower cost. The package with the greater cost and lower overall effectiveness should therefore be removed from the list.

Table 1-14 presents the complete list of technology packages which were described for vehicle type #6, which includes midsize and large cars equipped with a V8 engine with either SOHC or DOHC and 4 valves per head. The only exception is that the package including an HCCI engine has been removed as this technology is not expected to be commercially available in time for widespread introduction by 2016. The information listed in the first six columns is taken from Table 1-12. The values in the seventh column, which are explained below, are used to remove packages which would not likely be applied by a manufacturer and therefore, should not be included in the OMEGA modeling.

Table 1-14 Evaluation of Technology Packages for Vehicle Type #6

Engine	Transmission	System Voltage	Weight Reduction	Total CO2 Reduction	Total 2016 Cost	$/delta CO2 %
4.5L DOHC 4-Valve V8	AT 4 spd	12V	0%	7.6%	$214	$2,816
4.0L V6 GDI + CCP	AT 6 spd	12V	3%	17.9%	$883	$6,497
4.0L V6 w/ Deac GDI + CCP	AT 6 spd	42 S-S	5%	28.2%	$1633	$7,274
3.0L V6 Turbo DCP + GDI	AT 6 spd	42 S-S	5%	28.5%	$2333	$284,727
4.0L V6 w/ Deac GDI + CCP	DCT 6 spd	42 S-S	5%	31.9%	$1719	$(17,617)
3.0L V6 Turbo DCP + GDI	DCT 6spd	42 S-S	5%	32.1%	$2419	$2,363
3.0L V6 Turbo Diesel	DCT 6 spd	12V	5%	35.0%	$3456	$35,737
3.0L V6 w/ Deac GDI+CCP HEV	2-mode	HEV	0%	44.4%	$5953	$26,586
Remove Turbo with AT 6 spd						
4.5L DOHC 4-Valve V8	AT 4 spd	12V	0%	7.6%	$214	$2,816
4.0L V6 GDI + CCP	AT 6 spd	12V	3%	17.9%	$883	$6,497
4.0L V6 w/ Deac GDI + CCP	AT 6 spd	42 S-S	5%	28.2%	$1633	$7,274
4.0L V6 w/ Deac GDI + CCP	DCT 6 spd	42 S-S	5%	31.9%	$1719	$2,305
3.0L V6 Turbo DCP + GDI	DCT 6spd	42 S-S	5%	32.1%	$2419	$452,082
3.0L V6 Turbo Diesel	DCT 6 spd	12V	5%	35.0%	$3456	$35,737
3.0L V6 w/ Deac GDI + CCP HEV	2-mode	HEV	0%	44.4%	$5953	$26,586
Remove Turbo with DCT 6 spd						
4.5L DOHC 4-Valve V8	AT 4 spd	12V	0%	7.6%	$214	$2,816
4.0L V6 GDI + CCP	AT 6 spd	12V	3%	17.9%	$883	$6,497
4.0L V6 w/ Deac GDI + CCP	AT 6 spd	42 S-S	5%	28.2%	$1633	$7,274
4.0L V6 w/ Deac GDI + CCP	DCT 6 spd	42 S-S	5%	31.9%	$1719	$2,305
3.0L V6 Turbo Diesel	DCT 6 spd	12V	5%	35.0%	$3456	$56,828
3.0L V6 w/ Deac GDI + CCP HEV	2-mode	HEV	0%	44.4%	$5953	$26,586
Remove Diesel						
4.5L DOHC 4-Valve V8	AT 4 spd	12V	0%	7.6%	$214	$2,816
4.0L V6 GDI + CCP	AT 6 spd	12V	3%	17.9%	$883	$6,497
4.0L V6 w/ Deac GDI + CCP	AT 6 spd	42 S-S	5%	28.2%	$1633	$7,274
4.0L V6 w/ Deac GDI + CCP	DCT 6 spd	42 S-S	5%	31.9%	$1719	$2,305
3.0L V6 w/ Deac GDI + CCP HEV	2-mode	HEV	0%	44.4%	$5953	$34,012
Remove two AT 6 spd steps						
4.5L DOHC 4-Valve V8	AT 4 spd	12V	0%	7.6%	$214	$2,816
4.0L V6 w/ Deac GDI + CCP	DCT 6 spd	42 S-S	5%	31.9%	$1719	$6,184
3.0L V6 w/ Deac GDI + CCP HEV	2-mode	HEV	0%	44.4%	$5953	$34,012

The seventh, or last column of Table 1-14 is a measure of the incremental cost effectiveness of each package relative to the previous package. Specifically, it is the ratio of the incremental cost of the current package over the previous package to the incremental effectiveness of the current package over the previous package. In both cases (cost and effectiveness), the increment is the arithmetic difference. As discussed above, OMEGA uses a different measure of incremental effectiveness in its calculation of CO2 emissions. Here, however, the arithmetic difference in the effectiveness of two technology packages provides the best comparison across packages, since the base CO2 emissions inherent in the total effectiveness estimates is the same; that of the base vehicle. Therefore, a 10% difference between two packages with 7% and 17% effectiveness, respectively, represents the same CO2 emission reduction as a 10% difference between two packages with 27% and 37%

effectiveness, respectively. Generally, a low ratio of incremental cost to incremental effectiveness is better than a high ratio. Ideally, the technology packages included in the model would progress from lower ratios to higher ratios.

The topmost section of Table 1-14 shows all of the packages described earlier except for the HCCI engine package. The order of the packages has been rearranged slightly from that in Table 1-12 in order to place the packages in order of increasing total effectiveness. As can be seen, there are two very large anomalies in the ratios of incremental cost to incremental effectiveness. The ratio for the turbocharged engine with a 6 speed automatic transmission is very high, while that for the engine with cylinder deactivation with a dual clutch transmission is negative. The cause of this is that the cost of the latter package is lower than the former. If the latter package can achieve a 31.9% reduction in CO2 emissions at a cost of $1,719, then there is no point in considering a package which only achieves a 28.5% reduction in CO2 emissions for a cost of $2,333. Therefore, we removed the package for the turbocharged engine with a 6 speed automatic transmission and repeated the calculations. (In general, the package just prior to one with a negative ratio of incremental cost to incremental effectiveness should be removed.) The revised set of technology packages is shown in the second section of Table 1-14.

The second set of packages now shows one obvious anomaly. The ratio of incremental cost to incremental effectiveness for the turbocharged engine with a dual clutch transmission is more than a factor of 10 higher than any of the others. This occurs because this package only reduces CO2 emissions by 0.2% over the previous package for an incremental cost of $700. A manufacturer would be better off applying the next package (the diesel) to a portion of its vehicles than to apply the turbocharged engine with a dual clutch transmission package to a higher percentage of its vehicles. Therefore, we removed the package for the turbocharged engine with the dual clutch transmission and again repeated the calculations. The revised set of technology packages is shown in the third section of Table 1-14.

The greatest anomaly in the third set of ratios is that for the diesel package. It is more than twice the value of the ratio for the 2-mode hybrid. If we believed that manufacturers would prefer to implement diesel technology over strong hybridization for some reason, we could have left both packages in the modeling. However, absent such a reason, we removed the diesel engine package from vehicle type #6. The revised set of technology packages is shown in the fourth section of Table 1-14.

The greatest anomaly in the fourth section of the table is that the ratio of incremental cost to incremental effectiveness for the engine with cylinder deactivation and a dual clutch transmission is much lower than those for the two prior packages. In order to assess the benefit of removing the two prior packages, we do so in the fifth and last section of Table 1-14. As can be seen, the ratio of incremental cost to incremental effectiveness for the engine with cylinder deactivation and a dual clutch transmission increases to over $6,184. This is only marginally lower than the ratios for the two packages which have been excluded. Retaining the two packages provides a more gradual application of technology. This provides the model the choice of applying technology which is currently widespread in the fleet (6-speed automatic transmissions and 12 volt electrical systems) to a greater percentage of sales before applying more extensive technology (dual clutch transmissions and start stop technology). Therefore, we did not exclude the two technologies based on a strict use of the ratio of incremental cost to incremental effectiveness.

1.4 EPA's Lumped Parameter Approach for Determining Effectiveness Synergies

EPA engineers reviewed existing tools that could be used to develop estimates of the technology synergies, including the NEMS model[1]. However, the synergies in the NEMS model depend heavily upon an assumed technology application flow path; those technologies that the model would apply first would be expected to have fewer synergies than those applied later on. For this reason, and because this report includes many new technologies not available in NEMS, it was necessary for EPA to develop its own set of estimates. EPA used a well-documented engineering approach known as a lumped-parameter technique to determine values for synergies. At the same time, however, EPA recognized the availability of more robust methods for determining the synergistic impacts of multiple technologies on vehicle CO_2 emissions than the lumped-parameter approach, particularly with regard to applying synergy effects differentiated across different vehicle classes, and therefore augmented this approach with the detailed vehicle simulation modeling described in Section 1.4.7.

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:

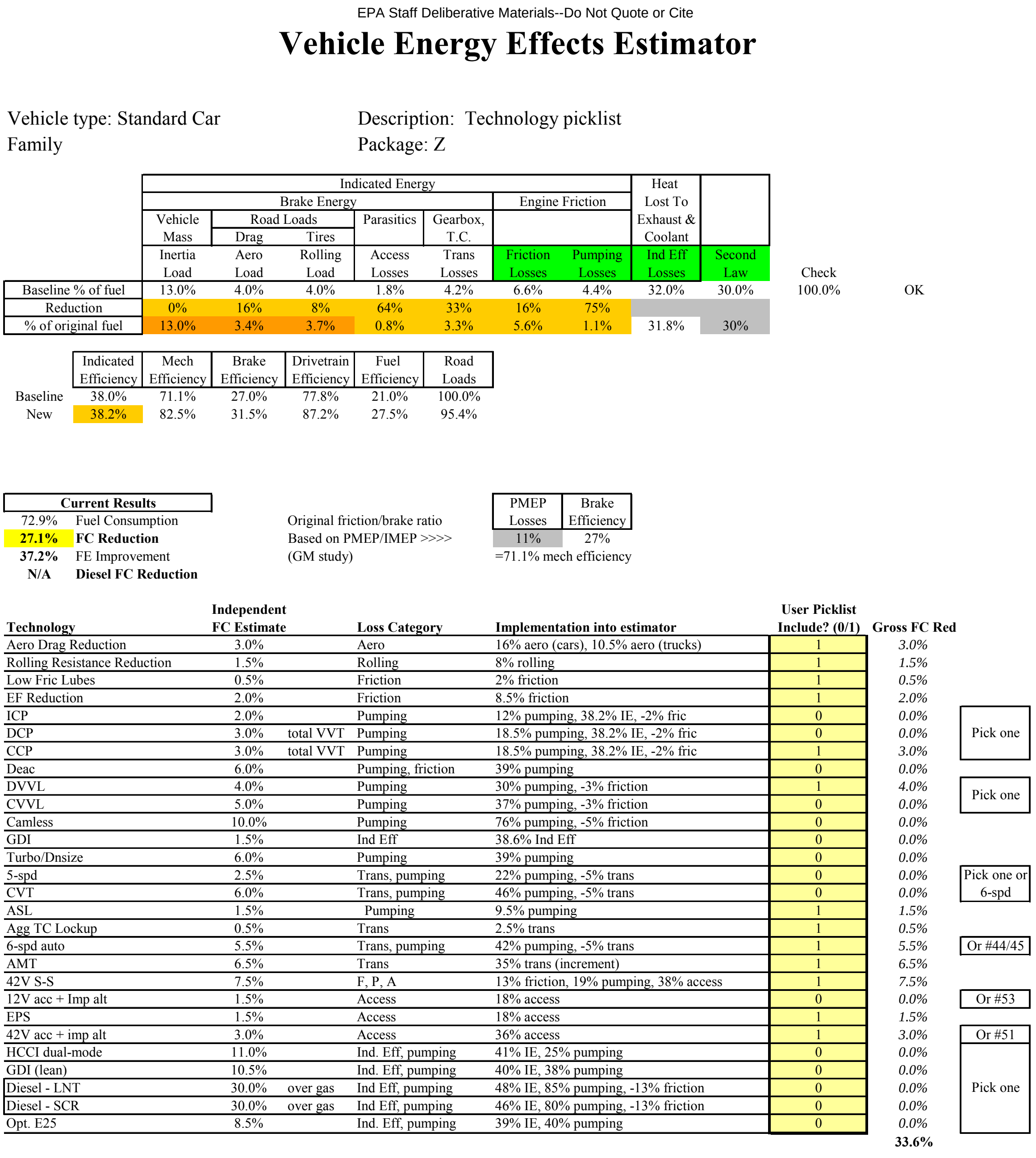
- Second law losses (thermodynamic losses inherent in the combustion of fuel),
- Heat lost from the combustion process to the exhaust and coolant,
- Pumping losses, i.e., work performed by the engine during the intake and exhaust strokes,
- Friction losses in the engine,
- Transmission losses, associated with friction and other parasitic losses,
- Accessory losses, related directly to the parasitics associated with the engine accessories and indirectly to the fuel efficiency losses related to engine warmup,
- Vehicle road load (tire and aerodynamic) losses;

with the remaining energy 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 categorized into the major types of engine losses it reduces, so that interactions between multiple technologies applied to the vehicle may be determined. When a technology is applied, its effects are estimated 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. Table

1-15 below is an example spreadsheet used by EPA to estimate the synergistic impacts of a technology package for a standard-size car.

Table 1-15 Sample Lumped Parameter Spreadsheet



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Vehicle Energy Effects Estimator

Vehicle type: Standard Car
Family

Description: Technology picklist
Package: Z

	Indicated Energy							Heat Lost To Exhaust & Coolant			
	Brake Energy					Engine Friction					
	Vehicle Mass	Road Loads		Parasitics	Gearbox, T.C.						
		Drag	Tires								
	Inertia Load	Aero Load	Rolling Load	Access Losses	Trans Losses	Friction Losses	Pumping Losses	Ind Eff Losses	Second Law	Check	
Baseline % of fuel	13.0%	4.0%	4.0%	1.8%	4.2%	6.6%	4.4%	32.0%	30.0%	100.0%	OK
Reduction	0%	16%	8%	64%	33%	16%	75%				
% of original fuel	13.0%	3.4%	3.7%	0.8%	3.3%	5.6%	1.1%	31.8%	30%		

	Indicated Efficiency	Mech Efficiency	Brake Efficiency	Drivetrain Efficiency	Fuel Efficiency	Road Loads
Baseline	38.0%	71.1%	27.0%	77.8%	21.0%	100.0%
New	38.2%	82.5%	31.5%	87.2%	27.5%	95.4%

Current Results	
72.9%	Fuel Consumption
27.1%	**FC Reduction**
37.2%	FE Improvement
N/A	**Diesel FC Reduction**

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

PMEP Losses	Brake Efficiency
11%	27%

=71.1% mech efficiency

Technology	**Independent FC Estimate**		**Loss Category**	**Implementation into estimator**	**User Picklist Include? (0/1)**	**Gross FC Red**	
Aero Drag Reduction	3.0%		Aero	16% aero (cars), 10.5% aero (trucks)	1	*3.0%*	
Rolling Resistance Reduction	1.5%		Rolling	8% rolling	1	*1.5%*	
Low Fric Lubes	0.5%		Friction	2% friction	1	*0.5%*	
EF Reduction	2.0%		Friction	8.5% friction	1	*2.0%*	
ICP	2.0%		Pumping	12% pumping, 38.2% IE, -2% fric	0	*0.0%*	Pick one
DCP	3.0%	total VVT	Pumping	18.5% pumping, 38.2% IE, -2% fric	0	*0.0%*	
CCP	3.0%	total VVT	Pumping	18.5% pumping, 38.2% IE, -2% fric	1	*3.0%*	
Deac	6.0%		Pumping, friction	39% pumping	0	*0.0%*	
DVVL	4.0%		Pumping	30% pumping, -3% friction	1	*4.0%*	Pick one
CVVL	5.0%		Pumping	37% pumping, -3% friction	0	*0.0%*	
Camless	10.0%		Pumping	76% pumping, -5% friction	0	*0.0%*	
GDI	1.5%		Ind Eff	38.6% Ind Eff	0	*0.0%*	
Turbo/Dnsize	6.0%		Pumping	39% pumping	0	*0.0%*	
5-spd	2.5%		Trans, pumping	22% pumping, -5% trans	0	*0.0%*	Pick one or 6-spd
CVT	6.0%		Trans, pumping	46% pumping, -5% trans	0	*0.0%*	
ASL	1.5%		Pumping	9.5% pumping	1	*1.5%*	
Agg TC Lockup	0.5%		Trans	2.5% trans	1	*0.5%*	
6-spd auto	5.5%		Trans, pumping	42% pumping, -5% trans	1	*5.5%*	Or #44/45
AMT	6.5%		Trans	35% trans (increment)	1	*6.5%*	
42V S-S	7.5%		F, P, A	13% friction, 19% pumping, 38% access	1	*7.5%*	
12V acc + Imp alt	1.5%		Access	18% access	0	*0.0%*	Or #53
EPS	1.5%		Access	18% access	1	*1.5%*	
42V acc + imp alt	3.0%		Access	36% access	1	*3.0%*	Or #51
HCCI dual-mode	11.0%		Ind. Eff, pumping	41% IE, 25% pumping	0	*0.0%*	Pick one
GDI (lean)	10.5%		Ind. Eff, pumping	40% IE, 38% pumping	0	*0.0%*	
Diesel - LNT	30.0%	over gas	Ind Eff, pumping	48% IE, 85% pumping, -13% friction	0	*0.0%*	
Diesel - SCR	30.0%	over gas	Ind Eff, pumping	46% IE, 80% pumping, -13% friction	0	*0.0%*	
Opt. E25	8.5%		Ind. Eff, pumping	39% IE, 40% pumping	0	*0.0%*	
						33.6%	

Table 1-16 below lists the technologies considered in this example, their corresponding individual technology effectiveness values, and a comparison of the gross combined package CO_2 reduction (i.e. disregarding synergies) to the lumped parameter results. The difference is the implied synergistic effects of these technologies combined on a package.

Table 1-16 Comparison of Lumped Parameter Analysis with Standard Car Package

TECHNOLOGY	INDIVIDUAL CO2 REDUCTION	CUMULATIVE CO2 REDUCTION
Aero Drag	3%	3%
Rolling Resistance Reduction	1.5%	4.5%
Low Friction Lubricants	0.5%	4.9%
Engine Friction Reduction	2.0%	6.8%
VVT – Coupled Cam Phasing	3.0%	9.6%
VVT – Discrete Variable Lift	4.0%	13.2%
Aggressive Shift Logic	1.5%	14.5%
Early Torque Convertor Lock-up	0.5%	15.0%
6-speed Automatic Transmission	5.5%	19.6%
6-speed Dual Clutch Transmission	6.5%	24.9%
Stop-start with 42 volt system	7.5%	30.5%
Electric Power Steering	1.5%	31.5%
42V acc + improved alternator	3.0%	33.6%
Gross combined effectiveness	**33.6%**	
Lumped Parameter Estimate	**27.1%**	
Estimated synergistic effects	**-6.5%**	

The synergy estimates obtained using the lumped parameter technique were subsequently compared to the results from the vehicle simulation work. EPA will continue to use the lumped parameter approach as an analytical tool, and (using the output data from the vehicle simulation as a basis) may adjust the synergies as necessary in the future.

1.4.1 Ricardo's Vehicle Simulation

Vehicle simulation modeling was performed by Ricardo, Inc. The simulation work addressed gaps in existing synergy modeling tools, and served to both supplement and update the earlier vehicle simulation work published by NESCCAF. Using a physics-based, second-by-second model of each individual technology applied to various baseline vehicles, the Ricardo model was able to estimate the effectiveness of the technologies acting either individually or in combination. This information could then be used to estimate the synergies of these technology combinations, and also to differentiate the synergies across different vehicle classes.

In total, Ricardo modeled five baseline vehicles and twenty-six distinct technology combinations, covering the full range of gasoline and diesel powertrain technologies used in the Volpe model, with the exception of the powersplit, plug-in and two-mode hybrid vehicle technologies. The five generalized vehicle classes modeled were a standard car, a full-size car, a small multi-purpose vehicle (MPV), a large MPV and a large truck. The complete list of vehicles and technology packages is given below in this section, along with a detailed explanation of the selection criteria.

Each technology package was modeled under a constraint of "equivalent performance" to the baseline vehicle. To quantify the performance, a reasonably comprehensive, objective set of vehicle performance criteria were used as a basis to compare with the baseline vehicle, characterizing the launch acceleration, passing performance and grade capability that a vehicle buyer might expect when considering a technology package. The main metrics used to compare vehicle performance are listed below in Table 1-17.

Table 1-17 Performance Metrics Used as Basis for "Equivalent Performance"

CHARACTERISTIC	PERFORMANCE METRIC
Overall Performance	Time to accelerate from 0-60 MPH
Launch Acceleration	Time to accelerate from 0-30 MPH
	Vehicle speed and distance after a 3-second acceleration from rest
Passing Performance	Time to accelerate from 30 to 50 MPH
	Time to accelerate from 50 to 70 MPH
Grade Capability	Maximum % grade at 70 MPH (standard car, large car, small MPV and large MPV)
	Maximum % grade at 60 MPH at GCVWR (large truck)

Notes: All accelerations are assumed at WOT (wide open throttle) condition. GCVWR = Gross Combined Vehicle Weight Rating

A summary of the vehicle simulation results is given below in Section 1.4.7, including the CO_2 emissions reduction effectiveness for each technology package. The full Ricardo vehicle simulation results, including the acceleration performance data, may be found in Ricardo's final report posted publicly at EPA's website.[2]

1.4.2 Description of Ricardo's Report

In this section, the structure, methodology and results from the Ricardo vehicle simulation report are summarized. EPA worked closely with Ricardo to develop baseline models of five generalized vehicle classes that could be validated against EPA certification data, and then used as a platform upon which to add various technology packages. The vehicle simulation modeling results generated by Ricardo consist of the following:

- Baseline vehicle characterization, to determine the baseline fuel consumption and CO_2 emissions over the EPA combined cycle federal test procedure (FTP) for five baseline vehicles, for validation with EPA certification data.
- Simulation of the vehicle technology combinations (applied to the baseline vehicles)

- Incremental technology effectiveness estimates, to examine the effect of adding technologies one-by-one. These could then be used more directly to validate synergies estimated using the lumped parameter method.

This section describes the selection process for each of the baseline vehicles and the technology packages, and summarizes the results of the vehicle simulation.

1.4.3 Determination of representative vehicle classes

In an effort to establish a reasonable scope for the vehicle simulation work and to update the earlier simulation done by NESCCAF, EPA chose five representative vehicle classes as the basis for evaluating technology benefits and synergies, representing the vehicle attributes of the projected highest-volume light-duty car and truck sales segments. These five classes covered a broad range of powertrain and vehicle characteristics, over which the effectiveness and synergies of each of the technologies could be evaluated. The main distinguishing attributes of the five vehicle classes considered by EPA and Ricardo are given below in Table 1-18.

Table 1-18 Attributes of the Five Generalized Vehicle Classes Considered by Ricardo

VEHICLE CLASS	STANDARD CAR	LARGE CAR	SMALL MPV	LARGE MPV	LARGE TRUCKS
EPA Vehicle Types Included	Compact, Midsize	Large CAR	Small SUV, Small Pickup	Minivans, Mid-SUV’s	Large SUV’s, Large Pickups
Curb Weight Range	2800-3600 lbs	>3600 lbs	3600-4200 lbs	4200-4800 lbs	>4800 lbs
Engine Type	I4	V6	I4	V6	V8
Drivetrain	FWD	RWD/AWD	FWD	FWD/AWD	4WD
Body Type	Unibody	Unibody	Unibody	Unibody	Ladder Frame
Towing Capability	None	None	Partial	Partial	Full
Example vehicles	Toyota Camry, Chevy Malibu, Honda Accord	Chrysler 300, Ford 500 / Taurus	Saturn Vue, Ford Escape, Honda CR-V	Dodge Grand Caravan, GMC Acadia, Ford Flex	Ford F-150, Chevy Silverado 1500, Dodge Ram

EPA then selected representative vehicle models for each of these classes, based on three main criteria:

- The vehicle should possess major attributes and technology characteristics that are near the average of its class, including engine type and displacement, transmission type, body type, weight rating, footprint size and fuel economy rating.

- It should be among the sales volume leaders in its class, or where there is not a clearly-established volume leader, the model should share attributes consistent with major sellers.
- The vehicle should have undergone a recent update or redesign, such that the technology in the baseline model could be considered representative of vehicles sold at the beginning of the proposed regulatory timeframe.

Consideration was also given to include the sales-leading vehicle manufacturers among the baseline models. Hence, the U. S. domestic manufacturers account for four of the five models (Chrysler 300, GM/Saturn Vue, Chrysler/Dodge Caravan, and the Ford F-150), while import manufacturers are represented in their strongest sales segment, the standard car class, by the Toyota Camry.

1.4.4 Description of Baseline Vehicle Models

The baseline vehicles selected to represent their respective vehicle classes are described below in Table 1-19, listed with the critical attributes that EPA used as selection criteria. While each attribute for these baseline vehicles does not match the precise average for its class, each of these baselines is an actual vehicle platform that allows validation of the simulation data with "real world" certification data.

Table 1-19 Description of Baseline Vehicles

VEHICLE CLASS		STANDARD CAR	LARGE CAR	SMALL MPV	LARGE MPV	LARGE TRUCKS
Baseline Vehicle		Toyota Camry	Chrysler 300	Saturn VUE	Dodge Grand Caravan	Ford F-150
CO2 Emissions* (g/mi)		327	409	415	435	575
Vehicle Attributes	**Base Engine**	DOHC I4	SOHC V8	DOHC I4	OHV V6	SOHC V8
	Displacement (L)	2.4	3.5	2.4	3.8	5.4
	Rate Power (HP)	154	250	169	205	300
	Torque (ft-lbs)	160	250	161	240	365
	Valvetrain Type	VVT (DCP)	Fixed	VVT (DCP)	Fixed	VVT (CCP)
	Valves/Cylinder	4	4	4	2	3
	Drivetrain	FWD	RWD	FWD	FWD	4WD
	Transmission	Auto	Auto	Auto	Auto	Auto
	# of Forward Speeds	5	5	4	4	4
	Curb Weight (lbs)	3108	3721	3825	4279	5004
	ETW (lbs)	3500	4000	4000	4500	6000
	GVWR (lbs)	--	--	4300	5700	6800
	GCWR (lbs)	--	--	--	--	14000
	Front Track Width (in.)	62	63	61.4	63	67
	Wheelbase (in.)	109.3	120	106.6	119.3	144.5
Performance Characteristics	**Displacement / Weight Ratio (L/ton)**	1.54	1.88	1.25	1.78	2.16
	Power / Weight Ratio (HP/ton)	99.1	134.4	88.4	95.8	119.9

*-Estimated CO_2 equivalent, taken from EPA adjusted combined fuel economy ratings.

1.4.5 Technologies Considered by EPA and Ricardo in the Vehicle Simulation

A number of advanced gasoline and diesel technologies were considered in the Ricardo study, comprising the majority of the technologies used in the Volpe model, with the exception of the hybrid electric vehicle technologies. In developing a comprehensive list of technologies to be modeled, EPA surveyed numerous powertrain and vehicle technologies and technology trends, in order to assess their potential feasibility in the next one to ten years.

The list of technologies considered therefore includes those that are available today (e.g., variable valve timing, six-speed automatic transmissions) as well as some that may not be ready for five to ten years (e.g., camless valve actuation and HCCI engines). Table 1-20 below lists the technologies that Ricardo included in the vehicle simulation models.

Table 1-20 Technologies Included in the Ricardo Vehicle Simulation

ENGINE TECHNOLOGIES	
Abbreviation	**Description**
DOHC	Dual Overhead Camshafts
SOHC	Single Overhead Camshaft
OHV	Overhead Valve (pushrod)
CCP	Couple Cam Phasing
DCP	Dual (independent) Cam Phasing
DVVL	Discrete (two-step) Variable Valve Lift
CVVL	Continuous Variable Valve Lift
Deac	Cylinder Deactivation
CVA	Camless Valve Actuation (full)
Turbo	Turbocharging and engine downsizing
GDI	Gasoline Direct Injection
Diesel	Diesel with advanced aftertreatment
HCCI	Homogenous Charge Compression Ignition (gasoline)
LUB	Low-friction engine lubricants
EFR	Engine Friction Reduction
TRANSMISSION TECHNOLOGIES	
Abbreviation	**Description**
L4	Lock-up 4-speed automatic transmission
L5	Lock-up 5-speed automatic transmission
L6	Lock-up 6-speed automatic transmission
DCT6	6-speed Dual Clutch Transmission
CVT	Continuously Variable Transmission
ASL	Aggressive Shift Logic
TORQ	Early Torque Converter Lock-up
ACCESSORY TECHNOLOGIES	
Abbreviation	**Description**
ISG (42V)	42V Integrated Starter-Generator
EPS	Electric Power Steering
EACC	Electric Accessories (water pump, oil pump, fans)
HEA	High-Efficiency Alternator
VEHICLE TECHNOLOGIES	
Abbreviation	**Description**
AERO	Aerodynamic drag reduction (10~20%)
ROLL	Tire Rolling Resistance reduction (10%)

1.4.6 Choice of Technology Packages

EPA chose a number of technology packages representing a range of options that manufacturers might pursue. In determining these technology combinations, EPA considered available cost and effectiveness numbers from the literature, and applied engineering judgment to match technologies that were compatible with each other and with each vehicle platform. Also, where appropriate, the same technologies were applied to multiple vehicle classes, to determine where specific vehicle attributes might affect their benefits and synergies. Table 1-21 below describes in detail the technology content in each technology package simulated by Ricardo.

Table 1-21 Description of the Vehicle Technology Packages Modeled by Ricardo

VEHICLE CLASS	TECHNOLOGY PACKAGE	ENGINE	VALVETRAIN	TRANSMISSION	ACCESSORIES
Standard Car	**Baseline**	**2.4 Liter I4**	**DOHC, DCP**	**L5**	**--**
	Z	2.4L I4, PFI	CCP, DVVL	DCT6	ISG (42V), EPA, EACC
	1	2.4L I4, GDI	DCP, DVVL	CVT	EPS, EACC, HEA
	2	2.4L I4, GDI	DCP	L6	ISG (42V), EPS, EACC
Small MPV	**Baseline**	**2.4 Liter I4**	**DOHC, DCP**	**L6**	**EPS**
	Z	2.4L I4, PFI	CCP, DVVL	DCT6	ISG (42V), EPA, EACC
	1	2.4L I4, GDI	DCP, DVVL	CVT	EPS, EACC, HEA
	2	2.4L I4, GDI	DCP	L6	ISG (42V), EPA, EACC
	15	1.5L I4, GDI, Turbo	DCP	DCT6	EPS, EACC, HEA
	15a	2.4L I4, GDI	CVA	DCT6	EPS, EACC, HEA
	15b	2.4L I4, GDI, HCCI	DCP, CVVL	DCT6	EPS, EACC, HEA
	5	1.9L I4, Diesel	DOHC	DCT6	EPS, EACC, HEA
Full Size Car	**Baseline**	**3.5 Liter V6**	**SOHC**	**L5**	**--**
	4	2.2L I4, GDI, Turbo	DCP	L6	EPS, EACC, HEA
	5	2.8L I4, Diesel	DOHC	DCT6	EPS, EACC, HEA
	Y1	3.5L V6, GDI	CVA	DCT6	EPS, EACC, HEA
	Y2	3.5L V6, GDI, HCCI	DCP, CVVL	DCT6	EPS, EACC, HEA
	6a	3.0L V6, GDI	DCP, CVVL	DCT6	EPS, EACC, HEA
	16	3.5L V6, GDI	CCP, Deac	L6	ISG (42V), EPA, EACC
Large MPV	**Baseline**	**3.8 Liter V6**	**OHV**	**L4**	**--**
	4	2.1L I4, GDI, Turbo	DCP	L6	EPS, EACC, HEA
	6b	3.0L V6, GDI	CCP, Deac	DCT6	EPS, EACC, HEA
	16	3.8L V6, GDI	CCP, Deac	L6	ISG (42V), EPA, EACC
Large Truck	**Baseline**	**5.4 Liter, V8**	**SOHC, CCP**	**L4**	**--**
	9	5.4L V8, GDI	CCP, Deac	DCT6	ISG (42V), EPA, EACC
	10	3.6L V6, GDI,	DCP	DCT6	EPS, EACC, HEA

		Turbo			
	11	4.8L V8, Diesel	DOHC	DCT6	EPS, EACC, HEA
	12	5.4L V8, GDI	CCP, Deac	L6	ISG (42V), EPA, EACC
	17	5.4L V8, GDI	DCP, DVVL	L6	EPS, EACC, HEA
	X1	5.4L V8, GDI	CVA	DCT6	EPS, EACC, HEA
	X2	5.4L V8, GDI, HCCI	DCP, CVVL	DCT6	EPS, EACC, HEA

Other: 20% Aerodynamic drag reduction, 10% tire rolling resistance reduction assumed for all vehicles, except Large Trucks. 10% Aerodynamic drag reduction assumed for Large Truck. Low-Friction lubricants and moderate engine friction reductions are assumed for all vehicles. Aggressive shift logic and early torque converter lockup strategies are assumed for all vehicles, where applicable.

1.4.7 Simulation Results

The CO_2 emissions results from the vehicle simulation are summarized below in Table 1-22 (for cars) and Table 1-23 (for light-duty trucks). The CO_2 estimates are given for the combined city and highway test cycles, according to the EPA Federal Test Procedure (FTP), with the technology package results compared with the baseline vehicle as shown.

It is important to reiterate that each of the technology package results were obtained with performance determined to be equivalent to the baseline vehicle. No attempt was made to project trends in performance during the proposed regulatory period, nor was the performance downgraded to give improved fuel efficiency. A full comparison of vehicle acceleration performance is given in the Ricardo final report.

Table 1-22 CO_2 Emissions Estimates Obtained from Vehicle Simulation (Cars)

VEHICLE	TECHNONOLGY PACKAGE	MAJOR FEATURES*	CO2 CITY	CO2 HWY	CO2 COMB	CO2 REDUCTION
			g/mi	g/mi	g/mi	%
Standard Car	**Baseline**	**2.4L I4, DCP, L5**	**338**	**217**	**284**	**--**
	Z	CCP, DVVL, DCT, ISG	250	170	214	24.7%
	1	GDI, DCP, DVVL, CVT	294	198	251	11.5%
	2	GDI, DCP, L6, ISG	277	180	233	17.8%
Full Size Car	**Baseline**	**3.5L V6, L5**	**420**	**279**	**356**	**--**
	4	2.2L I4, GDI, Turbo, DCP, L6	346	236	296	16.9%
	5	2.8L I4 Diesel, DCT	315	221	273	23.5%
	Y1	GDI, CVA, DCT	278	199	242	32.0%

	Y2	GDI, HCCI, DCT	290	197	248	30.4%
	6a	GDI, DCP, CVVL, DCT	331	235	288	19.2%
	16	GDI, CCP, Deac, L6, ISG	301	205	257	27.7%

*-Please refer to Table 1-20 for a full description of the vehicle technologies

Table 1-23 CO_2 Emissions Estimates Obtained from Vehicle Simulation (Light-Duty Trucks)

VEHICLE	TECHNONOLGY PACKAGE	MAJOR FEATURES*	CO2 CITY	CO2 HWY	CO2 COMB	CO2 REDUCTION
			g/mi	g/mi	g/mi	%
Small MPV	**Baseline**	**2.4L I4, DCP, EPS**	**367**	**253**	**316**	**--**
	Z	CCP, DVVL, DCT, ISG	272	208	243	23.0%
	1	GDI, DCP, DVVL, CVT	310	227	272	13.7%
	2	GDI, DCP, L6, ISG	291	211	255	19.3%
	15	1.5L I4 GDI, Turbo, DCP, DCT	272	212	245	22.5%
	15a	GDI, CVA, DCT	262	193	231	26.8%
	15b	GDI, HCCI, DCT	270	197	237	24.8%
	5	1.9L I4 Diesel, DCT	282	205	247	21.8%
Large MPV	**Baseline**	3.8L V6	458	313	393	--
	4	2.1L I4, GDI, Turbo, DCP, L6	357	256	312	20.6%
	6b	GDI, CCP, Deac, DCT	333	248	295	24.9%
	16	GDI, CCP, Deac, L6, ISG	325	225	280	28.7%
Large Truck	**Baseline**	5.4L V8, CCP	612	402	517	--
	9	GDI, CCP, Deac, DCT, ISG	432	315	379	26.7%
	10	3.6L V6, GDI, Turbo, DCP, DCT	404	319	366	29.3%
	11	4.8L V8 Diesel, DCT	444	326	391	24.4%
	12	GDI, CCP, Deac, L6, ISG	459	328	400	22.6%
	17	GDI, DCP, DVVL, L6	492	333	420	18.8%
	X1	GDI, CVA, DCT	422	314	374	27.8%
	X2	GDI, HCCI, DCT	425	311	374	27.7%

*-Please refer to Table 1-20 for a full description of the vehicle technologies

1.5 Comparison of Lumped-Parameter Results to Modeling Results

Considering the following:

1) EPA's lumped-parameter package estimates are comparable with those obtained from the detailed Ricardo simulations. This is illustrated in Figure 1-2 below.
2) EPA is confident in the plausibility of the individual technology effectiveness estimates in, based on the sources from which that information was assimilated, as detailed in Section 2 of this report.
3) Additionally, EPA expresses confidence in the overall Ricardo package results due to the robust methodology used in building the models and generating the results.

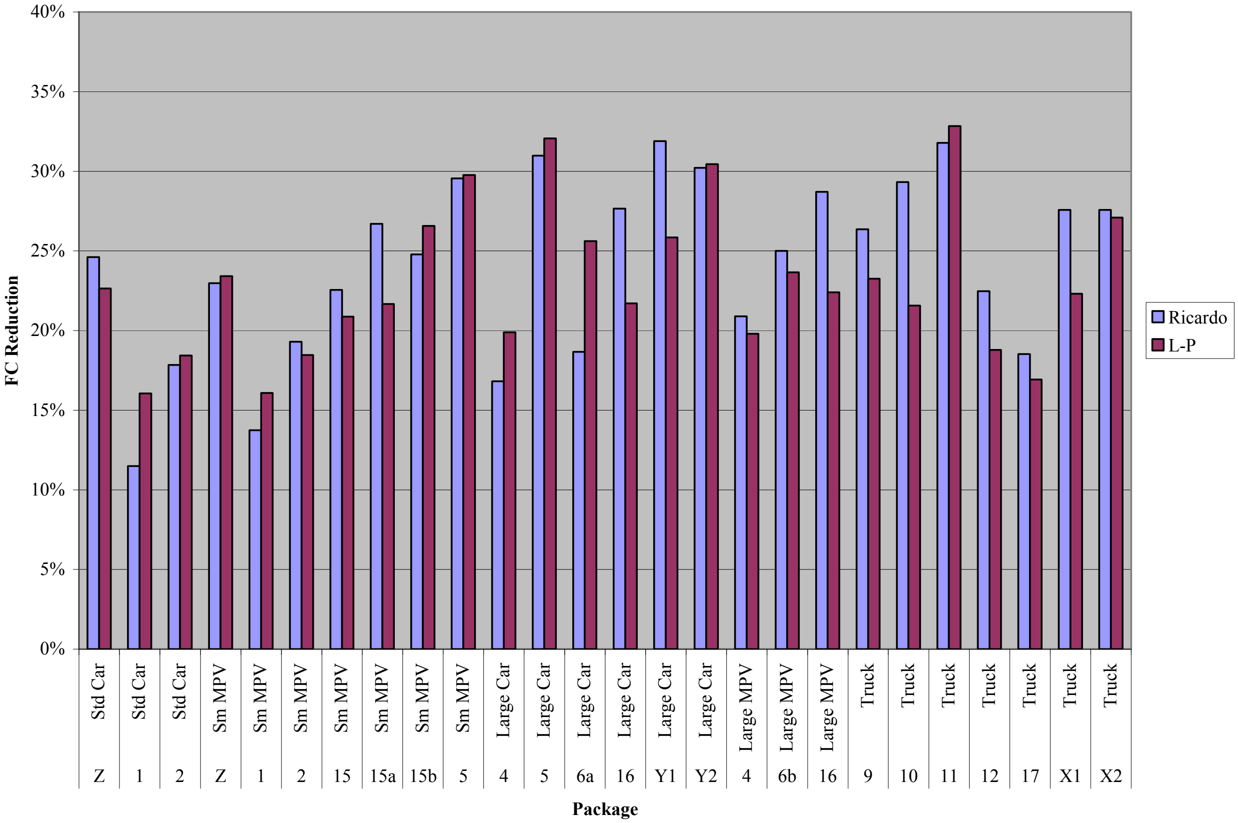

Figure 1-2 Comparison of Ricardo package results to equivalent lumped parameter package results

Based on this, EPA concludes that the synergies derived from the lumped parameter approach are generally plausible (with a few packages that garner additional investigation). EPA will continue to analyze this data, focusing on those packages where the differences between the two approaches are large.

The simulation results may present opportunities to improve the fidelity of the lumped-parameter approach by identifying differences between different platforms or important vehicle traits (such as displacement-to-weight ratio, e.g.). There might also be opportunity to infer (through detailed analysis) the individual effectiveness values for some technologies by comparing and isolating Ricardo package results across different vehicle platforms.

1.6 Using the Lumped-Parameter Technique to Determine Synergies in a Technology Application Flowpath (Identifying "Technology Pairs" to account for synergies)

In order to account for the real world synergies of combining of two or more technologies, the product of their individual effectiveness values must be adjusted based on known interactions, as noted above. When using an approach in which technologies are added sequentially in a pre-determined application path to each individual vehicle model, as used in NHTSA's 2006 fuel economy rule for light trucks[3], these interactions may be accounted for by considering a series of interacting technology pairs. EPA believes that a lumped parameter approach can be used as a means to estimate and account for synergies for such a technology application method. When using a sequential technology application approach which applies more than one technology, it is necessary to separately account for the interaction of each unique technology pair. Moreover, if the sequential technology application approach applies a technology that supersedes another, for example, where a VVLT system is substituted in place of a cylinder deactivation system, its incremental effectiveness must be reduced by the sum of the synergies of that technology with each individual technology that was previously applied, regardless of whether any of them have also been superseded. Figure 1-3 below provides an example of how technology pairs are identified for a specific technology application path similar to one used by NHTSA. In this example, an interaction is identified between each of the engine technologies (except GDI) with each of the transmission technologies. So, in this example, were the model to couple a turbocharged and downsized GDI engine with a 6-speed transmission, it would apply a series of many synergy pairs to the combined individual effectiveness values to arrive at the overall effectiveness.

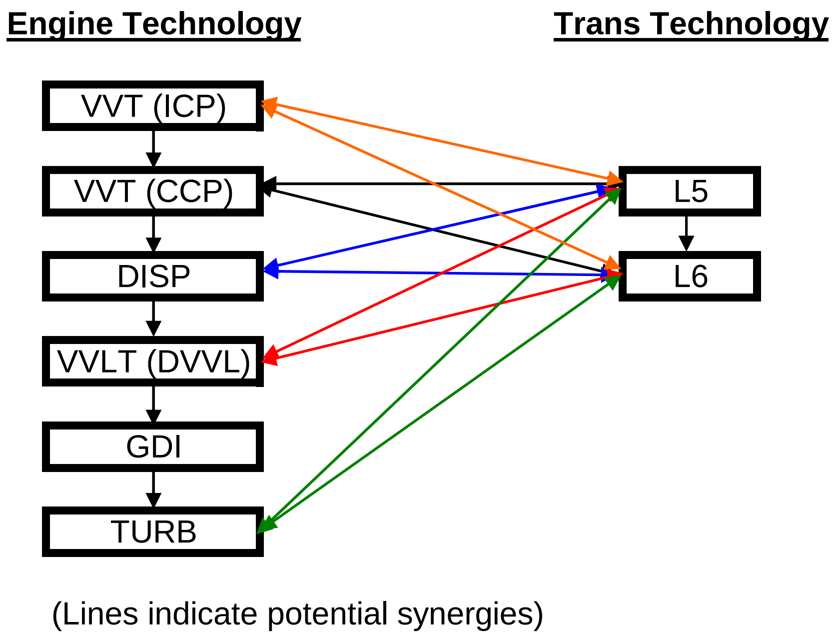

Figure 1-3 Illustration of technology pairings for a specific technology application path

References

All references can be found in the EPA DOCKET: **EPA-HQ-OAR-2009-0472.**

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[1] National Energy Modeling System, Energy Information Administration, U. S. Dept of Energy.

[2] "A Study of Potential Effectiveness of Carbon Dioxide Reducing Vehicle Technologies," EPA Report No. EPA420-R-08-004, available in the EPA docket EPA-HQ-OAR-2009-0472 and on the Internet at http://www.epa.gov/otaq/technology/420r08004a.pdf.

[3] NHTSA 2008-2011 CAFE FRM at 71 FR 17566.

CHAPTER 2: Air Conditioning

2.1 Overview of Air Conditioning Impacts and Technologies

Over 95% of the new cars and light trucks in the United States are equipped with air conditioner (MAC) systems. In the 1970's and 1980's, air conditioner systems were an optional (luxury) feature, but it now comes standard on almost all new vehicle models. The Mobile Air Conditioner (A/C) system is a unique and distinct technology on the automobile. It is different from the other technologies described in Chapter 3 of the joint Technical Support Document (TSD) in several ways. First, most of the technologies described in the joint TSD directly affect the efficiency of the engine, transmission, and vehicle systems. As such, these systems are almost always active while the vehicle is moving down the road or being tested on a dynamometer for the fuel economy and emissions test drive cycles. A/C on the other hand, is a parasitic load on the engine that only burdens the engine when the vehicle occupants demand it. Since it is not tested as a normal part of the fuel economy and emissions test drive cycles, it is referred to as an "off-cycle" effect. There are many other off-cycle loads that can be switched on by the occupant that affect the engine; these include lights, wipers, stereo systems, electrical defroster/defogger, heated seats, power windows, etc. However, these electrical loads individually amount to a very small effect on the engine (although together they can be significant). The A/C system (by itself) adds a significantly higher load on the engine as described later in this chapter. Secondly, present A/C systems leak a powerful greenhouse gas directly into the air - even when the vehicle is not in operation. No other vehicle system does this. Because of these factors, a distinct approach to control of MAC systems is justified, and a separate technical discussion is also warranted.

As just mentioned above, there are two mechanisms by which A/C systems contribute to the emissions of greenhouse gases. The first is through direct leakage of the refrigerant into the air. The hydrofluorocarbon refrigerant compound currently used in all recent model year vehicles is R134a (also known as 1,1,1,2-Tetrafluoroethane, or HFC-134a). Based on the higher global warming potential of HFCs, a small leakage of the refrigerant has a greater global warming impact than a similar amount of emissions of some other mobile source GHGs. R134a has a global warming potential (GWP) of 1430.

[2] This means that 1 gram of R134a has the equivalent global warming potential of 1,430 grams of CO2 (which has a GWP of 1).[4] In order for the A/C system to take advantage of the refrigerant's thermodynamic properties and to exchange heat properly, the system must

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[22] The global warming potentials (GWP) used in the NPRM analysis are consistent with Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4). At this time, the IPCC Second Assessment Report (SAR) global warming potential values have been agreed upon as the official U.S. framework for addressing climate change. The IPCC SAR GWP values are used in the official U.S. greenhouse gas inventory submission to the United Nations climate change framework. When inventories are recalculated for the final rule, changes in GWP used may lead to adjustments.

be kept at high pressures even when not in operation. Typical static pressures can range from 50-80 psi depending on the temperature, and during operation, these pressures can get to several hundred psi. At these pressures leakage can occur through a variety of mechanisms. The refrigerant can leak slowly through seals, gaskets, and even small failures in the containment of the refrigerant. The rate of leakage may also increase over the course of normal wear and tear on the system. Leakage may also increase more quickly through rapid component deterioration such as during vehicle accidents, maintenance or end-of-life vehicle scrappage (especially when refrigerant capture and recycling programs are less efficient). Small amounts of leakage can also occur continuously even in extremely "leak-tight" systems by permeating through hose membranes. This last mechanism is not dissimilar to fuel permeation through porous fuel lines. Manufacturers may be able to reduce these leakage emissions through the implementation of technologies such as leak-tight, non-porous, durable components. The global warming impact of leakage emissions also can be addressed by using alternative refrigerants with lower global warming potential. Refrigerant emissions can also occur during maintenance and at the end of the vehicle's life (as well as emissions during the initial charging of the system with refrigerant), and these emissions are already addressed by the CAA Title VI stratospheric ozone program, as described below.

The second mechanism by which vehicle A/C systems contribute to GHG emissions is through the consumption of additional fuel required to provide power to the A/C system and from carrying around the weight of the A/C system hardware year-round. The additional fuel required to run the system is converted into CO_2 by the engine during combustion. These increased emissions due to A/C operation can be reduced by increasing the overall efficiency of the vehicle's A/C system, as described below. EPA will not be addressing modifications to the excess weight of the A/C system, since the incremental increase in CO_2 emissions and fuel consumption due to carrying the A/C system is directly measured during the normal federal test procedure, and is thus already subject to the normal control program.

EPA's analysis indicates that together, these (A/C related) emissions account for about 9% of the greenhouse gas emissions from cars and light trucks. In this document, EPA will separate the discussion of these two categories of A/C-related emissions because of the fundamental differences in the emission mechanisms and the methods of emission control. Refrigerant leakage control is akin in many respects to past EPA fuel evaporation control programs (in that containment of a fluid is the key feature), while efficiency improvements are more similar to the vehicle-based control of CO_2 set out in the joint TSD (in that they would be achieved through specific hardware and controls).

EPA recognizes that California and the European Union also believe that A/C related emissions account for a significant part of greenhouse gas emissions. Both California and the European Union have either proposed or discussed programs to limit GHGs from A/C systems. EPA has evaluated these programs and this document discusses some similar features and others that emphasize additional emission reduction mechanisms.

2.2 Air Conditioner Leakage

2.2.1 Impacts of Refrigerant Leakage on Greenhouse Gas Emissions

There have been several studies in the literature which have attempted to quantify the emissions (and impact) of air conditioner HFC emissions from light duty vehicles. In this section, several of these studies are discussed.

2.2.1.1 In-Use Leakage Rates

Based on measurements from 300 European vehicles (collected in 2002 and 2003), Schwarz and Harnisch estimate that the average HFC direct leakage rate from modern A/C systems was estimated to be 53 g/yr.[5] This corresponds to a leakage rate of 6.9% per year. This was estimated by extracting the refrigerant from recruited vehicles and comparing the amount extracted to the amount originally filled (as per the vehicle specifications). The fleet and size of vehicles differs from Europe and the United States, therefore it is conceivable that vehicles in the United States could have a different leakage rate. The authors measured the average charge of refrigerant at initial fill to be about 747 grams (it is somewhat higher in the U.S. at 770g), and that the smaller cars (684 gram charge) emitted less than the higher charge vehicles (883 gram charge). Moreover, due to the climate differences, the A/C usage patterns also vary between the two continents, which may influence leakage rates.

Vincent et al., from the California Air Resources Board estimated the in-use refrigerant leakage rate to be 80 g/yr.[6] This is based on consumption of refrigerant in commercial fleets, surveys of vehicle owners and technicians. The study assumed an average A/C charge size of 950 grams and a recharge rate of 1 in 16 years (lifetime). The recharges occurred when the system was 52% empty and the fraction recovered at end-of-life was 8.5%.

2.2.1.2 Emission Inventory

The EPA publishes an inventory of greenhouse gases and sinks on an annual basis. The refrigerant emissions numbers that are used in the present analysis are from the Vintaging model, which is used to generate the emissions included in this EPA inventory source. The HFC refrigerant emissions from light duty vehicle A/C systems was estimated to be 61.8 Tg CO_2 equivalent in 2005 by the Vintaging model.[7,3]

In 2005, refrigerant leakage accounted for about 5.1% of total greenhouse gases from light duty sources. The following table shows the breakdown of greenhouse gases as broken down by the different emissions processes in 2005. The baseline tailpipe CO_2, N_2O and CH_4 emissions are from MOVES, the refrigerant emissions are from the Vintaging model, and the A/C CO2 emissions are from EPA and the National Renewable Energy Laboratory (NREL) as described below.

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[3] EPA reported the MVAC emissions at 56.6 Tg CO_2 EQ, using a GWP of 1300. This number has been adjusted using a GWP of 1430.

Table 2-1. CO2 equivalent emissions from light duty vehicles broken up by source or process.

Emissions source or process	Tg CO2 (equivalent)	Percentage of total
Tailpipe CO2 (w/o A/C)	1,076	88.6%
CO2 from A/C	47.2	3.9%
HFC-134a (Leakage)	61.8	5.1%
N2O	28.2	2.3%
CH4	1.9	0.2%
Total	1,215	

From a vehicle standpoint, the Vintaging model assumes that 42% of the refrigerant emissions are due to direct leakage (or "regular" emissions), 49% for service and maintenance (or "irregular" emissions), and 9% occurs at disposal or end-of-life as shown in the following table. These are based on assumptions of the average amount of chemical leaked by a vehicle every year, how much is lost during service of a vehicle (from professional service center and do-it-yourself practices), and the amount lost at disposal. These numbers vary somewhat over time based on the characteristics (e.g. average charge size and leakage rate) of each "vintage" of A/C system, assumptions of how new A/C systems enter the market, and the number of vehicles disposed of in any given year.

Table 2-2: Light duty vehicle HFC-134a emissions in 2005 from Vintaging model. HFC emissions can be converted to CO2 equivalent by multiplying by 1430 GWP.

Emission Process	HFC emissions (metric tons)	Fraction of total
Leakage	18,151	0.42
Maintenance/servicing	21,176	0.49
Disposal/end-of-life	3,890	0.09
Total	43,217	1.0

2.2.2 A/C Leakage Credit

The level to which each technology can reduce leakage can be calculated using the SAE Surface Vehicle Standard J2727 – HFC-134a Mobile Air Conditioning System Refrigerant Emission Chart. This industry standard was developed by SAE and the cooperative industry and government IMAC (Improved Mobile Air Conditioning) program using industry experience, laboratory testing of components and systems, and field data to establish a method for calculating leakage. With refrigerant leakage rates as low as 10 g/yr, it would be exceedingly difficult to measure such low levels in a test chamber (or shed). Since the J2727 method has been correlated to "mini-shed" results (where select components are tested in a small chamber, simulating real-world driving cycles), the EPA considers this method to be an appropriate surrogate for vehicle testing of leakage. It is also referenced by the California Air Resources Board in their Environmental Performance Label regulation and the State of Minnesota in their GHG reporting regulation.[8,9]

2.2.2.1 Why Is EPA Relying on a Design-Based Rule?

As with any design-based rule, it is possible to achieve compliance by simply selecting the minimum number of design attributes needed to meet a particular threshold or standard. Whether a design-based approach is used for emissions compliance or earning voluntary GHG credits, manufacturers will rightly choose the combination of design attributes which yield the maximum benefit at the lowest cost. However, there is a risk that some manufacturers may select poor quality, cheap parts, or implement the changes poorly, resulting in vehicles which ostensibly meet the rule's provisions, but in practice, fail to achieve their stated benefits. However, EPA believes that the market-driven incentive of assuring customer satisfaction will drive manufacturers to design A/C systems that perform as promised, and never need to be recharged. Also, it should be noted that the relative leakage rates assigned to various components, materials, and technologies in SAE J2727 are based on (and correlated to) actual leakage rates, as measured in bench- and field-test studies of vehicles and components.

In the case of refrigerant leakage, it would be very costly and burdensome to design, develop, and implement a test procedure and facility for measuring refrigerant leakage on each and every vehicle type a manufacturer produces. With leakage levels on many new vehicles expected to be as low as 9 g/yr (0.001 g/hr), it would be difficult to accurately measure the actual leakage rate. Even if it were possible to build a suitable facility capable of accurately measuring very low levels of refrigerant leakage, such a facility would still not exercise the A/C system across its normal range of operation, both in terms of engine and vehicle speeds as well as ambient conditions (e.g. under high compressor load, leakage past the compressor shaft seal on a running system can be 20 times higher than the static leakage level).[10] In addition, it is very likely that any performance-based test would become obsolete in the timeframe of this rulemaking, as low-GWP refrigerants are likely to be adopted by manufacturers.

In the absence of a vehicle-level performance test to measure the how a particular A/C system design functions (and the difficulty in creating such a test), EPA is proposing to rely upon the best available design metrics for quantifying system performance. EPA believes that the SAE J2727 method as an appropriate method for quantifying the expected yearly refrigerant leakage rate from A/C systems.

2.2.2.2 How Are Credits Calculated?

The A/C credit available to manufacturers will be calculated based on how much a particular vehicle's annual leakage value is reduced against the average new vehicle, and will be calculated using a method drawn directly from the SAE J2727 approach. By scoring the minimum leakage rate possible on the J2727 components enumerated in the proposed rule (expressed in the proposed rule as a measure of annual leakage), one earns the maximum A/C credit (on a gram per mile basis).

The A/C credit available to manufacturers will be calculated based on the reduction to a vehicle's yearly leakage rate, using the following equation:

Equation 1 – Credit Equation

A/C Credit = (MaxCredit) * [1 - (§86.166-12 Score/AvgImpact[4]) * (GWPRefrigerant/1430)]

There are four significant terms to the credit equation. Each is briefly summarized below, and is then explained more thoroughly in the following sections. Please note that the values of many of these terms change depending on whether HFC-134a or an alternative refrigerant are used. The values are shown in Table 2-3, and are documented in the following sections.

- "MaxCredit" is a term for the maximum amount of credit entered into the equation before constraints are applied to terms. The maximum credits that could be earned by a manufacturer is limited by the choice of refrigerant and by assumptions regarding maximum achievable leakage reductions.
- "Score/AvgImpact" is the leakage score of the A/C system as measured according to the §86.166-12 calculation in units of g/yr, where the minimum score which is deemed feasible is fixed.
- "AvgImpact" is the annual average impact of A/C leakage.
- "GWPRefrigerant" is the global warming potential for direct radiative forcing of the refrigerant as defined by EPA (or IPCC).

Table 2-3: Components of the A/C Credit Calculation

	HFC-134a		Alternative Refrigerant	
	Cars	Trucks	Cars	Trucks
MaxCredit equation input (grams /mile CO2 EQ)	12.6	15.6	13.8	17.2
A/C credit maximum (grams /mile CO2 EQ)	6.3	7.8	13.8	17.2
§86.166-12 Score AvgImpact (grams / HFC year)	8.3	10.4	8.3	10.4
Avg Impact (grams / HFC year)	16.6	20.7	16.6	20.7

2.2.2.2.1 Max Credit Term

In order to determine the maximum possible credit on a gram per mile basis, it was necessary to determine the projected real world HFC emissions per mile in 2016. Because HFC is a leakage type emission, it is largely disconnected from vehicle miles traveled

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[4] Proposed section 86.166-12 sets out the individual component leakage values based on the SAE value.

(VMT).[5] Consequently, the total HFC inventory in 2016 was calculated, and then calculated the relevant VMT. The quotient of these two terms is the HFC contribution per mile.

Consistent with the methodology presented in DRIA chapter 5, the HFC emission inventories were estimated from a number of existing data sources. The per-vehicle per-year HFC emission of the current (reference) vehicle fleet was determined using averaged 2005 and 2006 registration data from the Transportation Energy Databook (TEDB) and 2005 and 2006 mobile HFC leakage estimates from the EPA Emissions and Sinks report described above.[11,12] The per-vehicle per-year emission rates were then adjusted to account for the new definitions of car and truck classes (described in preamble section I), by increasing the car contribution proportionally by the percentage of former trucks that are reclassified as cars. This inventory calculation assumes that the leakage rates and charge sizes of future fleets are equivalent to the fleet present in the 2005/2006 reference years. Preliminary EPA analysis indicates that this may increasingly overstate the future HFC inventory, as charge sizes are decreasing.

The per-vehicle per-year average emission rate was then scaled by the projected vehicle fleet in each future year (using the fleet predicted in the emissions analysis) to estimate the HFC emission inventory if no controls were enacted on the fleet. After dividing the 2016 inventory by total predicted VMT in 2016, an average per mile HFC emission rate ("base rate") was obtained.

The base rate is an average in-use number, which includes both old vehicles with significant leakage, as well as newer vehicles with very little leakage. The new vehicle leakage rate is discussed in section 2.2.2.2.2, while deterioration is discussed in section 2.2.5.

- <u>Max Credit with Conventional Refrigerant (HFC-134a)</u>
  Two adjustments were made to the base rate in order to calculate the Maximum HFC credit with conventional refrigerant. First, EPA has determined that 50% leakage prevention is the maximum potentially feasible prevention rate in the 2012-2016 timeframe (section 2.2.3). Some leaks will occur and are expected, regardless of prevention efforts. The accuracy of the J2727 approach (as expressed in proposed §86.112), as a design based test, decreases as the amount of expected leakage diminishes. 50% of the base rate is therefore proposed to be set as the maximum potential leakage credit for improvements to HFC leakage using conventional refrigerant.

  Second, EPA expects that improvements to conventional refrigerant systems will affect both leakage and service emissions, but will not affect end of life emissions. EPA expects that reductions in the leakage rate from A/C systems will result in fewer visits for maintenance and recharges. This will have the side benefit of reducing the emissions leftover from can heels (leftover in the recharge cans) and the other releases

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[5] In short, leakage emissions occur even while the car is parked, so the connection to a gram/mile credit is not straightforward. However, HFC emissions must be converted to a gram/mile basis in order to create a relevant credit.

that occur during maintenance. However, as disposal/end of life emissions will be unaffected by the leakage improvements (and also are subject to control under the rules implementing Title VI of the CAA), the base rate was decreased by a further 9% (Table 2-2).

- Max Credit with Alternative Refrigerant
  Emission reductions greater than 50% are possible with alternative refrigerants. As an example, if a refrigerant with a GWP of 0 were used, it would be possible to eliminate all refrigerant GHG emissions. In addition, for alternative refrigerants, the EPA believes that vehicles with reduced GWP refrigerants should get credit for end of life emission reductions. Thus, the maximum credit with alternative refrigerant is about 9% higher than twice the maximum leakage reduction.

A final adjustment was made to each credit to account for the difference between real-world HFC emissions and test-cycle CO_2 emissions. It has been shown that the tests currently used for CAFE certification represents an approximately 20% gap from real world fuel consumption and the resulting CO_2 emissions.[13] Because the credits from direct a/c improvements are taken from a real world source, and are being traded for an increase in fuel consumption due to increased CO_2 emissions, the credit was multiplied by 0.8 to maintain environmental neutrality (Table 2-4).

Table 2-4 HFC Credit Calculation for Cars and Trucks based on a GWP of 1430

	HFC Inventory (MMT CO2 EQ)	VMT (Billions of Miles)	Total HFC EmissionsPer Mile (CO_2 EQ Gram/mile)	HFC Leakage and Service EmissionsPer Mile (CO_2 EQ Gram/mile)	Maximum Credit w/ alternative refrigerant (Adjusted for On-road gap & including end of life)	Maximum Credit w/o alternative refrigerant (50% of Adjusted HFC & excluding end of life)
Car	27.4	1,580	17.2	15.5	13.8	6.3
Truck	30.4	1,392	21.5	19.6	17.2	7.8
Total	57.8	2,972	18.6	16.9	14.9	6.8

2.2.2.2.2 Proposed section 86.166-12, implementing the J2727 Score Term

The J2727 score is the SAE J2727 yearly leakage estimate of the A/C system as calculated according to the J2727 procedure. The minimum score for cars and trucks is a fixed value, and the section below describes the derivation of the minimum leakage scores that can be achieved using the J2727 procedure.

In contrast to the studies discussed in section 2.2.1.1 which discussed the HFC emission rate of the in-use fleet (which includes vehicles at all stages of life), the SAE J2727 estimates leakage from new vehicles. In the development of J2727, two relevant studies were assessed to quantify new vehicle emission rates. In the first study, measurements from relatively new (properly functioning and manufactured) Japanese-market vehicles were collected. This study was based on 78 in-use vehicles (56 single evap, 22 dual evap) from 7 Japanese auto makers driven in Tokyo and Nagoya from April, 2004 to December, 2005. The study also measured a higher emissions level of 16 g/yr for 26 vehicles in a hotter climate (Okinawa). This study indicated the leakage rate to be close to 8.6 g/yr for single evaporator systems and 13.3 g/yr for dual evaporator systems.[14] A weighted (test) average gives 9.9 g/yr. In the second study, emissions were measured on European-market vehicles up to seven years age driven from November, 2002 to January, 2003.[15] The European vehicle emission rates were slightly higher than the Japanese fleet, but overall, they were consistent. The average emission rate from this analysis is 17.0 g/yr with a standard deviation of 4.4 g/yr. European vehicles, because they have smaller charge sizes, likely understate the leakage rate relative to the United States. To these emission rates, the J2727 authors added a factor to account for occasional defective parts and/or improper assembly and to calibrate the result of the SAE J2727 calculation with the leakage measured in the vehicle and component leakage studies.

We adjust this rate up slightly by a factor proportional to the average European refrigerant charge to the average United States charge (i.e. 770/747 from the Vintaging model and Schwarz studies respectively). The newer vehicle emission rate is thus 18 g/yr for the average newer vehicle emissions. This number is a combined car and truck number, and although based on the limited data, it was not possible to separate them.

To derive the minimum score, the 18 gram per year rate was used as a ratio to convert the gram per mile emission impact into a new vehicle gram per year for the test. The car or truck direct a/c emission factor (gram per mile) was divided by the average emission factor (gram per mile) and then multiplied by the new vehicle average leakage rate (gram per year)

Equation 2 – J2727 Minimum Score

> J2727 Minumum Score = Car or truck average pre control emissions (gram per mile)/ Fleet average pre-control emissions (grams per mile) x New vehicle annual leakage rate (grams per year) x Minimum Fraction

By applying this equation, the minimum J2727 score is fixed at 8.3 g/yr for cars and 10.4 g/yr for trucks. This corresponds to a total fleet average of 18 grams per year, with a maximum reduction fraction of 50%

The GWP Refrigerant term in Equation 1 allows for the accounting of refrigerants with lower GWP (so that this term can be as low as zero in the equation), which is why the same minimum score is kept regardless of refrigerant used.

It is technically feasible for the J2727 Minimum score to be less than the values presented in the table. But this will usually require the use of an electric compressor (see below for technology description), which the EPA does not expect to see with high penetrations within the 2012-2016 timeframe, as this technology is likely to accompany hybrid vehicle and stop-start technologies, and not conventional vehicles.

2.2.2.2.3 AvgImpact Term

AvgImpact is the average annual impact of A/C leakage, which is 16.6 and 20.7 g/yr for cars and trucks respectively. This was derived using Equation 2, but by setting the minimum fraction to one.

2.2.2.2.4 GWPRefrigerant Term

This term is relates to the global warming potential (GWP) of the refrigerant as documented by EPA. A full discussion of GWP and its derivation is too lengthy for this space, but can be found in many EPA documents.[16] This term is used to correct for refrigerants with global warming potentials that differ from HFC-134a. As just explained, this term accounts for the GWP of any refrigerant used, and can be as low as zero.

2.2.3 Technologies That Reduce Refrigerant Leakage and their Effectiveness

In this section, the baseline technologies which were used in the EPA's analysis of refrigerant leakage are described as well as the effectiveness of the leakage-reducing technologies that are believed will be available to manufacturers in the 2012-to-2016 timeframe of this proposed rulemaking. An EPA analysis to determine a baseline leakage emission rate was conducted in the 2006-to-2007 timeframe, and at that time, it was estimated that the A/C system in new vehicles would leak refrigerant at an average rate of 18 g/yr, which represents the types of A/C components and technologies currently in use. EPA believes, through utilization of the leakage-reducing technologies described below, that it will be possible for manufacturers to reduce refrigerant leakage 50%, relative to the 18 g/yr baseline level.[17] EPA also believes that all of these leakage-reducing technologies are currently available, and that many manufacturers have already begun using them to improve system reliability and in anticipation of the State of California's Environmental Performance Label regulations and the State of Minnesota's reporting requirements for High Global Warming Potential Gases.

In describing the technologies below, only the relative effectiveness figures are presented, as the individual piece costs are not known. The EPA only has costs of complete systems based on the literature, and the individual technologies are described below.

2.2.3.1 Baseline Technologies

The baseline technologies assumed for A/C systems which have an average annual leak rate of 18 g/yr are common to many mass-produced vehicles in the United States. In these mass-produced vehicles, the need to maintain A/C system integrity (and the need to avoid the customer inconvenience of having their A/C system serviced due to loss of refrigerant) is often balanced against the cost of the individual A/C components. For manufacturers seeking improved system reliabilty, components and technologies which reduce leakage (and possibly increase cost) are selected, whereas other manufacturers may choose to emphasize lower system cost over reliabilty, and choose components or technologies prone to increased leakage. In the absence of standards or credits concerning refrigerant leakage, it is the market forces of cost and reliability which determine the technology a manufacturer chooses. In EPA's baseline scenario, the following assumptions were made concerning the definition of a baseline A/C system:

- all flexible hose material is rubber, without leakage-reducing barriers or veneers, of approximately 650 mm in length for both the high and low pressure lines
- all system fittings and connections are sealed with a single o-rings
- the compressor shaft seal is a single-lip design
- one access port each on the high and low pressure lines
- two of the following components: pressure switch, pressure relief valves, or pressure transducer
- one thermostatic expansion valve (TXV)

The design assumptions of EPA baseline scenario are also similar to the sample worksheet included in SAE's surface vehicle standard J2727 – HFC-134a Mobile Air Conditioning System Refrigerant Emission Chart.[18] In the J2727 emission chart, it is the baseline technologies which are assigned the highest leakage rates, and the inclusion of improved components and technologies in an A/C system will reduce this annual leakage rate, as a function of their effectiveness relative to the baseline. EPA considers these 'baseline' technologies to be representative of recent model year vehicles, which, on average, can experience a refrigerant loss of 18 g/yr. However, depending on the design of a particular vehicle's A/C system (e.g. materials, length of flexible hoses, number of fittings and adaptor plates, etc.), it is possible to achieve a leakage score much higher (i.e. worse) than 18 g/yr. According to manufacturer data submitted to the State of Minnesota, 19% of 2009 model year vehicles have a J2727 refrigerant score greater than 18 g/yr, with the highest-scoring vehicle reporting a leakage rate of 30.1 g/yr.[19] The average leakage was found to be 15.1 g/yr, though this value is not sales weighted.

2.2.3.2 Flexible Hoses

The flexible hoses on an automotive A/C system are needed to isolate the system from engine vibration and to allow for the engine to roll within its mounts as the vehicle accelerates and decelerates. Since the compressor is typically mounted to the engine, the lines going to-and-from the compressor (i.e. the suction and pressure lines) must be flexible, or unwanted vibration would be transferred to the body of the vehicle (or other components), and excessive strain on the lines would result. It has been industry practice for many years to manufacture these hoses from rubber, which is relatively inexpensive and durable. However, rubber hoses are not impermeable, and refrigerant gases will eventually migrate into the atmosphere. To reduce permeation, two alternative hose material can be specified. The first material, is known as a standard 'veneer' (or 'barrier') hose, where a polyamide (polymer) layer - which has lower permeability than rubber - is encased by a rubber hose. The barrier hose is similar to a veneer hose, except that an additional layer of rubber is added inside the polyamide layer, creating three-layer hose (rubber-polyamide-rubber). The second material is known as 'ultra-low permeation', and can be used in a veneer or barrier hose design. This ultra-low permeation hose is the most effective at reducing permeation, followed by the standard veneer or barrier hose. Permeation is most prevalent during high pressure conditions, thus it is even more important that these low permeable hoses are employed on the high pressure side, more so than on the low pressure side. EPA expects that many manufacturers will begin using these technologies (and many have already begun doing so) to reduce refrigerant leakage.

According to J2727, standard barrier veneer hoses have 25% the permeation rate of rubber hose, and ultra low permeable barrier veneer hoses have 10% the permeation rate (as compared to a standard baseline rubber hose of the same length and diameter).

2.2.3.3 System Fittings and Connections

Within an automotive A/C system and the various components it contains (e.g. expansion valves, hoses, rigid lines, compressors, accumulators, heat exchangers, etc.), it is necessary that there be an interface, or connection, between these components. These interfaces may exists for design, manufacturing, assembly, or serviceability reasons, but all A/C systems have them to some degree, and each interface is a potential path for refrigerant leakage to the atmosphere. In SAE J2727 emission chart, these interfaces are described as fittings and connections, and each type of fitting or connection type is assigned an emission value based on its leakage potential; with a single o-ring (the baseline technology) having the highest leak potential; and a metal gasket having the lowest. In between these two extremes, a variety of sealing technologies, such as multiple o-rings, seal washers, and seal washers with o-rings, are available to manufacturers for the purpose of reducing leakage. It is expected that manufacturers will choose from among these sealing technology options to create an A/C system which offers the best cost-vs-leakage rate trade-off for their products.

The relative effectiveness of the fitting and connector technology is presented in Table 2-5. For example, the relative leakage factor of 125 for the baseline single O-ring is 125 times more "leaky" than the best technology - the metal gasket.

Table 2-5 : Effectiveness of Fitting and Connector Technology

Fitting or Connector	Relative Leakage
Single O-ring	125
Single Captured O-ring	75
Multiple O-ring	50
Seal Washer	10
Seal Washer with O-ring	5
Metal Gasket	1

2.2.3.4 Compressor Shaft Seal

A major source of refrigerant leakage in automotive A/C systems is the compressor shaft seal. This seal is needed to prevent pressurized refrigerant gasses from escaping the compressor housing. As the load on the A/C system increases, so does the pressure, and the leakage past the seal increases as well. In addition, with a belt-driven A/C compressor, a side load is placed on the compressor shaft by the belt, which can cause the shaft to deflect slightly. The compressor shaft seal must have adequate flexibility to compensate for this deflection, or movement, of the compressor shaft to ensure that the high-pressure refrigerant does not leak past the seal lip and into the atmosphere. When a compressor is static (not running), not only are the system pressures lower, the only side load on the compressor shaft is that from tension on the belt, and leakage past the compressor shaft is at a minimum. However, when the compressor is running, the system pressure is higher and the side load on the compressor shaft is higher (i.e. the side load is proportional to the power required to turn the compressor shaft) - both of which can increase refrigerant leakage past the compressor shaft seal. It is estimated that the rate of refrigerant leakage when a compressor is running can be 20 times that of a static condition.[10] Due to the higher leakage rate under running conditions, SAE J2727 assigns a higher level of impact to the compressor shaft seal. In the example shown in the August 2008 version of the J2727 document, the compressor is responsible for 58% of the system refrigerant leakage, and of that 58%, over half of that leakage is due to the shaft seal alone (the remainder comes from compressor housing and adaptor plate seals). To address refrigerant leakage past the compressor shaft, manufacturers can use multiple-lip seals in place of the single-lip seals.

2.2.4 Technical Feasibility of Leakage-Reducing Technologies

EPA believes that the leakage-reducing technologies discussed in the previous sections are available to manufacturers today, are relatively low in cost, and that their feasibility and effectiveness have been demonstrated by the SAE IMAC teams. EPA also believes – as has been demonstrated in the J2727 calculations submitted by manufacturers to the State of Minnesota – that reductions in leakage from 18 g/yr to 9 g/yr are possible (e.g. the 2009 Saturn Vue has a reported leakage score of 8.5 g/yr). In addition to earning credit for reduced refrigerant leakage, some manufacturers may, within the timeframe of this rulemaking, choose to introduce alternative refrigerant systems, such as HFO-1234yf.

2.2.5 Deterioration of Leakage Controls in A/C Systems

In order to determine the cost savings from the improvements to the leakage system, it is necessary to project the point at which the vehicle will require servicing and an additional refrigerant charge.

There are two mechanisms of deterioration that are modeled: the normal deterioration that results in increasing leakage and the “avoidable” deterioration of the condenser & compressor components. This model is developed to help us estimate the costs of the A/C reductions. It is especially needed to determine the period over which the discounted cost savings should be applied.[6]

Normal deterioration occurs throughout all components of the A/C system. Hoses, fittings, compressors, etc all wear with age and exposure to heat (temperature changes), vibration, and the elements. It is assumed that the system deterioration rates decrease (proportionally) as the base leakage rates are decreased with the use of improved parts and components. The base deterioration rate is modeled as a linear function, such that the (new vehicle) leakage rate is 18 g/yr at age zero and 59 g/yr at the "average" age of 5 years old. The 18 gram leakage rate for new vehicles has been documented in section 2.2.2, while the 59 gram mid-life leakage rate is drawn from the Vintaging model and is documented below.

The Vintaging model assumes a constant leakage + servicing emission rate of 18% per year for modern vehicles running with HFC-134a refrigerant. As the emission rates do not change by age in vintaging, the emission rate is the average rate of loss over the vehicle's life.

Applying the percentages in Table 2-2, this corresponds to a leakage rate of 7.6% (59 grams) per year and a servicing loss rate of 8.8% (68 grams) per year averaged over the vehicle's life. The model assumes an average refrigerant charge of 770 grams for vehicles sold in 2002 or later and does not currently assume that these charge sizes will change in the future; however, the model may be updated as new information becomes available. The resulting vehicle emission rates are presented in Table 2-6.

Table 2-6: Annual in-use vehicle HFC-134a emission rate from Vintaging model.

Emission Process	Leak rate (%/year)	Leak rate (g/year)
Leakage	7.6%	59
Servicing/maintenance	8.8%	68

The average leakage emissions rate of 59-68 g/yr is higher with Schwarz's European[5] study and lower than CARB's study,[6] and thus is within the range of results in the literature.

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[6] Air conditioning leakage controls are the only technology in this proposed rule that has an assumed deterioration that affects the effectiveness of the technology. This is partly because sufficient data is not available for many of the technologies in chapter 3 of the TSD. Moreover, it is not expected that deterioration of powertrain technologies will lead to emissions increases on the scale of those seen when criteria pollutant technologies deteriorate. The deterioration from the latter can increase emissions by factors of 10 or even 100 or more. Similarly, air conditioning leakage technologies can and do deteriorate, contributing to significantly higher emissions over time. For this reason, a deterioration model is proposed below. This model only applies for leakage, and not for indirect CO2 (tailpipe) emissions due to A/C. For the latter, a partly functioning system may lead to somewhat higher emissions, but when it finally fails, it is one of the few technologies where the emissions are no longer relevant, i.e. an A/C system that no longer functions, no longer emits indirect emissions.

This model is presented in Figure 2-1 with the assumption that the average vehicle (A/C system) last about 10 years. Technically, the assumption is that the A/C system lasts 10 years and not the vehicle per se. Inherent in this assumption is that the vehicle owner will not repair the A/C system on an older vehicle due to the expensive nature of most A/C repairs late in life relative to the value of the vehicle. It is also assumed that the refrigerant requires a recharge when the state of charge reaches 50% for the analysis in this section. This deterioration/leakage model approach will be used later to estimate the cost of maintenance savings due to low leak technologies (from refills) as well as the benefits of leakage controls.

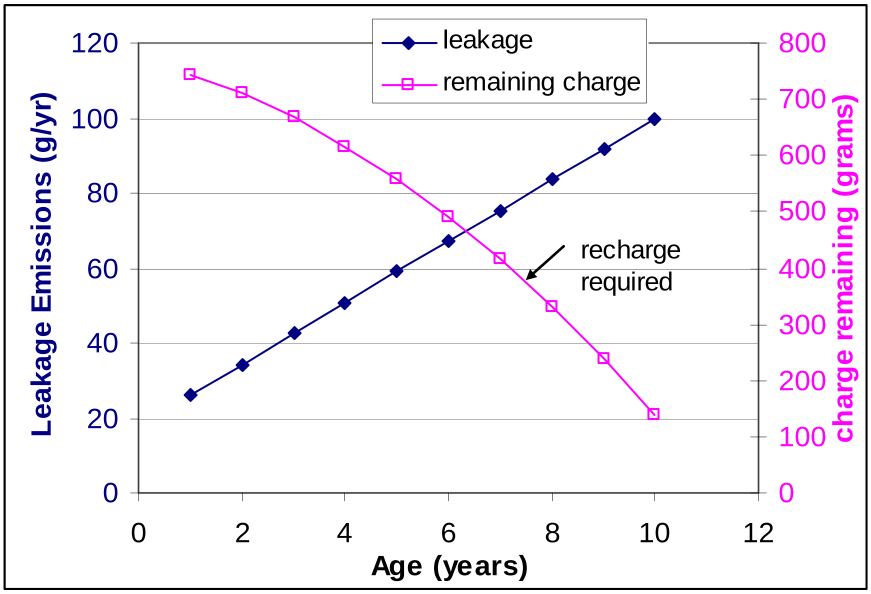

Figure 2-1. Deterioration rate of refrigerant leakage.

Figure 2-2 shows how the leakage rates vary with age as the initial leakage rates are decreased to meet new proposed standards (with improved components and parts). The deterioration lines of the lower leakage rates were determined by applying the appropriate ratio to the 17 g/yr base deterioration rate. Figure 2-3 shows the refrigerant remaining, which includes a line indicating when a recharge is required (50% charge remaining out of an initial charge of 770g). So a typical vehicle meeting a leakage score of 8.5 g/yr (new) will not require a recharge until it is about 12 years old.

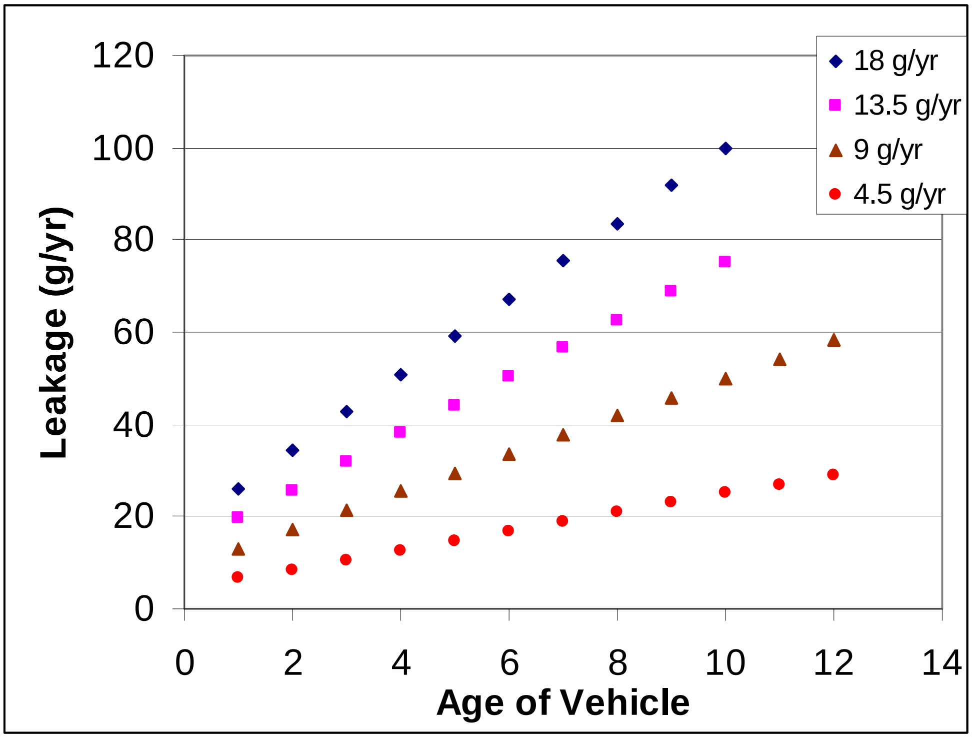

Figure 2-2. A/C refrigerant leakage rate for different technologies as vehicles age.

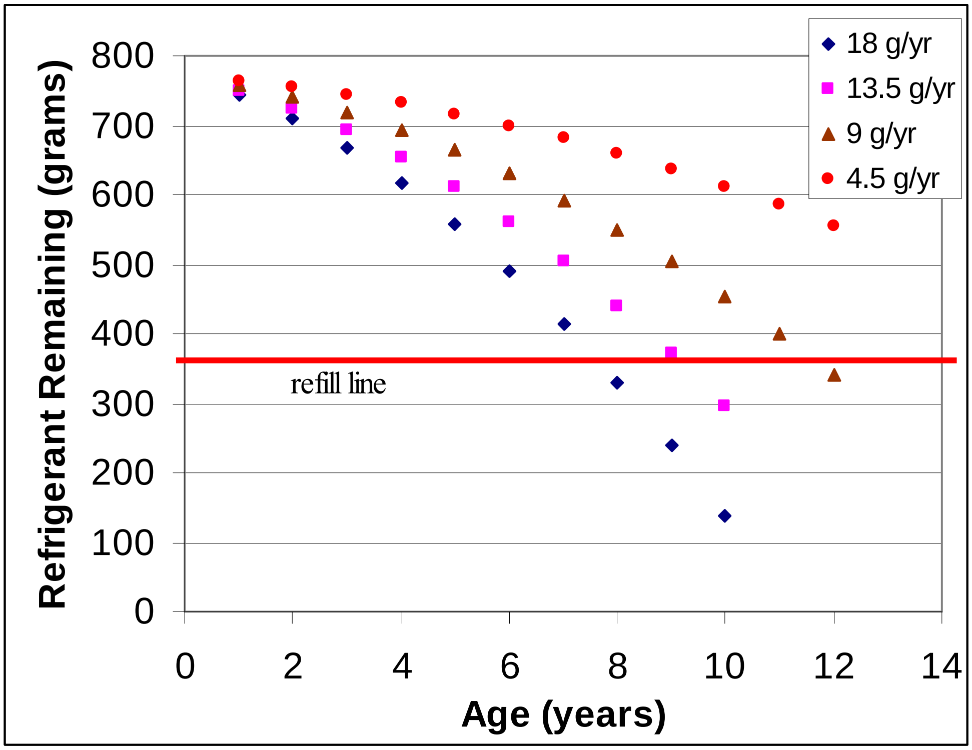

Figure 2-3. A/C refrigerant remaining in a typical system as vehicles age and deteriorate.

2.2.6 Other Benefits of improving A/C Leakage Performance

The EPA is assuming that a reduction in leakage emissions from new vehicles will also improve the leakage over the lifetime of the vehicle. There is ample evidence to show that A/C systems that leak more also have other problems that occur (especially with the compressor) due to the lack of oil circulating in the system. Thus, it is expected that an A/C system which utilizes leak-reducing components and technologies should, on average, last longer than one which does not.

An European study conducted in 2001 (by Schwarz) found that the condenser is the component most likely to fail and result in a total leak.[20] The study also found that compressor component was most likely the culprit when other malfunctions were present (other than total loss). A more recent (and larger) study found that condensers required replacement at half the rate of a compressor (10% vs 19% of the entire part replacement rate), and that evaporators and accumulators failed more often.[10] The same study also found that many of the repairs occurred when the vehicles were aged 5-10 years. Both these studies indicate that the condenser and compressor are among the major causes of failure in an A/C system. Leakage reductions in the system are expected to greatly reduce the incidence of compressor repair, since one of the main root causes of compressor failure is a shortage of lubricating oil, which originates from a shortage of refrigerant flowing through the system (and it is a refrigerant-oil mixture which carries lubricating oil to the compressor).[21]

Monitoring of refrigerant volume throughout the life of the A/C system may provide an opportunity to circumvent some previously described failures specifically related to refrigerant loss. Similar to approaches used today by the engine on-board diagnostic systems (OBD) to monitor engine emissions, a monitoring system that informed the vehicle operator of a low refrigerant level could potentially result in significant reductions in A/C refrigerant emissions due to component failure(s) by creating an opportunity for early repair actions. While most A/C systems contain sensors capable of detecting the low refrigerant pressures which result from significant refrigerant loss, these systems are generally not designed to inform the vehicle operator of the refrigerant loss, and that further operation of the system in this state can result in additional component damage (e.g. compressor failure). Electronic monitoring of the refrigerant may be achieved by using a combination of existing A/C system sensors and new software designed to detect refrigerant loss before it progresses to a level where component failure is likely to occur.

2.3 CO_2 Emissions due to Air Conditioners

2.3.1 Impact of Air Conditioning Use on Fuel Consumption and CO2 Emissions

Three studies have been performed in recent years which estimate the impact of A/C use on the fuel consumption of motor vehicles. In the first study, the National Renewable Energy Laboratory (NREL) and the Office of Atmospheric Programs (OAP) within EPA have performed a series of A/C related fuel use studies.[22,23] The energy needed to operate the A/C compressor under a range of load and ambient conditions was based on testing performed by Delphi, an A/C system supplier. They used a vehicle simulation model, ADVISOR, to convert these loads to fuel use over the EPA's FTP test cycle. They developed a personal "thermal comfort"-based model to predict the percentage of drivers which will turn on their A/C systems under various ambient conditions. Overall, NREL estimated A/C use to represent 5.5% of car and light truck fuel consumption in the U.S.

In the second study, the California Air Resources Board (ARB) estimated the impact of A/C use on fuel consumption as part of their GHG emission rulemaking.[24] The primary technical analysis utilized by ARB is summarized in a report published by NESCCAF for ARB. The bulk of the technical work was performed by two contractors: AVL Powertrain Engineering and Meszler Engineering Services. This work is founded on that performed by NREL-OAP. Meszler used the same Delphi testing to estimate the load of the A/C compressor at typical ambient conditions. The impact of this load on onroad fuel consumption was estimated using a vehicle simulation model developed by AVL - the CRUISE model - which is more sophisticated than ADVISOR. These estimates were made for both the EPA FTP and HFET test cycles. (This is the combination of test cycle results used to determine compliance with NHTSA's current CAFE standards.) NREL's thermal comfort model was used to predict A/C system use in various states and seasons.

The NESCAFF results were taken from Table 3-1 of their report and are summarized in Table 2-7.[25]

Table 2-7: CO2 Emissions Over 55/45 FTP/HFET Tests and From A/C Use (g/mi)

	Small Car	Large Car	Minivan	Small Truck	Large Truck
55/45 FTP/HFET	278	329	376	426	493
Indirect A/C Fuel Use	16.8	19.1	23.5	23.5	23.5
Total	294.8	348.1	399.5	449.5	516.5
Indirect A/C Fuel Use	5.7%	5.5%	5.9%	5.2%	4.6%

NESCAFF estimated that nationwide, the average impact of A/C use on vehicle fuel consumption ranged from 4.6% for a large truck or SUV, to 5.9% for a minivan. The total

CO2 emissions were determined using a 55%/45% weighting of CO2 emissions from EPA FTP and HFET tests plus A/C fuel use (hereafter referred to simply as FTP/HFET). .For the purposes of this analysis of A/C system fuel use, the percentage of CO2 emissions and fuel use are equivalent, since the type of fuel being used is always gasoline.[7]

In order to compare the NESCCAF and ARB estimates to that of NREL-OAP, weighting factors for the five vehicle classes were developed. NESCCAF presented sales percentages for the five vehicle classes in Table 2-1 of their report.[25] These are shown below in Table 2-8. Since these sales percentages do not sum to 100% (possibly due to round-off or because some vehicles do not fit into any of the five categories) the percentages were normalized so that they summed to 100%. The car and truck categories were then weighted by their lifetime VMT, normalized to that of cars.[8] This meant a relative weighting factor for the three truck categories of 1.11 relative to a factor of 1.0 for cars. The percentage of lifetime VMT represented by each vehicle class were then determined. These estimates are shown on the last line of Table 2-8.

Table 2-8: Sales and VMT by Vehicle Class

	Small Car	Large Car	Minivan	Small Truck	Large Truck
NESCCAF sales	22%	25%	7%	23%	21%
Normalized NESCCAF sales	22.4%	25.5%	7.1%	23.5%	21.4%
Lifetime VMT weighting factor	1.00	1.00	1.11	1.11	1.11
VMT	21.2%	24.1%	7.5%	24.6%	22.5%

Using the percentages of VMT represented by each vehicle class, the A/C fuel use impacts of NESCCAF and ARB were weighted and determined that they represent 5.3% and 4.2% of fuel use over the FTP/HFET, respectively, including the A/C fuel use.

In the final study, EPA evaluated the impact of A/C use on fuel consumption as part of its recent rulemaking which revised the onroad fuel economy labeling procedures for new motor vehicles.[26] EPA estimated the impact of the A/C compressor on fuel consumption from vehicle emission measurements taken over its SC03 emissions test. SC03 is a 10 minute test where the vehicle is operated at city speeds, at 95 degrees F, 40% relative humidity and a solar load of 850 Watts/m^2. In addition, prior to the test, the vehicle has been pre-heated for

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[7] Because NESCCAF estimated A/C fuel use nationwide, while ARB focused on that in California, the NESCCAF and EPA methodologies and results are coempared below.

[8] Based on annual mileage per vehicle from the Volpe Model discounted at 7% per year. Discounted lifetime mileages are 102,838 for cars and 114,350 for trucks.

10 minutes under these conditions, so the interior cabin starts the test at an elevated temperature. Testing of 500 late model vehicles over both the FTP and SC03 test cycles indicated that fuel consumption was 27% higher on the SC03 test than over a combination of Bag 2 and Bag 3 fuel consumption designed to match the vehicle load of the SC03 test. EPA assumed that the A/C compressor was engaged 100% of the time over SC03 due to the high ambient temperature, short duration and vehicle pre-heating test conditions.

EPA does not measure A/C emissions at highway speeds. Thus, this impact had to be estimated based on the city-like SC03 test. EPA tested six vehicles (four conventional and two hybrid) over the FTP, SC03, and HFET emission tests in a standard test cell at 60 F, 75 F, and 95 F with and without the A/C system operating in order to assess the relative impact of A/C use at city and highway speeds. The data indicated that it was more accurate to assume that the impact of the A/C compressor on fuel consumption was the same at city and highway speeds when compared in terms of fuel burned per unit time than when compared in terms of fuel use per mile. Thus, EPA estimated the impact of A/C in terms of fuel use per mile at highway speeds by multiplying the A/C related fuel use at city speeds by the ratio of the speed of the city test to that of the highway test. For average driving in the U.S., this ratio was estimated to be 0.348. The result was that the impact of engaging the A/C compressor 100% of the time at highway speeds increased fuel use by 9.7%, versus 27% at city speeds. These percentages are based on the assumptions that fuel is only consumed during warmed up driving, hence ignoring cold start fuel use.

EPA's estimate in the Fuel Economy Labeling rule of in-use A/C compressor engagement was based on a test program covering 1004 trips made by 19 vehicles being operated by their owners in Phoenix, Arizona.[27] The results of this testing were correlated against heat index, a function of temperature and humidity, and time of day, to represent solar load. Nationwide, EPA estimated that the A/C compressor was engaged 15.2% of the time. However, much of this time, the ambient conditions are less severe than those of the SC03 test. Therefore, EPA reduced this percentage to 13.3% to normalize usage to the load experienced during SC03 conditions. On a nationwide basis, EPA estimated that the A/C system was turned on an average of 23.9% of the time.[28] Resulting in 14.3 g/mi per vehicle CO2-equivalent impact due to A/C use (where 30% of the vehicle fleet is equipped with automatic A/C controls, and 70% of the fleet is equipped with manual controls).[9]

This estimate does not include defroster usage, while the NREL-OAP and ARB-NESCCAF estimates do include this. EPA considered adding the impact of defroster usage based in large part on NREL-OAP estimates. NREL-OAP estimates that the defroster is in–use 5.4% of the time. However, the load of the compressor under defrosting conditions is very low. EPA estimated that including defroster usage would increase the percentage of time that the compressor was engaged at a load equivalent to that over SC03 from 13.3% to 13.7%. While this defroster impact was quantified, EPA decided not to include it in its final 5-cycle

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[9] Fraction of fleet equipped with automatic A/C control is based on is based on industry estimates and an EPA analysis of the percentage of 2008 U.S. car sales – as published in the 2009 Ward's Automotive Yearbook - for vehicle categories likely to be equipped with automatic A/C (e.g. middle luxury car, specialty, middle luxury SUV, large luxury SUV, et. al.)

fuel economy formulae. Based on the A/C usage factor of 13.3% and EPA's 5-cycle formulae, A/C system use increases onroad fuel consumption by 2.4%. Including defroster use modestly increased this value to 2.5%.

Comparing the results of the three studies, the EPA estimate gives the smallest A/C system impact, while the NREL-OAP estimate is the highest. The NESCCAF and NREL-OAP studies give very similar results. The overall difference between the estimates is more than a factor of two.

It is difficult to directly compare the three estimates. The NREL-OAP and ARB-NESCCAF methodologies are very similar. However, the EPA methodology is quite different, as will be discussed further below. This complicates the comparison, making it difficult to compare smaller segments of each study directly. In addition, as will be seen, each study utilizes assumptions or estimates which contain uncertainties. These uncertainties are not well characterized. EPA concluded that it is not possible to determine a single best estimate of A/C fuel use from these studies. However, EPA was able to identify a couple of aspects of the studies which could be improved for the purpose of this analysis. Doing so, the overall difference between the studies was reduced by roughly one half. This process is described below.

The first step in this comparison will reduce the number of studies from three to two. The NREL-OAP and ARB-NESCCAF methodologies are very similar, since both utilize the NREL-OAP comfort model to estimate A/C usage onroad. They also both use essentially the same estimate of A/C compressor load from Delphi to estimate the load which the compressor puts on the engine. ARB-NESCCAF utilized the vehicle simulation tool, AVL's CRUISE model, to estimate the impact of A/C load on fuel economy, while NREL employed the ADVISOR model (both models assumed a rather simple A/C system load). In addition, ARB-NESCCAF modeled both city and highway driving (i.e., the 55/45 FTP/HFET), while NREL-OAP only modeled the FTP. Thus, EPA will focus on the NESCCAF estimate over that of NREL-OAP, though as mentioned above, their overall estimates are very similar. Also, because NESCCAF estimated A/C fuel use nationwide, while ARB focused on that in California, EPA will focus on comparing the NESCCAF and EPA methodologies and results below. With respect to EPA's estimates from the 2006 rulemaking, the estimate including defroster use will be used, since NESCCAF considered defroster use, as well. As way of reminder, on a nationwide average basis, the NESCAFF estimates indicate that A/C use represents 5.3% of total fuel consumption, while EPA estimates this at 2.5%.

NESCCAF and EPA break down the factors which determine the impact of A/C use on onroad fuel consumption differently. NESCCAF breaks down the process into three parts. The first is the frequency that drivers turn on their A/C system. The second is the average load of the A/C compressor at various ambient conditions, including compressor cycling. The third is the impact of this average A/C compressor load on fuel economy over various driving conditions.

In contrast, in the fuel labeling rulemaking, EPA breaks down the process into two parts. The first is the frequency that the A/C compressor is engaged at various ambient conditions. This includes both the frequency that the driver turns on the A/C unit and the frequency that the compressor is engaged when the system is turned on. The second is the impact of the A/C compressor on fuel economy over various driving conditions when the compressor is engaged.

The most direct comparison that can be made between the two studies is the estimate of A/C system use. Because EPA measured both A/C system on/off condition as well as compressor engaged/disengaged condition in the Phoenix test program, it is possible to compare the percentage of A/C system use as measured in the Phoenix study and extrapolated to the U.S. to that of the NREL-OAP comfort model.

In its rulemaking analysis, based on its Phoenix study and extrapolation procedure, EPA estimated that on average, the A/C unit was turned on 23.9% of the time. This does not include defroster use. There, EPA also determined that the NREL-OAP thermal comfort model predicts a higher percentage of 29%, again ignoring defroster use. Since EPA utilized NREL-OAP's estimate of defroster use in its analysis, this estimate does not contribute to the difference in the two estimates. Also, fuel use is very low during defroster use compared to air conditioning at high ambient temperatures, so the difference between the 23.9% and 29% estimates is the most relevant factor. By itself (ignoring fuel use during defrosting), this difference would cause the NESCCAF A/C fuel use estimate to be 27% higher than that of EPA. The overall difference between the 5.3% and 2.5% estimates is 112%. Thus, the difference in estimated A/C system use explains about one-fourth of the overall difference between the two studies.

NREL's thermal comfort model for vehicle A/C use is based on a model designed to the represent the comfort of a person walking outside and wearing one of two different sets of clothes. A number of assumptions had to be made in order to extrapolate this outdoor model to a person sitting in a vehicle. The predictions of NREL-OAP's thermal comfort model have not been confirmed with any vehicle/occupant testing and their air conditioner settings. Therefore, its predictions, while reasonable, are of an unknown accuracy.

EPA's Phoenix study was performed over a relatively short period of time, roughly seven weeks. It was conducted in only one city, Phoenix. Thus, the variation in climate evaluated was limited. The number of vehicles tested was also fairly small, nineteen. However, over 1000 trips were monitored by these 19 vehicles. EPA extrapolated the measured A/C compressor engagement under these limited ambient conditions to other conditions using a metric called the heat index, which combines temperature and humidity into a single metric. Heat index is conceptually similar to NREL-OAP's comfort model. This allowed the results found in the generally dry climate of Phoenix to be extrapolated to both cooler and more humid conditions typical of the rest of the U.S. No testing has yet been performed to confirm the accuracy of this extrapolation.

Given the two very different approaches to estimating vehicle A/C system use, it is notable that the difference in the two estimates is only a relative 27%. As both the EPA and NREL-OAP models of A/C system use involve assumptions or extrapolations which have not been verified, it is not possible to determine which one is more accurate. Thus, the differences in the EPA and ARB estimates of the impact of A/C use on onroad fuel consumption due to these two different sources of A/C usage cannot be resolved at this time.

With respect to the operation of the A/C compressor at various ambient and driving conditions, EPA bases its estimate on the Phoenix vehicle test study. This is subject to the same uncertainties described above, due mainly to the limited scope of the data. NREL-OAP relies on test results published by W.O. Forrest of Delphi. Forrest describes the factors which affect the load of the A/C system on the engine: the percentage of time the compressor is engaged, compressor displacement, compressor speed, air flow across the evaporator, engine operating condition and ambient conditions. The load curves presented by Forrest apply to a 210 cc compressor and show load as a function of compressor speed for six sets of ambient conditions. The loads include the effect of compressor cycling. However, no mention is made of airflow rates across the evaporator, which would vary with engine speed. It is not clear whether these curves were based on bench testing or onroad vehicle testing. Also, only one A/C system appears to have been tested. It is not clear how well these curves would apply to other manufacturers' systems, nor even to others produced by Delphi. Forrest states that the loads for other compressor displacements can be approximated by assuming that the load is proportional to compressor displacement. However, this is clearly an approximation and does not address differences inherent in particular A/C system applications. The fact that the NESCCAF analysis is based on the testing of only a single A/C system and does not address the effect of varying airflow rates under different driving conditions appears to be the largest sources of uncertainty in their estimate.

It is not possible to directly compare these two estimates of compressor operation. EPA's Phoenix study provides an estimate of the percentage of time that the compressor is engaged when the A/C system is on. On the other hand, compressor cycling is implicitly included in the Delphi load curves. Since the load curves of a continuous operating compressor were not presented, the degree of cycling cannot be determined. Thus, the effect of any differences in the NESCCAF and EPA estimates of compressor engagement cannot be quantified.

With respect to the impact of the A/C compressor load on fuel economy, EPA relies on a comparison of measured fuel economy over the two warmed up bags of its FTP test (when the A/C system is inoperative) and its SC03, A/C emissions test. The vehicles on both tests are run at city speeds. EPA based its estimates on the testing of over 600 recent model year vehicles. Thus, for the conditions addressed by the SC03 test, EPA's estimate of the impact of A/C system load on fuel economy is well supported. However, in order to combine this measurement with the Phoenix study, EPA needed an estimate of the percentage of time that the compressor was engaged during the SC03 test. The SC03 test does not include a measurement of this factor, so EPA had to estimate the percentage of time that the compressor was engaged during the test. As noted above, EPA assumed that the A/C compressor was engaged 100% of the time during the SC03 test given its short duration and the pre-heating of the vehicle. Thus, for a given ambient condition, if the compressor was estimated to be engaged 25% of the time, then the incremental amount of fuel used due to A/C system was 25% of the difference between the fuel use over the SC03 test and a 39%/61% weighting of the fuel use over Bags 2 and 3 of the FTP, respectively.

EPA has evidence to show that most vehicles' A/C compressors are engaged 100% of the time over SC03.[29] The vehicle pre-heating, short test duration and the requirement that the driver window be rolled down, make it extremely likely that the vehicle compartment never reaches a comfortable temperature by the end of the test. However, it is possible that the compressor still cycled to some degree during the test. All compressors shut down when the heat exchanger nears 32 F in order to avoid icing. The cold heat exchanger continues to cool the refrigerant while the compressor is shut down, but the compressor is not putting an additional load on the engine and increasing fuel consumption. As it is impossible for the compressor to operate more than 100% of the time, any error in EPA's assumption can only lower the actual compressor use below 100%. If compressor engagement was lower than 100%, this would mean that fuel use at 100% compressor engagement would be higher than currently estimated. Thus, it is possible that this assumption that the A/C compressor is engaged 100% during SC03 is causing EPA's estimate of A/C fuel use to be under-estimated to some degree.

There are additional uncertainties involved in EPA's assumption that a vehicle's A/C fuel use is constant in terms of gallons per hour, and thus inversely proportional to vehicle speed when presented in terms of gallons per mile. EPA testing of six vehicles as part of the Fuel Economy Labeling rulemaking (used to estimate A/C compressor usage in highway driving conditions, as noted above) confirmed that A/C fuel use was roughly constant in terms of gallons per hour. However, this testing was performed in a standard emission test cell. Air flow through the engine compartment was the same at city and highway speeds. The city test was only 20 minutes long and the highway test was only 10 minutes long. There was also significant variability in the individual vehicle test results. Thus, while the testing showed that EPA's assumption was reasonable, there is an unknown degree of uncertainty associated with extrapolating the measured A/C fuel use at city speeds to highway speeds. One could attempt to quantify the uncertainty using the test results of the six vehicles. However, these vehicles were not randomly selected and two of the six vehicles were Prius hybrids. Thus, it is not clear how representative the results of a statistical analysis of these data would be.

An A/C load adjustment factor is also applied to account for the change in compressor load which occurs when the compressor is engaged at different temperatures. The study which developed this data data is based on an A/C model developed by Nam (2000).[30]

NESCCAF starts with A/C compressor load curves which describe the A/C compressor load as a function of compressor speed for six ambient conditions. These curves, along with A/C - on percentages from the thermal comfort model, were used to interpolate between the six compressor load curves to estimate the load curves applicable to the ambient conditions existing during driving times for a large number of cities across the U.S. The resulting curves are averaged using the VMT estimated to occur in each city to produce a single load curve representing the entire U.S.

NESCCAF then input this national average load curve into AVL's CRUISE model to estimate the effect of A/C on fuel consumption over the FTP and HFET cycles. The CRUISE model simulates vehicle operation and fuel consumption over specified driving conditions. The load of the A/C compressor (based on bench testing) was added to the other loads being placed on the vehicle, such as inertia, friction, aerodynamic drag, etc. The A/C loads included the cycling of the compressor as a function of ambient condition. In actuality, the engine will experience the full load of the compressor at some times and no load at other times. This could produce a slightly different fuel use impact than applying the average load of the compressor all of the time. However, this error is likely very small. The A/C load curves vary as a function of engine speed, but not vehicle speed. However, as air flow by the heat exchanger will vary as a function of vehicle speed, compressor cycling and evaporator cooling efficiency is likely to vary, as well. However, the degree of error associated with any of these simplifications is unknown.

A detailed comparison of this aspect of the two analyses would require reconstructing both models to produce A/C fuel use estimates for specific ambient conditions. This is beyond the scope of the study. Also, once the differences were known, it would still be difficult to decide which estimate was superior.

There is one aspect of each analysis which appears to be an improvement over the other. In addition to A/C, EPA evaluated a number of other reasons why onroad fuel economy differs from that measured over the FTP and HFET cycles. Among these were higher speed and more aggressive driving, ambient temperatures below 75 F, short trips, wind, under-inflated tires, ethanol containing fuel, etc. This does not affect the absolute volume of fuel used by the A/C system, but it does raise the total amount of fuel consumed onroad, effectively lowering the percentage of fuel due to A/C use.

NESCCAF estimated the impact of the A/C compressor load on fuel use during city and highway driving using the CRUISE model. While it is not clear that this is superior to EPA's SC03 data, the CRUISE model is likely more accurate for highway driving than an extrapolation of the SC03 data (i.e. EPA's six vehicle study described above). While CRUISE was not able to represent all aspects of vehicle operation, such as airflow across the evaporator, it does simulate the difference in engine speed and load between city and highway driving. This allows a detailed simulation of the A/C compressor speed during this driving, which is a primary factor in estimating A/C compressor load. EPA's extrapolation of the impact over SC03 essentially assumes that engine speed and airflow over the evaporator are the same during both city and highway driving, or that any differences cancel each other. This is unlikely. Therefore, NESCCAF's highway estimates are likely more accurate than EPA's.

Since the two analyses were performed so differently, the CRUISE results for highway driving cannot be simply substituted for EPA's estimates. However, one way to utilize the CRUISE highway results is to determine the ratio of the impact of the A/C load on fuel use over the HFET to that over the FTP. This ratio can then be substituted for EPA's assumption that the impact of A/C load is constant with time (inversely proportional to vehicle speed in terms of gallons per mile.

Adjusting the NESCCAF estimates for the other factors reducing onroad fuel economy relative to the FTP/HFET is straightforward. EPA found that all such factors, including A/C, reduced onroad fuel economy to 80% of the FTP/HFET. In other words, onroad fuel consumption is 25% higher (1/0.8) than over the FTP/HFET. Thus, the CO2 emissions over the FTP/HFET shown above in Table 2-7 are multiplied by a factor of 1.25 to represent onroad CO2 emissions. A/C fuel use is unaffected. A/C fuel use as a percentage of onroad fuel use is simply the ratio of the A/C fuel use divided by the estimated onroad fuel use.

These figures are shown in Table 2-9 below. The VMT weighted average of these percentages is 4.4%, 0.9% lower than the estimate presented above.

Table 2-9: Adjusted NESCCAF CO2 Emissions Over 55/45 FTP/HFET Tests and From A/C Use (g/mi)

	Small Car	Large Car	Minivan	Small Truck	Large Truck
55/45 FTP/HFET	349	413	472	535	619
Indirect A/C Fuel Use	16.8	19.1	23.5	23.5	23.5
Indirect A/C Fuel Use	4.8%	4.6%	5.0%	4.4%	3.8%

Incorporating the relative impact of A/C load on fuel consumed over the HFET versus FTP cycles from CRUISE requires a few steps. Table 2-10 shows the incremental CO2 emissions from the A/C compressor load from the CRUISE simulations of the FTP and HFET cycles. The top half of the table shows the incremental fuel use in terms of grams CO2 per mile. These figures were taken from Tables B-20 through B-23 of the NESCCAF report.[31] For the large car, two base vehicles were simulated. EPA selected the vehicle with the conventional gasoline engine with variable valve timing and lift. The large truck was not modeled using CRUISE. Further in the study, Meszler assumed that the A/C fuel impact was proportional to compressor displacement. The large truck is assumed to have the same compressor displacement as the minivan and small truck. Thus, the A/C fuel impact was estimated for the large truck as the average of the impacts for the minivan and small truck. The bottom half of the table shows the incremental fuel use in terms of grams CO2 per minute. These figures were calculated by multiplying the A/C fuel impacts in grams per mile by the average speeds of the FTP and HFET cycles: 19.6 and 48.2 mph and converting hours to minutes. The final line of the table shows the ratio of the incremental fuel use in terms of grams CO2 per minute for the HFET cycle to that over the FTP.

Table 2-10: Impact of A/C on Fuel Use: System

	Small Car	Large Car	Minivan	Small Truck	Large Truck
A/C impact: 100% A/C System On Time (g/mi)					
FTP	67.4	56.6	81.8	89.7	85.8
HFET	32.3	31.9	45.0	47.4	46.2
A/C impact: 100% A/C System On Time (g/minute (g/min))					
FTP	22.02	18.49	26.7	29.3	28.0
HFET	25.95	25.63	36.2	38.1	37.1
HFET/FTP (g/min)/(g/min)	1.18	1.39	1.35	1.30	1.32

As can be seen in the last line of Table 2-10, the ratio of A/C CO2 emissions over the HFET to that over the FTP is greater than 1.0 for each of the five vehicles. VMT weighting the CO2 emissions for each of the five vehicle groups produces an average ratio of 1.30. EPA assumed that this ratio was 1.0. Thus, EPA likely underestimated the impact of A/C fuel use during highway driving by 30%. For the purposes of EPA's onroad fuel economy labeling rule, this under-estimation is small, because the impact of A/C on highway fuel economy is small. However, when estimating the impact of A/C fuel use, the difference is more significant. EPA's five cycle formulae for estimating onroad fuel economy was adjusted to reflect this 1.32 factor. The impact of A/C fuel use on onroad fuel economy including defrosting increased from 2.5% to 2.8%. Thus, instead of a range of 2.5-5.3% for the impact of A/C on onroad fuel consumption, the range is now 2.8-4.4%. The difference between the two estimates has been cut almost in half.

There is one more adjustment that should be made to both estimates. Both EPA and NESCCAF assume that all A/C systems are in working condition. However, A/C systems do leak refrigerant, sometimes to the point where the system no longer works. Since the cost of repairing a leak can be significant, some vehicle owners do not always choose to repair the system. For its MOBILE6 emission model, EPA estimated the percentage of vehicles on the road with inoperative A/C systems as a function of vehicle age. Coupling these estimates with the amount of VMT typically driven by vehicles as a function of age, EPA estimates that 8% of all the VMT in the U.S. is by vehicles with inoperative A/C systems. These systems do not impact fuel consumption. Thus, both the NESCCAF and EPA estimates should be multiplied by 0.92. Doing this, the impact of A/C on onroad fuel consumption is estimated to be 2.6-to-4.1%.

2.3.2 Technologies That Improve Efficiency of Air Conditioning and Their Effectiveness

EPA estimates that the CO_2 emissions from A/C related load on the engine accounts for about 3.9% of total greenhouse gas emissions from passenger vehicles in the United States. This is equivalent to CO_2 emissions of approximately 14 g/mi per vehicle. The A/C usage is inherently higher in hotter months and states; however, vehicle owners may use the A/C systems throughout the year in all parts of the nation. That is, people use A/C systems to cool and dry the cabin air for passenger comfort on hot humid days, as well as to de-humidify the air used for defogging/de-icing the front windshield to improve visibility.

Most of the excess load on the engine comes from the compressor, which pumps the refrigerant around the system loop. Significant additional load on the engine may also come from electrical or hydraulic fan units used for heat exchange across the condenser and radiator. The controls that EPA believes manufacturers would use to earn credits for improved A/C efficiency would focus primarily, but not exclusively, on the compressor, electric motor controls, and system controls which reduce load on the A/C system (e.g. reduced ‘reheat’ of the cooled air and increased of use recirculated cabin air). EPA is proposing a program that would result in improved efficiency of the A/C system (without sacrificing passenger comfort) while improving the fuel efficiency of the vehicle, which has a direct impact on CO_2 emissions.

The cooperative IMAC program described above has demonstrated that average A/C efficiency can be improved by 36.4% (compared to a baseline A/C system), when utilizing “best-of-best” technologies. EPA considers a baseline A/C system contains the following components and technologies; internally-controlled fixed displacement compressor (in which the compressor clutch is controlled based on ‘internal’ system parameters, such as head pressure, suction pressure, and/or evaporator outlet temperature); blower and fan motor controls which create waste heat (energy) when running at lower speeds; thermostatic expansion valves; standard efficiency evaporators and condensers; and systems which circulate compressor oil throughout the A/C system. These baseline systems are also extraordinarily wasteful in their energy consumption because they add heat to the cooled air out of the evaporator in order to control the temperature inside the passenger compartment. Moreover, many systems default to a fresh air setting, which brings hot outside air into the cabin, rather than recirculating the already-cooled air within the cabin.

The IMAC program indicates that improvements can be accomplished by a number of methods related only to the A/C system components and their controls including: improved component efficiency, improved refrigerant cycle controls, and reduced reheat of the cooled air. The program EPA is proposing would encourage the reduction of A/C CO_2 emissions from cars and trucks by 40% from current baseline levels through a credit system. EPA believes that the component efficiency improvements demonstrated in the IMAC program, combined with improvements in the control of the supporting mechanical and electrical devices (i.e. engine speeds and electrical heat exchanger fans), can go beyond the IMAC levels and achieve a total efficiency improvement of 40%. The following sections describe the technologies EPA believes manufacturers can use to attain these efficiency improvements.

2.3.2.1 Reduced Reheat Using a Externally-Controlled, Variable-Displacement Compressor

The term 'external control' of a variable-displacement compressor is defined as a mechanism or control strategy where the displacement of the compressor adjusted electronically, based on the temperature setpoint and/or cooling demand of the A/C system control settings inside the passenger compartment. External controls differ from 'internal controls' that internal controls adjust the displacement of the compressor based on conditions within the A/C system, such has head pressure, suction pressure, or evaporator outlet temperature. By controlling the displacement of the compressor by external means, the compressor load can be matched to the cooling demand of the cabin. With internal controls, the amount of cooling delivered by the system may be greater than desired, at which point the cooled cabin air is then 'reheated' to achieve the desired cabin comfort. It is this reheating of the air which results reduces the efficiency of the A/C system – compressor power is consumed to cool air to a temperature less than what is desired.

Reducing reheat through external control of the compressor is a very effective strategy for improving A/C system efficiency. The SAE IMAC team determined that an annual efficiency improvement of 24.1% was possible using this technology.[32] EPA estimates that additional improvements with this technology, when fully developed, calibrated, and optimized to particular vehicle's cooling needs - and combined with increased use of recirculated cabin air - can result in an efficiency improvement of 40%, compared to the baseline system.

2.3.2.2 Reduced Reheat Using a Externally-Controlled, Fixed-Displacement or Pneumatic Variable-Displacement Compressor

When using a fixed-displacement or pneumatic variable-displacement compressor (which controls the stroke, or displacement, of the compressor based on system suction pressure), reduced reheat can be realized by disengaging the compressor clutch momentarily to achieve the desired evaporator air temperature. This disengaging, or cycling, of the compressor clutch must be externally-controlled in a manner similar to that described in

2.3.2.1. EPA believes that a reduced reheat strategy for fixed-displacement and pneumatic variable-displacement compressors can result in an efficiency improvement of 20%. This lower efficiency improvement estimate (compared to an externally-controlled variable displacement compressor) is due to the thermal and kinetic energy losses resulting from cycling a compressor clutch off-and-on repeatedly.

2.3.2.3 Defaulting to Recirculated Cabin Air

In ambient conditions where air temperature outside the vehicle is much higher that the air inside the passenger compartment, most A/C systems draw air from outside the vehicle and cool it to the desired comfort level inside the vehicle. This approach wastes energy because the system is continuously cooling the hotter outside air instead of having the A/C system draw it's supply air from the cooler air inside the vehicle (also known as 'recirc'). By only cooling this inside air (i.e. air that has been previously cooled by the A/C system), less energy is required, and A/C Idle Tests conducted by EPA indicate that an efficiency improvement 30% improvement is possible. A mechanically-controlled door on the A/C system's air intake typically controls whether outside air, inside air, or a mixture of both, is drawn into the system. Since the typical 'default' position of this air intake door is outside air (except in cases where maximum cooling capacity is required, in which case, many systems automatically switch this door to the recirculated air position), EPA is proposing that, as cabin comfort and de-fogging conditions allow, an efficiency credit be granted if a manufacturer defaults to recirculated air whenever the outside ambient temperature is greater than 75°F. To maintain the desired quality inside the cabin (in terms of freshness and humidity), EPA believes some manufacturers will equip their A/C systems with humidity sensors, which will allow them to adjust the blend of fresh-to-recirculated air and optimize the controls for maximum efficiency.

2.3.2.4 Improved Blower and Fan Motor Controls

In controlling the speed of the direct current (DC) electric motors in an air conditioning system, manufacturers often utilize resistive elements to reduce the voltage supplied to the motor, which in turn reduces its speed. In reducing the voltage however, these resistive elements produce heat, which is typically dissipated into the air ducts of the A/C system. Not only does this waste heat consume electrical energy, it contributes to the heat load on the A/C system. One method for controlling DC voltage is to use a pulsewidth modulated (PWM) controllers for each motor. A PWM controller can reduce the amount of energy wasted, and based on Delphi estimates of power consumption for these devices, EPA believes that when more efficient speed controls are applied to both the blower and fan motors, an overall improvement in A/C system efficiency of 15% is possible.[33]

2.3.2.5 Electronic Expansion Valve

The expansion valve in an A/C system is used to "throttle" the flow high pressure liquid refrigerant upstream of the evaporator. By throttling the refrigerant flow, it is possible to control the amount of expansion (superheat) that the refrigerant will undergo, and by extension, the amount of heat removed from air passing through the evaporator. With a conventional, or thermostatic, expansion valve (TXV), the amount of expansion is controlled by an internal temperature reference to assure a constant temperature level for the expanded refrigerant gas, which is typically a few degrees Celsius above the freezing point of water (which may be too cool for the desired cabin comfort level). In the case where the air exiting the evaporator is too cool (or over-cooled), it will be necessary to reheat it by directing some of the airflow through the heater core. It is this reheating of the air which results in reduced system efficiency, as additional compressor energy is consumed in the process of over-cooling the air. However, if the expansion of the refrigerant is controlled externally – such as by an electronic signal from the A/C control unit – it is possible to adjust the level of expansion, or superheat, to only to the level necessary to meet the current cooling needs of the passenger compartment. This electronic expansion valve (EXV) approach is similar to the reduced reheat strategy, except that instead of controlling the mass of refrigerant flowing through the system by controlling the compressor output, the mass flow is controlled by the EXV. By reducing the amount of refrigerant expanding, or controlling the level of superheat in the gas-phase refrigerant, the temperature of the evaporator can be increased and controlled to the point where reheating of the air is not necessary, the SAE IMAC team determined that an annual efficiency improvement of 16.5% is possible. EPA estimates the when fully developed, calibrated, and optimized to the requirements of particular system design, use of EXV technology can result in a 20% efficiency improvement over the baseline TXV system.

2.3.2.6 Improved-Efficiency Evaporators and Condensers

The evaporators and condensers in an A/C system are designed to transfer heat to and from the refrigerant – the evaporator absorbs heat from the cabin air and transfers it to the refrigerant, and the condenser transfer heat from the refrigerant to the outside ambient air. The efficiency, or effectiveness, of this heat transfer process directly effects the efficiency of the overall system, as more work, or energy, is required if the process is inefficient. A method for measuring the heat transfer effectiveness of these components is to determine the Coefficient of Performance (COP) for the system using the industry-consensus method described in the SAE surface vehicle standard J2765 – Procedure for Measuring System COP of a Mobile Air Conditioning System on a Test Bench.[34] If these components can demonstrate a 10% improvement in COP versus the baseline components, EPA estimates that a 20% improvement in overall system efficiency is possible.

2.3.2.7 Oil Separator

The oil present in a typical A/C system circulates throughout the system for the purpose of lubricating the compressor. Because this oil is in contact with inner surfaces of evaporator and condenser, and a coating of oil reduces the heat transfer effectiveness of these devices, the overall system efficiency is reduced.[35] It also adds inefficiency to the system to be "pushing around and cooling" an extraneous fluid that results in a dilution of the thermodynamic properties of the refrigerant. If the oil can be contained only to that part of the system where it is needed – the compressor – the heat transfer effectiveness of the evaporator and condenser will improve. The overall COP will also improve due to a reduction in the flow of diluent. The SAE IMAC team estimated that overall system COP could be improved by 8% if an oil separator was used.[17] EPA believes that if oil is prevented from prevented from circulating throughout the A/C system, an overall system efficiency improvement of 10% can be realized.

2.3.3 Technical Feasibility of Efficiency-Improving Technologies

EPA believes that the efficiency-improving technologies discussed in the previous sections are available to manufacturers today, are relatively low in cost, and that their feasibility and effectiveness has been demonstrated by the SAE IMAC teams and various industry sources. EPA also believes that when these individual components and technologies are fully designed, developed, and integrated into A/C system designs, manufacturers will be able to achieve the estimated reductions in CO2 emissions and earn appropriate A/C Efficiency Credits, which are discussed in the following section.

2.3.4 A/C Efficiency Credits

In model years 2012 through and 2016, manufacturers would be required to demonstrate that vehicles receiving credit for A/C efficiency improvements are equipped with the type of components and/or controls needed to qualify for a certain level of CO_2 credit. For model years 2014 and later, the design-based approach will be supplemented with a vehicle performance test, which has been modified slightly from that proposed in the GHG Mandatory Reporting Rule. In particular, EPA is proposing that the range of allowable ambient temperature for a valid A/C Idle Test be limited to 75 ± 2 °F (as opposed to 68-to-86 °F for a valid FTP test) and that the humidity in the test cell be limited to 50 ± 5 grains of water per pound of dry air (where there are no such humidity constraints on an FTP test, only a humidity correction for NOx). This narrowing of the allowable range of ambient conditions was done to improve the accuracy and repeatability of the test results. Since the performance of an A/C system (and the amount of fuel consumed by the A/C system) are directly influenced by the heat energy, or enthalpy, of the air within the test cell – where criteria pollutants are not - it was necessary to control the enthalpy, and limit its effect on the test results. In addition, EPA is proposing a modification to the interior fan settings for vehicles with manual A/C controls. In the proposed reporting rule, vehicle with manual A/C controls were to be run on the 'high' fan setting for the duration of the A/C on portion of the test. However, EPA believes that this fan speed setting would unduly penalize vehicles with manual controls when compared to those with automatic control - as automatic controls adjust the fan speed to lower setting as the target interior temperature is reached (which is similar to what a driver does on a vehicle with manual controls). In recognition of this disparity in the proposed test procedure, EPA is revising the test to allow vehicles with manual A/C controls to average the result obtained on the high fan speed setting with the result obtained on the low fan speed setting. The additional 10-minute idle sequence on the low fan speed setting is to be run immediately following the high fan sequence (no additional prep cycle is required). This revised performance test will assure that the A/C components and/or system control strategies a manufacturer chooses to implement are indeed delivering the efficiency gains projected for each. The performance test discussed in section II of the preamble is the A/C Idle Test, but in that section, EPA also discusses how a modified SC03 test could also be used to measure the efficiency of A/C systems.

To establish an average A/C CO2 rate for the A/C systems in todays vehicles, the EPA conducted laboratory tests to measure the amount of additional CO2 a vehicle generated due to A/C use on the proposed Idle Test.[36] The results of this test program are summarized in Table 2-11, and represent a wide cross-section of vehicle types in the U.S. market. The average A/C CO2 result from this group of vehicles is the value against which results from vehicle testing (beginning in 2014) will be compared. The EPA conducted laboratory tests to tested over 60 vehicles representing a wide range of vehicle types (e.g. compact cars, midsize cars, large cars, sport utility vehicles, small station wagons, and standard pickup trucks).

Table 2-11 Summary of A/C Idle Test Study Conducted by EPA at the National Vehicle Fuel and Emissions Laboratory

Vehicle Makes Tested	19
Vehicle Models Tested	29
Model Years Represented (number of vehicles in each model year)	1999 (2), 2006 (21), 2007 (39)
EPA Size Classes Represented	Minicompact, Compact, Midsize, and Large Cars Sport Utility Vehicles Small Station Wagons Standard Pickup Trucks
Total Number of A/C Idle Tests	62
Average A/C CO2 (g/min)	21.3
Standard Deviation of Test Results (± g/min)	5.8

The majority of vehicles tested were from the 2006 and 2007 model years and their A/C systems are representative of the 'baseline' technologies, in terms of efficiency (i.e. to EPA's knowledge, these vehicles do not utilize any of the efficiency-improving technologies described in Table 2-12). The individual test results from this testing are shown in Figure 2-4. EPA attempted to find a correlation between the A/C CO2 results and a vehicle's interior volume, footprint, and engine displacement, but was unable to do so, as there is significant "scatter" in the test results. This scatter is generally not test-to-test variation, but scatter amongst the various vehicle models and types – there is no clear correlation between which vehicles perform well on this test, and those which do not. EPA did attempt to find a correlation between the idle test results and a vehicle's interior volume, footprint, or engine displacement, but no clear correlation could be found. What is clear, however, is that load placed on the engine by the A/C system is not consistent, and in certain cases, larger vehicles perform better than smaller ones, in terms of their A/C CO2 result.

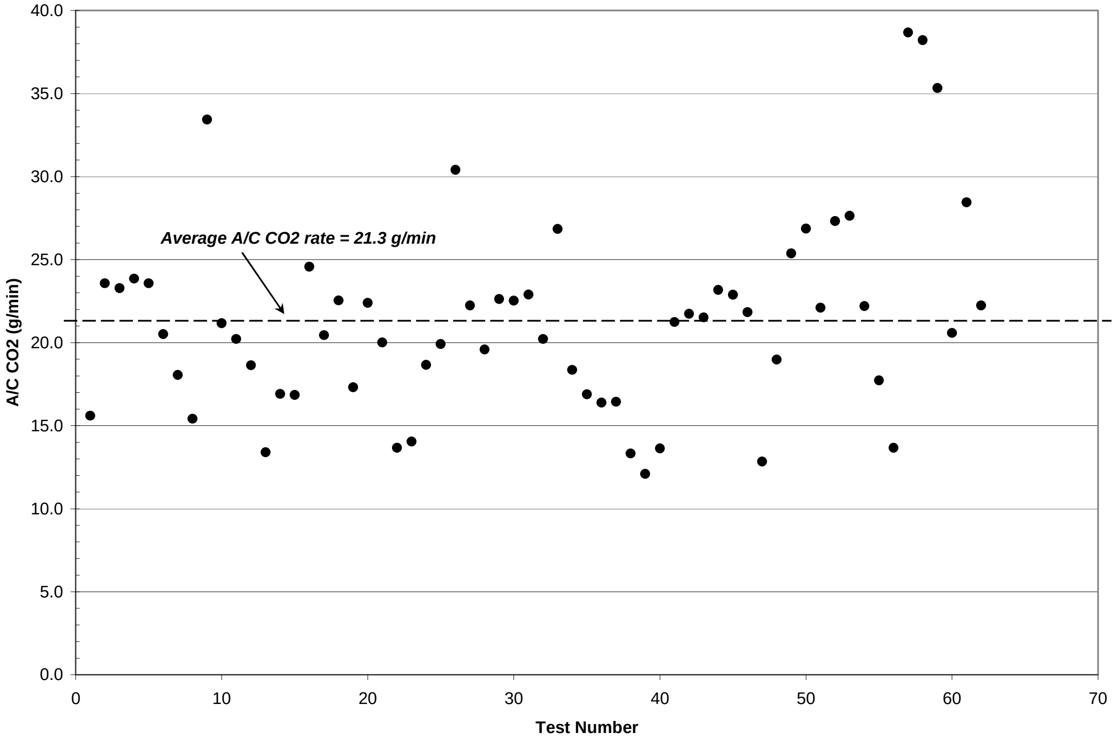

Figure 2-4 EPA A/C Idle Test Results from Various Vehicle Model Types

Part of this variation in the proposed A/C Idle Test results may be due to the components a manufacture chooses to use in a particular vehicle. Where components such as compressors are shared across vehicle model types (e.g. a compressor may be 'over-sized' for one application, but the use of a common part amongst multiple model types results in a cost savings to the manufacturer). Some of the variation may also be due to the amount of cooling capacity a vehicle has at idle. One manufacturer indicated that one of their vehicles which produced a below-average A/C CO2 result, is also known for having A/C performance at idle which does not meet customer expectations, but off-idle, performs very well. Therefore, it will be necessary for manufacturers to balance the cooling capacity of the A/C system under idle conditions against the overall A/C system efficiency.

Some of this variation between various models may also be due to the efficiency of the fan(s) which draw air across the condenser – since an external fan is not placed in front of the vehicle during the A/C Idle Test, it is the vehicle's fan which is responsible for rejecting heat from the condenser (and some models may do this more efficiently than others). In this case, EPA believes that an SC03-type test – run in a full environmental chamber with a "road-speed" fan on the front of the vehicle – would be a better measure of how a vehicle's A/C system performs under transient conditions, and any limitations the system may have at idle could be counter-balanced by improved performance and efficiency elsewhere in the drive cycle. However, since idle is significant part of real-world and FTP drive cycles (idle represents 18% of the FTP), EPA believes that the focus in this rulemaking on A/C system efficiency under idle conditions is justified.

The average A/C CO2 result for the vehicles tested was 21.3 g/min. Starting in the year 2014, in order to qualify for A/C Efficiency Credits, it will be necessary for manufacturers to demonstrate the efficiency of their systems by running an A/C Idle Test on each vehicle model for which they are seeking credit. To qualify for credit, it will be necessary for each model to achieve an A/C CO2 result less than or equal to 14.9 g/min (which is 30% less than the average value observed in the EPA testing). EPA chose the 30% improvement over the "average" value to drive the fleet of vehicles toward A/C systems which approach or exceed the efficiency of current best-in-class vehicles. EPA believes this approach will cause manufacturers to tailor the size A/C components and systems to the cooling needs of a particular vehicle model and focus on the overall efficiency of their A/C systems. EPA believes this approach strikes a reasonable balance between avoiding granting credits for improvements which would occur in any case, and encouraging A/C efficiency improvements which would not otherwise occur. Once manufacturers begin using the technologies described in Table 2-12 – and develop these technologies for the requirements of each vehicle, with a focus on achieving optimum efficiency – EPA believes it will be possible to demonstrate that a vehicle is indeed achieving the reductions in A/C CO2 emissions that are estimated for this rulemaking.

We believe that it is possible to identify the A/C efficiency-improving components and control strategies most-likely to be utilized by manufacturers and are assigning a CO2 'credit' to each. In addition, EPA recognizes that to achieve the maximum efficiency benefit, some components can be used in conjunction with other components or control strategies. Therefore, the system efficiency synergies resulting from the grouping of three or more individual components are additive, and will qualify for a credit commensurate with their overall effect on A/C efficiency. A list of these technologies – and the credit associated with each – is shown in Table 2-12. If the more than one technology is utilized by a manufacturer for a given vehicle model, the A/C credits can be added, but the maximum credit possible is limited to 5.7 g/mi. This maximum credit represents a 40% improvement over a 14.3 g/mi per vehicle CO2-equivalent impact due to A/C use. This 14.3 g/mi impact is derived from the EPA's 2006 estimate of fuel consumption due to A/C use of 12.11 g/mi. However, the 2006 estimate needed to be adjusted upward to reflect the increased prevalence of "automatic" A/C controls in modern vehicles (the Phoenix study used in the EPA's 2006 estimate was from

1990s-vintage vehicles, which do not include a significant number of vehicles with automatic climate control systems). To derive the newer estimate, a scenario was first modeled in which 100% of vehicles used in the Phoenix study were equipped with automatic A/C systems (which increases the amount of time the compressor is engaged in moderate ambient conditions), which resulted in the 12.11 g/mi estimate increasing to 17.85 g/mi. Industry and supplier estimates were then used for the number of vehicles equipped with automatic A/C systems - as well as vehicle sales data from the 2009 Ward's Automotive Yearbook – and projected that 38% of new vehicles are equipped with automatic A/C systems.[37] Finally, the percentages of vehicles with and without automatic A/C systems were multiplied by their respective impact on fuel consumption (0.62 x 12.11 + 0.38 x 17.85) to produce our estimate of 14.3 g/mi. This credit is the same for cars and trucks because the A/C components, cooling requirements, and system functions are similar for both vehicle classes. Therefore, EPA believes the level of efficiency improvement and the maximum credit possible should be similar for cars and trucks as well.

Table 2-12: Efficiency-Improving A/C Technologies and Credits

Technology Description	Estimated Reduction in A/C CO2 Emissions	A/C Credit (g/mi CO2)
Reduced reheat, with externally-controlled, variable-displacement compressor	30%	1.7
Reduced reheat, with externally-controlled, fixed-displacement or pneumatic variable displacement compressor	20%	1.1
Default to recirculated air whenever ambient temperature is greater than 75 °F	30%	1.7
Blower motor and cooling fan controls which limit waste energy (e.g. pulsewidth modulated power controller)	15%	0.9
Electronic expansion valve	20%	1.1
Improved evaporators and condensers (with system analysis on each component indicating a COP improvement greater than 10%, when compared to previous design)	20%	1.1
Oil Separator	10%	0.6

The estimates for the percent reduction in A/C CO2 for each technology is based in part on the results of SAE IMAC Team 2 (Improved Efficiency) final report, which both provides a baseline for calculating creditable improvements, and also provides a level of improvement for each technology. The estimated percent reduction in A/C CO2 emissions for each was adjusted upward to reflect continuous improvement in the design, calibration, and implementation of these technologies. These technologies, which, when combined, can allow manufacturers to achieve the 40% reduction in CO2 emissions.

2.4 Costs of A/C reducing technologies

This section describes the cost estimates for reductions in air conditioner related GHG emissions as well as the cost savings that result from improved technologies. These estimates are largely determined from literature reviews of publications and public presentations made by parties involved in the development and manufacture of A/C systems as well as from EPA analyses. The cost savings are estimated from the literature as well as the supplemental deterioration models based analysis described above.

For leakage, or direct, emissions, EPA assumes that reductions can be achieved without a change in refrigerant, though it is possible that by 2020 a new technology and refrigerant will be a much more viable option than it is today. For example, an alternative refrigerant with a GWP less than 150 and can be used directly in current A/C systems will be able to meet the leakage credit requirements without significant engineering changes or cost increases. However, in order to reduce the leakage in conventional R134a systems by 50%, it has been estimated that the manufacturer cost would increase by $15 per vehicle in 2002 dollars, employing existing off-the-shelf technologies such as the ones included in the J2727 leakage charts.[10] Converting this to 2007 dollars using the GDP price deflator (see Appendix 3.A of the Draft Joint TSD) results in a cost of $17. With the indirect cost markup factor of 1.11 for a low complexity technology the compliance cost becomes $19. Using this as the 2012MY cost and applying time based learning results in a 2016MY cost of $17 for leakage reduction technology. Table 2-13 shows how these costs may be distributed on a year by year basis as the proposed program phases in over 5 years.

We expect that a reduction in leakage will lead to fewer servicing events for refrigerant recharge. In 2006, the EPA estimated the average cost to the vehicle owner for a recharge maintenance visit was $100. However, recent information indicates that the industry average cost of recharging an automotive air conditioner is $147.[38] With the new AC systems, such $100 or $147 maintenance charges could be moved delayed until later in the vehicle life and, possibly, one of more events could be eliminated completely. This provides potential savings to consumers as a result of the new technology. Note that these potential maintenance savings are not included in the cost and benefit analysis presented in Chapters 6 and 8 of this DRIA. However, EPA intends to include an estimate of maintenance savings in the final rule analysis and believe that this higher estimate for the cost of recharging an A/C system would serve as the basis for those maintenance savings in the cost analysis of the final rule.

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[10] Author unknown, Alternative Refrigerant Assessment Workshop, SAE Automotive Alternative Refrigerant Symposium, Arizona, 2003.

For indirect CO2 emissions due to A/C, it has been estimated that a 25-30% reduction can be achieved at a manufacturer cost of 44€, or $51 in 2005 dollars.[11] The IMAC Efficiency Improvement team of the Society of Automotive Engineers realized an efficiency improvement of 36.4% based on existing technologies and processes.[32] For the idle test, EPA estimates that further reductions with software controls can achieve a total reduction of 40%. Converting the $51 value to 2007 dollars results in $54 (using the GDP price deflator as explained in Appendix 3.A of the Draft Joint TSD) and applying a 1.11 indirect cost multiplier for a low complexity technology (as described in Chapter 3 of the Draft Joint TSD) gives a total compliance cost of $60. Using this as the 2012MY cost and applying time based learning (as described in Chapter 3 of the Draft Joint TSD) results in a 2016MY cost of $53.

In the 2008 Advance Notice of Proposed Rule, EPA presented a quick analysis of the potential fuel savings associated with the control of indirect emissions via new AC technology. There EPA assumes a reference 2010 fuel economy of 30 mpg for cars and 24 for trucks. With a 20% real-world shortfall, this becomes 24 and 19 mpg respectively. As described in appendix A of the GHG advanced notice (and above), A/C impacts overall fuel consumption by 2.6-to-4.1%, and that an ultimate efficiency improvement of 40% is achievable. EPA used the AEO 2008 fuel price, discount values, vehicle scrappage and VMT figures employed elsewhere in the advanced proposal to calculate a $96 cost savings for cars and $130 for trucks for the life of the vehicle. Assuming the same 0.23 factor to account for rebound and emissions, these savings increase to $118 for cars and $159 for trucks. This was noted in the GHG advance notice as being a potentially significant cost savings for the vehicle owner compared to the cost of the efficiency improvements. EPA has not updated this analysis for this rule. For the analysis in support of this rule, as presented in Chapter 6 of this DRIA, the indirect AC fuel savings has been included in the total fuel savings resulting from the proposal.

Table 2-13 presents the compliance costs associated with new AC technology with estimates for how those costs might change as vehicles with the technology are introduced into the fleet. Costs shown are averages per vehicle since not all vehicles would include the new technology but would, instead, include the technology according to the penetration estimates shown in the table.

Table 2-13: Estimated Costs in each Model Year for New AC Technology, 2007 dollars

	2012	2013	2014	2015	2016
Penetration	25%	40%	55%	75%	85%
AC Leakage (Direct)	$4	$7	$9	$13	$14
AC Indirect	$13	$21	$29	$40	$45
Total	$18	$28	$39	$53	$60

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[11] The 0.87 Euro-US dollar conversion is dated today but was valid in 2005. 2005 Euros are converted to 2005 US dollars then 2005 US dollars are converted to 2007 US dollars.

2.5 Air Conditioning Credit Summary

A summary table is shown with the estimated usage of the A/C credits. EPA projected the penetration rates as a reasonable ramp to the 85% penetration cap in 2016. The 85% penetration cap was set to maintain consistency with the technology penetration caps used in OMEGA. The car and truck sales fractions were drawn from an adjusted version of AEO 2009, as documented in DRIA Chapter 5. As documented above, no use of alternative refrigerant is projected in this in this analysis, although this assumption may be revisited in the final rule (Table 2-14).

Table 2-14 : Credit Summary with Estimated Penetration Rates

	Model Year				
	2012	**2013**	**2014**	**2015**	**2016**
Estimated Penetration	25%	40%	60%	80%	85%
Car Sales Fraction	63%	64%	64%	66%	66%
Truck Sales Fraction	37%	36%	36%	34%	34%
Car Direct Credit	2.0	3.1	4.7	6.2	6.6
Car Indirect Credit	1.4	2.3	3.4	4.6	4.8
Total Car Credit	3.0	4.8	7.2	9.6	10.2
Truck Direct Credit	1.6	2.5	3.8	5.0	5.4
Truck Indirect Credit	1.4	2.3	3.4	4.6	4.8
Total Truck credit	3.4	5.4	8.1	10.8	11.5
Fleet average credits	***3.1***	***5.0***	***7.5***	***10.0***	***10.6***

References

All references can be found in the EPA DOCKET: **EPA-HQ-OAR-2009-0472.**

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[4] IPCC. Chapter 2. Changes in Atmospheric Constituents and in Radiative Forcing. September 2007.

[5] Schwarz, W., Harnisch, J. 2003. "Establishing Leakage Rates of Mobile Air Conditioners." Prepared for the European Commission (DG Environment), Doc B4-3040/2002/337136/MAR/C1.

[6] Vincent, R., Cleary, K., Ayala, A., Corey, R. 2004. "Emissions of HFC-134a from Light-Duty Vehicles in California." SAE 2004-01-2256.

[7] EPA, 2009, Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2007. http://www.epa.gov/climatechange/emissions/usinventoryreport.html

[8] State of California, Manufacturers Advisory Correspondence MAC #2009-01, "Implementation of the New Environmental Performance Label," http://www.arb.ca.gov/msprog/macs/mac0901/mac0901.pdf.

[9] State of Minnesota, "Reporting Leakage Rates of HFC-134a from Mobile Air Conditioners," http://www.pca.state.mn.us/climatechange/mac-letter-082908.pdf.

[10] Society of Automotive Engineers, "IMAC Team 4 – Reducing Refrigerant Emissions at Service and Vehicle End of Life," June, 2007.

[11] Office of Energy Efficiency and Renewable Energy, U.S. Department of Energy. Transportation Energy Data Book: Edition 27. 2008.

[12] Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2005. http://epa.gov/climatechange/emissions/downloads06/07CR.pdf

[13] EPA, "Fuel Economy Labeling of Motor Vehicle Revisions to Improve Calculation of Fuel Economy Estimates Final Technical Support Document (179 pp, 2.1MB, EPA420-R-06-017, December 2006

[14] Ikegama, T., Kikuchi, K.. 2006. "Field Test Results and Correlation with SAEJ2727." Proceedings of the SAE 7th Alternative Refrigerant Systems Symposium.

[15] Atkinson, W., Baker, J., Ikegami, T., Nickels, P. 2006. "Revised SAEJ2727: SAE Interior Climate Control Standards Committee Presentation to the European Commission."

[16] EPA. 2009 U.S. Greenhouse Gas Inventory Report. INVENTORY OF U.S. GREENHOUSE GAS EMISSIONS AND SINKS: 1990-2007 (April 2009)

[17] Society of Automotive Engineers, "IMAC Team 1 – Refrigerant Leakage Reduction, Final Report to Sponsors," 2006.

[18] Society of Automotive Engineers Surface Vehicle Standard J2727, issued August 2008, http://www.sae.org

[19] Minnesota Pollution Control Agency, "Model Year 2009 Leakage Rate List," http://www.pca.state.mn.us/climatechange/mobileair.html.

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[20] Schwarz, W., “Emission of Refrigerant R-134a from Mobile Air-Conditioning Systems,” Study conducted for the German Federal Environmental Office, September, 2001.

[21] “A/C Triage – Ensuring Replacement Compressor Survival, “ AC Delco Tech Connect, Volume 12, Number 5, January/February 2005, http://www.airsept.com/Articles/CompressorGuard/ACDelcoTechConnectJanFeb05.pdf.

[22] Johnson, Valerie H., “Fuel Used for Vehicle Air Conditioning: A State-by-State Thermal Comfort-Based Approach,” SAE 2002-01-1957, 2002.

[23] Rugh, John P, Valerie Hovland, and Stephen O. Andersen, “Significant Fuel Savings and Emission Reductions by Improving Vehicle Air Conditioning,” Mobile Air Conditioning Summit, Washington DC., April 14-15, 2004.

[24] California Environmental Protection Agency Air Resources Board, “STAFF REPORT: Initial statement of reasons for proposed rulemaking, public hearing to consider adoption of regulations to control greenhouse gas emissions from motor vehicles,” 2004.

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

[26] Fuel Economy Labeling of Motor Vehicles: Revision to Improve Calculation of Fuel Economy Estimates; Final Rule, 71 FR 77872, December 27, 2006.

[27] Koupal, J., “Air Conditioning Activity Effects in MOBILE6” EPA Report Number M6.ACE.001, 1998.

[28] EPA Technical Support Document for Fuel Economy Label Regulations, November, 2006.

[29] Nam, E.K., “Understanding and Modeling NOx Emissions from Automobiles During Hot Operation,” PhD Thesis, University of Michigan, 1999.

[30] Nam, E. K., “Understanding and Modeling NOx Emissions from Air Conditioned Automobiles,” SAE Technical Paper Series 2000-01-0858, 2000.

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

[32] Society of Automotive Engineers, “IMAC Team 2 – Improved Efficiency, Final Report,” April 2006.

[33] Memo to docket, “Meeting with Delphi and Presentation to EPA,” March 2009.

[34] Society of Automotive Engineers Surface Vehicle Standard J2765, issued October 2008, http://www.sae.org.

[35] Barbat, Tiberiu, et al, “CFD Study of Phase Separators in A/C Automotive Systems,” SAE 2003-01-0736, 2003.

[36] EPA, “AC Idle Test Results_Summary for docket,” August 2009.

[37] “2009 Ward’s Automotive Yearbook,” Ward’s Automotive Group, 2009. ISBN Number 978-0-9105-89-26-0.

[38] California Air Resources Board, “Staff Analysis of Proposed Early Action for Climate Change Mitigation in California,” 2007, http://www.arb.ca.gov/cc/hfc-mac/documents/hfcdiy.pdf.

CHAPTER 3: Technical Basis of the Standards

3.1 Technical Basis of the Standards

3.1.1 Summary

As explained in section III.D of the preamble to the proposed rule, in developing the proposed standard, EPA built on the technical work performed by the State of California during its development of its statewide GHG program. This led EPA to evaluate a Clean Air Act national standard which would require the same degree of technology penetration that would be required for California vehicles under the California program. In essence, EPA evaluated the stringency of the California Pavley 1 program but for a national standard. However, as further explained in the preamble, before being able to do so, technical analysis was necessary in order to be able to assess what would be an equivalent national new vehicle fleet-wide CO2 performance standards for model year 2016 which would result in the new vehicle fleet in the State of California having CO2 performance equal to the performance from the California Pavley 1 standards. This technical analysis is documented in this sub-chapter of the DRIA.

Table 3-1 presents the calculated emission levels at which the national GHG standard would ensure that vehicle sales in California of federally compliant vehicles would have fleet average GHG emissions that are equal to the fleet average that would be achieved under the California program described in Sections 1900, 1960 and 1961.1 of Title 13, California Code of Regulations ("Pavley I") by model year 2016:

Table 3-1: Fleet Average National CO_2 Emission Levels for Model Years 2012-2016

	MODEL YEAR				
	2012	**2013**	**2014**	**2015**	**2016**
Fleet Average Tailpipe Emission Level (CO_2 gram / mile)	288	281	275	263	250

Manufacturer's use of credits and other program flexibilities may alter the program stringency beyond that which is shown here.

3.1.2 Overview of Equivalency Calculation.

The calculation of the fleet-wide national MY 2015 and MY 2016 CO_2 emission levels which would be equivalent to California's Pavley I program is briefly outlined here.

1. Based on the California new vehicle fleet mix (predicted sales) and the CA program provisions, EPA calculated the fleetwide average CO_2 emissions achieved in CA from the 2015 and 2016 model year fleets.

2. The estimate of fleetwide average CO_2 emissions was disaggregated into achieved car and truck CO_2 emission levels at the national level using the new car and truck definitions proposed for this rule.

3. Based on the anticipated national fleet mix, the achieved car and truck levels were weighted together to determine the national targets which would achieve reductions equivalent to Pavley I in California.

This calculation accounts for the compositional difference between the CA vehicle fleet and the National fleet (i.e., CA has a higher proportion of cars than the average state), and for various parameters in the CA program.

3.1.2.1 Calculating CO_2 Equivalent Emissions under the California Program

To calculate the CO_2 equivalent emissions in California under Pavley I, the California Passenger Car and Light Truck standards were combined with the California fleet mix in order to calculate the anticipated emissions under the California standards from the California fleet.

The Passenger Car and Light Truck Standards were drawn from Sections 1900, 1960 and 1961.1 of Title 13, California Code of Regulations. Intermediate and small volume manufacturer standards were calculated based on guidance within the regulation, as well as EPA analysis of current manufacturer product mix. These standards, less 2 grams per mile of CO_2 equivalent emissions due to methane (CH_4) and nitrous oxide (N_2O), are shown in Table 3-2. CH_4 and N_2O were excluded because the proposed EPA program separately addresses these emissions (Preamble section III).

Table 3-2: California Regulatory Standards excluding CH_4 and N_2O (grams CO_2 equivalent per mile)

	MY 2015 Standard	MY 2016 Standard
California Car (PC/LDT1) Standard	211	203
Intermediate/Small Volume Manufacturer California Car Standard	314	229
CA LDT2/MDPV Standard	339	330
Intermediate/Small Volume Manufacturer LDT2/MDPV Standard	360	357

The projected fleet mix, as defined under Pavley I, was then determined in California. Significantly, the California program deviates from historic definitions of "classic" cars and trucks. In brief, Pavley I defines "PC/LDT1" as passenger cars and light duty trucks below 3,750 pounds, while "LDT2" include all trucks intended to convey passengers that weigh less than 10,000 pounds. The details of this classification scheme are found in the California regulations.

In order to estimate the emission contribution of PC/LDT1 and LDT2 in California, EPA estimated the respective fleet fractions. EPA estimated the national sales mix in 2015 and 2016 at 60% passenger cars and 40% light duty trucks. This estimate is supported by the Energy Information Administrations' Annual Energy Outlook 2009, which estimated passenger cars at 59.4% of 2016 new vehicle sales in its published reference case.[39] Due to the American Recovery and Reinvestment Act of 2009, the Annual Energy Outlook reference case has since been updated to project 2016 sales at 57.1% passenger cars.

The projected 60% passenger cars, 40% light duty trucks sales fraction was then applied to the California vehicle fleet mix. In such a scenario, the California Air Resource Board (ARB) estimated that PC/LDT1s comprise approximately 66% of the new light duty vehicle fleet in California and that LDT2s comprise the remainder (34%).

Once the PC/LDT1 and LDT2 fractions of California new vehicle sales were determined, EPA estimated the fraction of vehicle sales in the intermediate and small volume manufacturer categories. These manufacturers, which sell less than 60,000 vehicles per year in California, are subject to less stringent emission standards under Pavley I. While estimates of future sales by manufacturer fluctuate, manufacturers such as Subaru, Porsche, Hyundai and Volkswagen were considered beneath this threshold for the purpose of this analysis. Based on EPA market analysis, small/intermediate volume manufacturers were estimated at 9% of total California PC/LDT1 sales and 5% of total California LDT2 Sales. The final product mix assumed in California in 2015 and 2016 under a 60/40 national sales scenario is shown in Table 3-3.

Table 3-3: California Sales Mix under a 60% Classic Car 40% Classic Truck National Sales Scenario

	Sales %
PC/LDT1 Sales	60%
Intermediate Volume PC/LDT1 *sales*	6%
California LDT2 Sales	32%
Intermediate Volume LT2 sales	2%

The product mix was multiplied by the relevant standard and summed in order to calculate the achieved average CO_2 emissions for the new California fleet. As an example in 2016:

Achieved Fleetwide CO_2 Equivalent Emissions =

(PC/LDT1 standard x PC/LDT1 Percentage) + (LT2 standard x LT2 Percentage) + (Intermediate Volume PC/LDT1 standard x Intermediate Volume PC/LDT1 Percentage) + Intermediate Volume LT2 standard x Intermediate Volume LT2 Percentage)

=

(0.6 x 203) + (0.06 x 229) + (0.32 x 330) + (0.02 x 357) = 248 grams.

(eq.1)

Based on the projected 60% passenger car, 40% light duty truck national sales mix (Table 3-3), the achieved fleetwide CO_2 equivalent tailpipe emission level expected in California in 2016 is 248 grams / mile.

This analysis was repeated for model year 2015. In order to achieve equivalency, the national program must produce a fleetwide average emission level in California that is no higher than 261 grams CO_2 / mile in 2015 and 248 grams CO_2 / mile in 2016.

3.1.2.2 Translating the CA fleetwide average emissions into Cars (Passenger Automobiles) and Trucks (Non-Passenger Automobiles)

In order to describe the national fleet, the California fleet-wide average CO_2 emission level was translated into car and truck achieved emissions levels. However, the regulatory definitions in EPA's Title II programs differ. Passenger Automobiles (PA) are defined as two wheel drive SUVs below 6,000 lbs. gross vehicle weight as well as classic cars. The remaining light duty fleet is defined as Non-Passenger Automobiles (NPA) (Table 3-4).

Table 3-4: Summary of Fleet Description Methods

REGULATOR	CAR DEFINITION	TRUCK DEFINITION
National Highway Transit Safety Association (CAFE Through MY 2010)	Car – Passenger Car	Truck – LDT1-4 and MDPV
California ARB	Car – PC + LDT1	Light Truck – LDT2-4 and MDPV
EPA	Passenger Automobile – PC + 2 wheel drive SUVs below 6,000 GVW	Non-Passenger Automobile – Remaining light duty fleet

To disaggregate the combined California fleet emission level into PA and NPA vehicles, the 2015 and 2016 California achieved levels were multiplied by ratios derived from National Highway Transit Association (NHTSA) analysis of the emissions from PA and NPA vehicles.[40] Based on the NHTSA analysis, EPA estimates that PAs have an emission contribution equivalent to 91% of the California MY 2016 fleet average, while NPA have an emission contribution equivalent to 119% of the California achieved CO_2 fleet average emissions. These ratios, and the PA/NPA achieved emission levels, are shown in Table 3-5.

Table 3-5: PA and NPA Emission Levels under Pavley I

Regulatory Class	Ratio	MY 2015 Achieved Emission Level	MY 2016 Achieved Emission Level
PA	0.91	238	227
NPA	1.19	312	297

3.1.2.3 Calculating the 2015 and 2016 Fleetwide CO_2 emission Targets under the EPA Proposal

To determine the MY 2015 and MY 2016 fleetwide targets under the EPA proposal, the achieved emission levels from PA and NPA (Table 3-5) were reweighted into a national fleet-wide average based upon the anticipated national fleet of 60% passenger car, 40% light duty truck. Based on NHTSA analysis presented in the MY 2011 CAFE final rule, this fleet is expected to be comprised of approximately 66.4% PA and 33.6% NPA.[41] The PA and NPA achieved emission levels were weighted into a national fleetwide average based upon these percentages. The resulting 2015 fleetwide target is 263 grams CO_2 / mile, while the 2016 target is 250 grams CO_2 /mile.

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3.1.2.4 Calculation of 2012-2014 "California Equivalent" Targets

The methodology used to calculate the 2015 and 2016 California Equivalent levels was repeated for the 2012-2014 model years. The most significant departure from the previously described methodology is that sales projections differ in MY 2012-2014 as compared to MY 2015-2016.

EPA assessment of projected vehicle sales during MY 2012-2014 supported a lower proportion of car sales than the 60% fraction projected during MY 2015-2016. March 2009 AEO vehicle sales estimates were therefore substituted in these earlier years. Using the methodology described in section **Error! Reference source not found.**, the AEO estimates were used to project PC/LDT1 fractions in CA, and PA and NPA sales fractions nationally (Table 3-6).

Table 3-6: National PA and NPA Sales Fractions estimated in March 2009 AEO Projections

Regulatory Class	MY 2012	MY 2013	MY 2014
AEO Car fraction	55.0%	56.1%	57.4%
AEO Truck fraction	45.0%	43.9%	42.6%
PC/LDT1 in CA	61.0%	62.1%	63.4%
LT2 in CA	39.0%	37.9%	36.6%
PA fraction Nationally	62.1%	63.0%	64.1%
NPA fraction Nationally	37.9%	37.0%	35.9%

Per the previously described methodology, the calculated CA sales fractions were then multiplied by the Pavley I standards for MY 2012 – MY 2014 (Table 3-7). Consistent with the 2015/16 analysis, small manufacturers were assumed to remain a constant 9% of California PC/LDT1 sales and 5% of California LDT2 Sales.

Table 3-7: 2012-2014 California Regulatory Standards excluding CH_4 and N_2O (grams CO_2 equivalent per mile)

	MY 2012	MY 2013	MY 2014
California Car (PC/LDT1) Standard	231	225	220
Intermediate/Small Volume Manufacturer California Car Standard	314	314	314
CA LDT2/MDPV Standard	359	353	348
Intermediate/Small Volume Manufacturer LDT2/MDPV Standard	360	360	360

The resulting achieved emission levels in California are 286 grams CO_2 / mile in MY 2012, 279 grams CO_2 / mile in MY 2013 and 273 grams CO_2 / mile in MY 2014. In order to derive PA and NPA achieved emission levels, these achieved emission levels were multiplied by MY-specific ratios derived from National Highway Transit Association (NHTSA) analysis. [42]

The projected PA and NPA emission levels were then recombined into a national fleet achieved emission level based on the national PA and NPA sales fractions shown in Table 3-6 (Table 3-8).

Table 3-8: PA and NPA Emission Levels under Pavley I

Regulatory Class	MY 2012 Achieved Emission Level	MY 2013 Achieved Emission Level	MY 2014 Achieved Emission Level
PA	260	253	248
NPA	334	328	323
Fleet Average	**288**	**281**	**275**

3.2 Analysis of Footprint Approach for Establishing Individual Company Standards

One of the fundamental issues associated with the vehicle fleet average CO2 emission standard is the structure of the standard; i.e., the basis for the determination of the standard for each vehicle manufacturer.

Vehicle CO2 emissions are closely related to fuel economy. Over 99 percent of the carbon atoms in motor fuel are typically converted to tailpipe CO2, and therefore, for any given fuel with a fixed hydrogen-to-carbon ratio, the amount of CO2 emitted (grams) is directly correlated to the volume of fuel that is consumed (gallons), and therefore CO2 g/mile is essentially inversely proportional to vehicle fuel economy, expressed as miles per gallon. As part of the CAFE program, EPA measures vehicle CO2 emissions and converts them to mpg and generates and maintains the federal fuel economy database. Additionally, EPA calculates the individual manufacturers' CAFE values each year, and submits these values to NHTSA.

EPA is proposing footprint-based CO2 standards for cars and light trucks. EPA believes that this program design has the potential to promote CO2 reductions across a broad range of vehicle manufacturers, while simultaneously accounting for other important societal objectives cognizable under section 202 (a) such as consumer choice and vehicle safety. EPA believes a footprint-based system will also provide a more level playing field among manufacturers, as all models with similar size will have the same CO2 emission targets, across all manufacturers.

In 2007, EPA evaluated several vehicle attributes on which to base proposed CO2 standards for both cars and light trucks: footprint, curb weight, engine displacement, interior volume, and passenger carrying capacity. All of these attributes have varied advantages and disadvantages. EPA's evaluation centered on three primary criteria (all of which reflect factors relevant under section 202 (a)). 1) Correlation with tailpipe CO2 emissions. Since emissions of CO2 are controlled, there must be a reasonable degree of correlation from a technical perspective between a proposed attribute and vehicle CO2 emissions performance. 2) The relationship between the attribute and potential CO2 reducing technologies. In order to promote emissions reductions, choice in technology for the manufacturers, and cost-effective solutions, it is important that an attribute not discourage the use of important CO2 control strategies. 3) How much the attribute would encourage compliance strategies that tend to circumvent the goal of CO2 reduction. EPA believes that it is important to choose an attribute that minimizes the risk that manufacturers would change the magnitude of the attribute as a method of compliance. 4) The consistency of the attribute with existing or proposed regulations. EPA does not want to create a program that competes with others that accomplish similar goals. The 2007 analysis examines potential attributes against these criteria and is outlined below.

3.2.1 "Footprint" as a vehicle attribute

EPA is proposing to base the individual manufacturers fleetwide CO2 standards on the vehicle footprint attribute. Footprint is defined as a vehicle's wheelbase multiplied by average track width. In other words, footprint is the area enclosed by the points at which the wheels meet the ground.

In 2006, NHTSA adopted footprint as the basis for fuel economy standards in its Reformed CAFE program for light trucks, and in 2008, the agency extended this program structure to regulate passenger cars for MY 2011 and beyond. NHTSA used projected sales, footprint, and mpg data from automakers' product plans, along with information on the cost and effectiveness of fuel economy technologies, to create a footprint versus fuel economy curve shown below in Figure 3-1 for cars and Figure 3-2 for trucks that establishes fuel economy targets for every model's footprint value. Chapter V of NHTSA's RIA for the MY 2011 CAFE program contains more detailed information how the MY 2011 car and truck curves were generated.

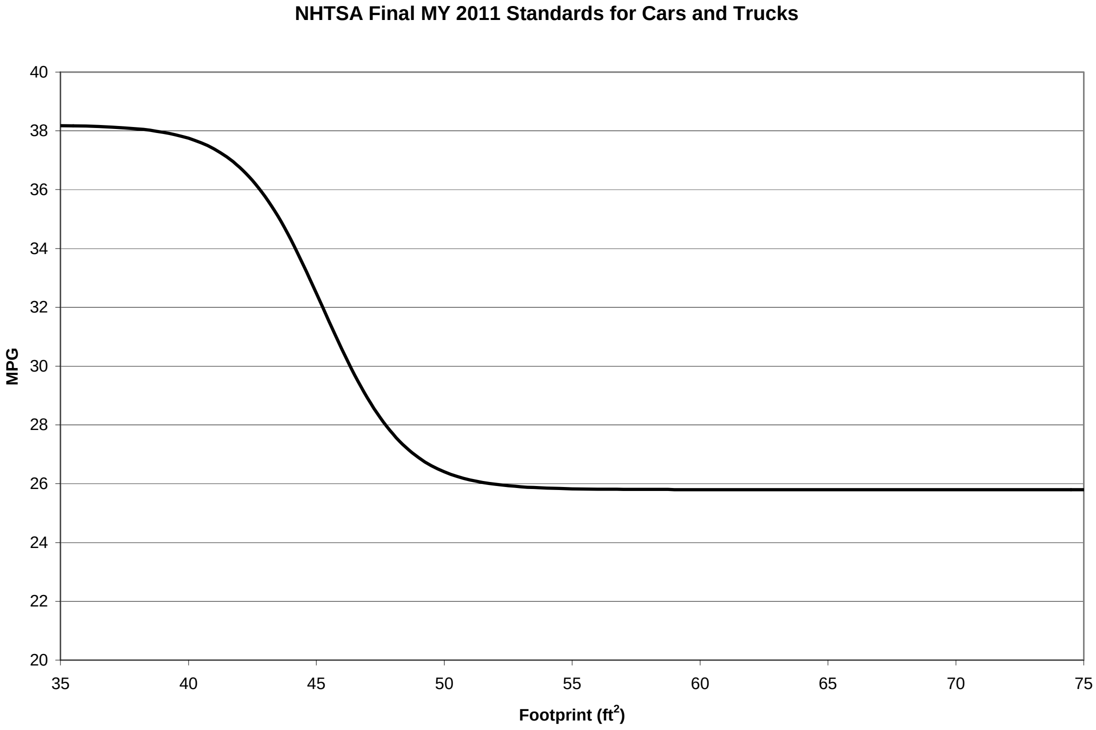

Figure 3-1 NHTSA Reformed CAFE Curve for MY 2011 Cars

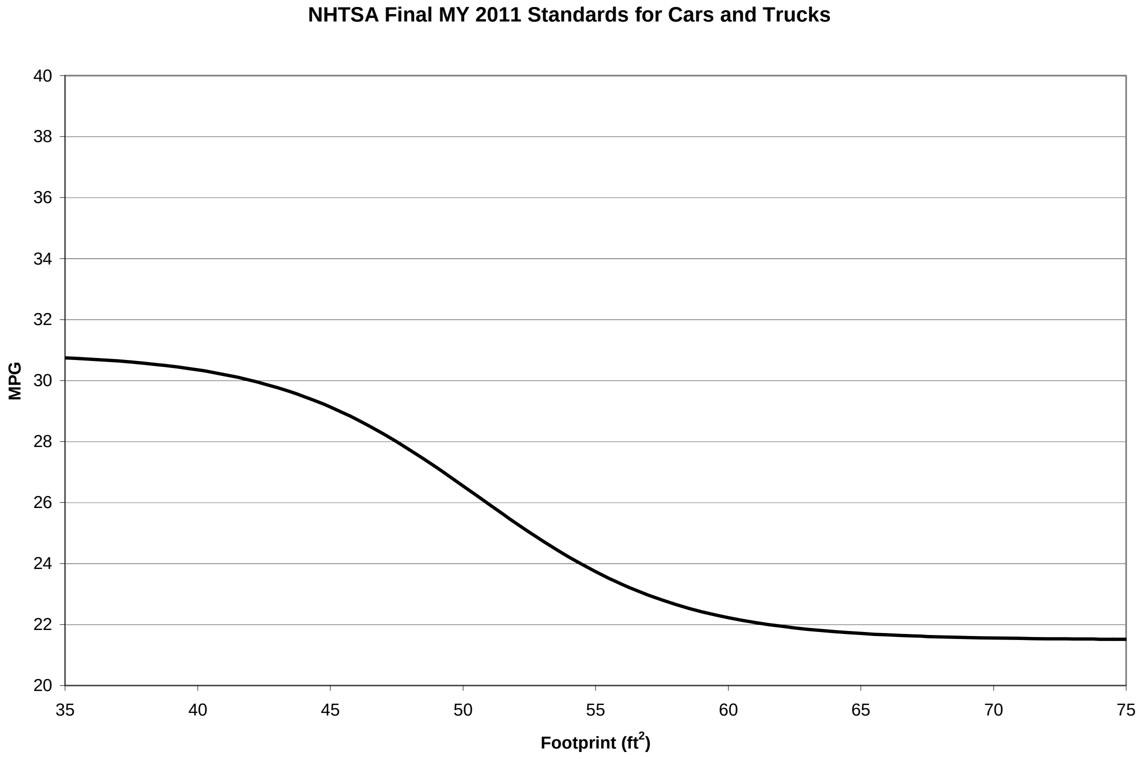

Figure 3-2 NHTSA Reformed CAFE Curve for MY 2011 Trucks

The overall fleet-wide fuel economy compliance value for an individual manufacturer is then calculated at the end of the model year by a sales-weighted, harmonic average of the fuel economy targets for all models sold by that manufacturer. In the rulemaking process, NHTSA also considered weight, towing capacity, and four wheel drive capability as alternative attributes, but rejected them in favor of footprint.[43]

EPA evaluated footprint as the attribute for setting vehicle CO2 standards based on the four criteria outlined above.

3.2.1.1 Correlation to tailpipe CO2 emissions

Figure 3-3 and Figure 3-4 describe the relationship of tailpipe CO2 emissions and vehicle footprint. These figures were generated using the manufacturer's 2007 confidential product plans, the most current projections at the time of the analysis. EPA has since received new product plans and developed a new baseline dataset from publicly available information. However, EPA has not redone the analysis below with this new data as the general trends are not expected to have changed.

The first plot describes the model year 2007 car fleet and the second plot describes the model year 2007 truck fleet. The circles represent the sales volume of a particular model, where a larger circle corresponds to higher sales projection and a smaller circle corresponds to a lower sales projection. In order to determine how closely footprint and CO2 emissions were correlated, a linear least-squares regression was performed for cars and trucks separately. It should be noted that NHTSA used non-sales-weighted minimum absolute difference (MAD) regressions to develop the slopes of the proposed fuel economy and CO2 emission standards. The reader is referred to the preamble to the proposed rule for a discussion of the reasons for use of non-sales-weighted MAD regressions for this purpose.

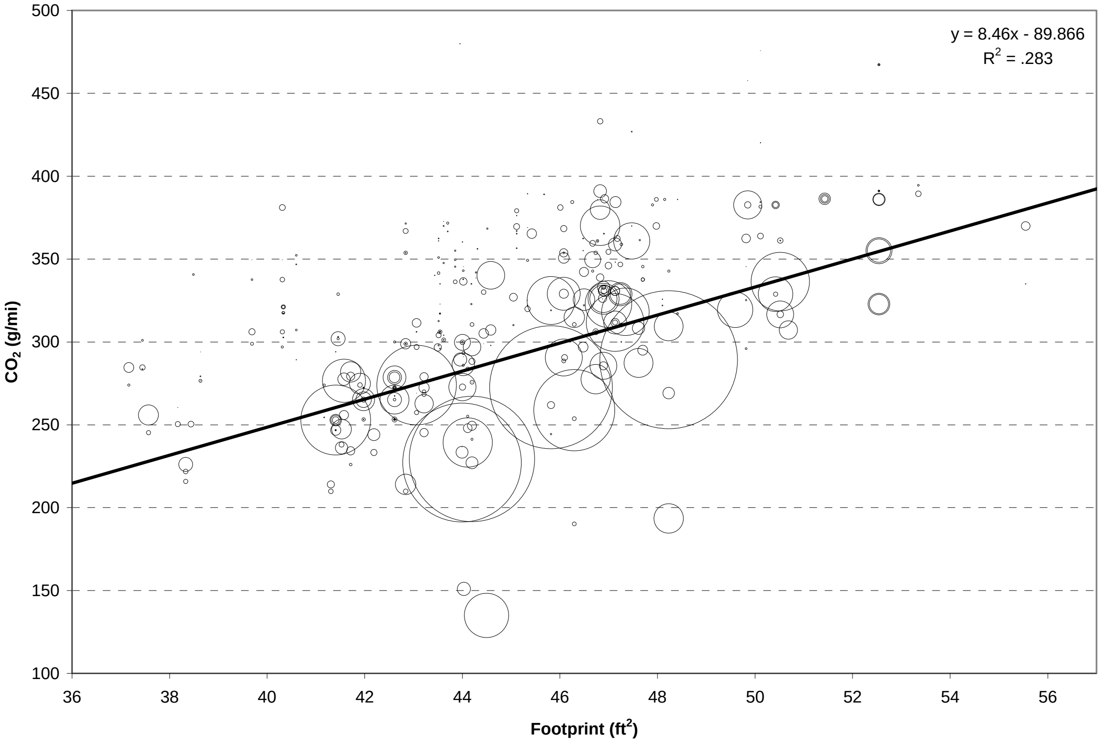

Figure 3-3 Model Year 2007 Cars; Sales-weighted Linear Regression of CO2 Tailpipe Emissions and Footprint

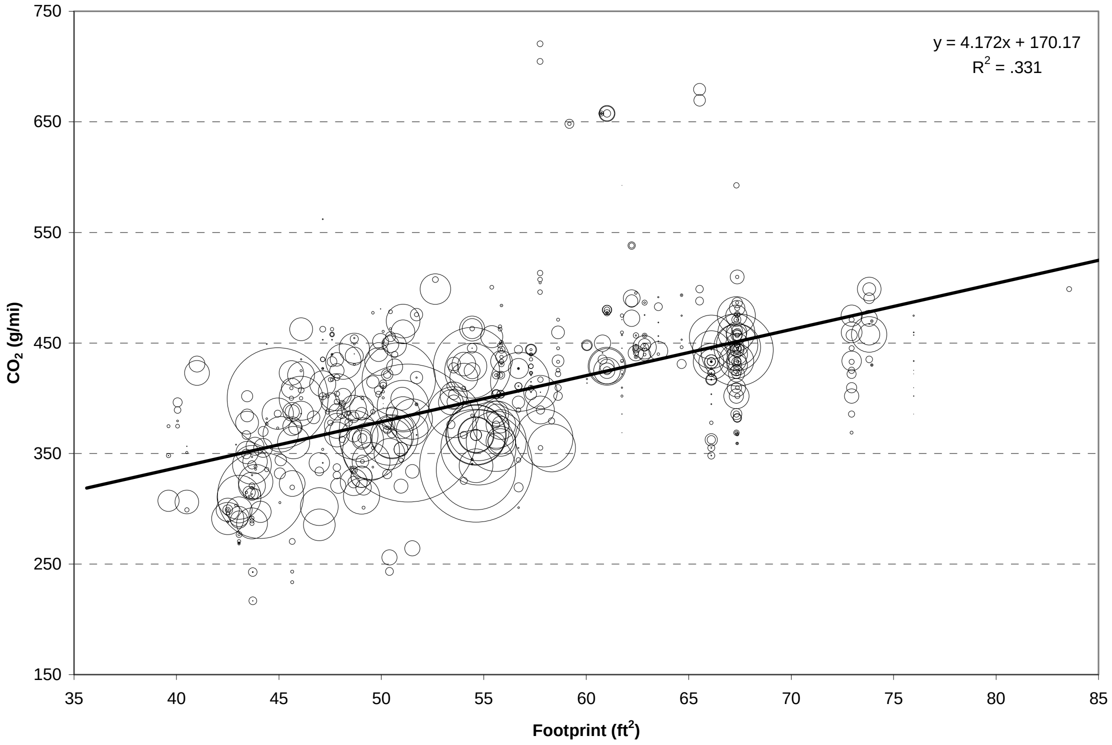

Figure 3-4 Model Year 2007 Trucks; Sales-weighted Linear Regression of CO2 Tailpipe Emissions and Footprint

As illustrated in the above figures, the R^2 values for model year 2007 cars and trucks are 0.283 and 0.331 respectively (both statistically significant to a confidence level greater than 99%), indicating that there is a non-random correlation to CO2 emissions. As vehicle size increases, its CO2 emissions tend to increase.

3.2.1.2 Relationship with CO2-reducing strategies

The footprint attribute would encourage all CO2 control strategies with the exception of vehicle downsizing. All other things being equal, vehicle downsizing tends to correspond to lower vehicle weight, which results in lower CO2 emissions. However, smaller vehicles would have smaller footprints and would be subject to lower, more stringent, CO2 emissions targets, discouraging downsizing as a compliance strategy. Also, absent other design changes, decreasing vehicle size could reduce vehicle safety for that vehicle's driver, especially for those vehicles less than 4000 pounds.[44] Thus, the fact that footprint discourages vehicle downsizing is viewed by many safety advocates as a positive aspect. This continues to be an important factor in NHTSA's adoption of footprint in its Reformed CAFE program.

A footprint attribute also would not discourage the use of lightweight materials, as a lighter vehicle with no change in footprint would more easily comply with its CO2 target. Therefore, in choosing the footprint attribute, the use of lightweight material would remain a viable compliance option, an important factor as lightweight materials can simultaneously reduce mobile CO2 emissions and improve vehicle safety. NHTSA came to the same conclusion in its Reformed CAFE rulemaking.[45] Though there can be a trend between weight and size, EPA is not equating the two. Moreover, EPA is assuming that manufacturers can and will lightweight their vehicles at a given footprint level as a potential compliance strategy.

3.2.1.3 Sensitivity of CO2 control to compliance-related vehicle adjustments

Depending on the attribute, manufacturers may find it more economically attractive to comply in a way that tends to compromise the expected emission reduction benefits of the program. Specifically, a manufacturer would have the opportunity to increase its average fleet footprint over time in order to comply with a less stringent standard, which would circumvent the CO2 reduction goals of the program. However, major changes in a vehicle's footprint typically require a substantial redesign of the vehicle, which typically occurs every 5-7 years. NHTSA made this same finding in the Reformed CAFE rulemaking.[46] While definitive historical footprint data is not available, EPA believes that footprint has grown more modestly in the past than many other attributes.

3.2.1.4 Consistency with other existing or proposed regulatory programs

EPA and NHTSA have coordinated closely in developing parallel GHG and MPG standards in order to avoid creating a "patchwork" of regulations. Since NHTSA has in recent history used footprint as the basis for its CAFE program and is proposing to continue using this metric, footprint remains the simplest, most natural option with respect to the goal of avoiding excessive regulatory burden on the manufacturers.

Under the Clean Air Act, the State of California may petition EPA for the authority to create more stringent mobile source emissions regulations at the state level. EPA has granted California this privilege and the California program outlined does not utilize the footprint (or any) attribute; instead the regulatory structure is based on a universal (or unreformed) standard. Despite differences in the structure of the standards, the EPA federal program is expected to have an equivalent stringency when compared to the California program, thus making it a 50-state program. In order to account for early AC credits offered by the California program, EPA has also chosen to adopt a very similar credit system outlined in Chapter 2 of the RIA, which offers an additional layer of consistency.

3.2.2 Alternative Attributes

Some manufacturers have suggested using a vehicle's curb weight for an attribute-based standard. Curb weight is defined in EPA regulations (CFR 86.1803-01) as the actual or estimated weight of the vehicle with all standard equipment, plus the fuel weight at nominal tank capacity, plus the weight of optional equipment. Figure 3-5 and Figure 3-6 below show plots of tailpipe CO2 emissions versus curb weight for 2007 car and truck models respectively, where circle size indicates the sales volume of each model.

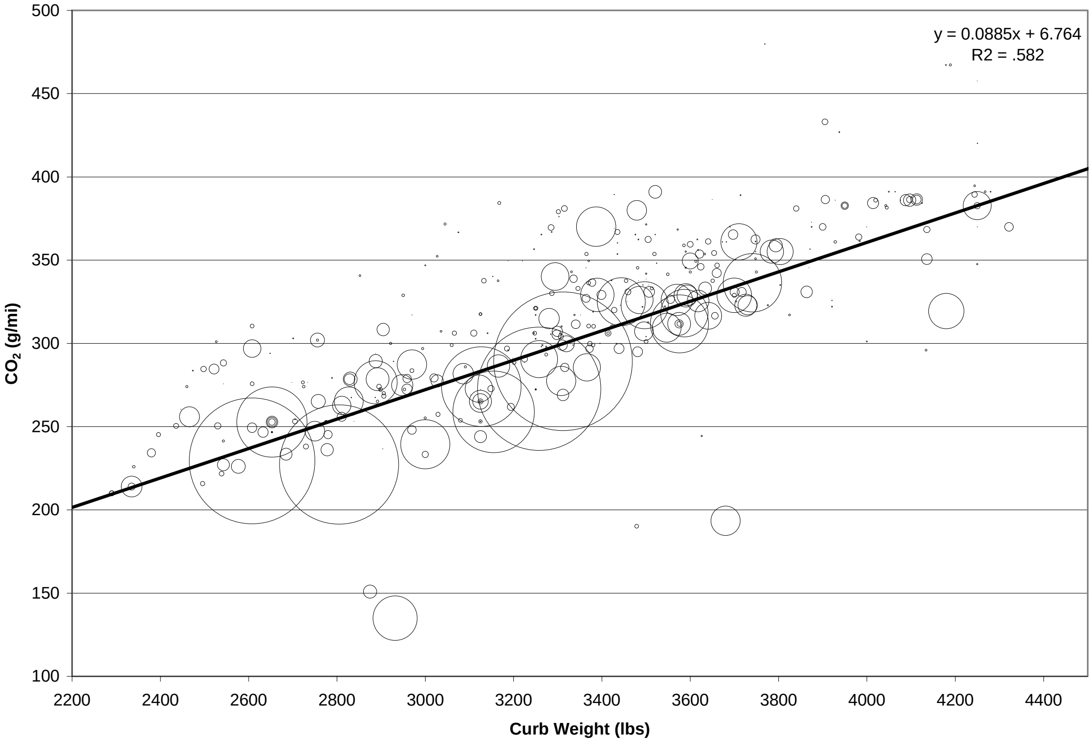

Figure 3-5 Model Year 2007 Cars; Sales-weighted Linear Regression of CO2 Tailpipe Emissions and Curb Weight

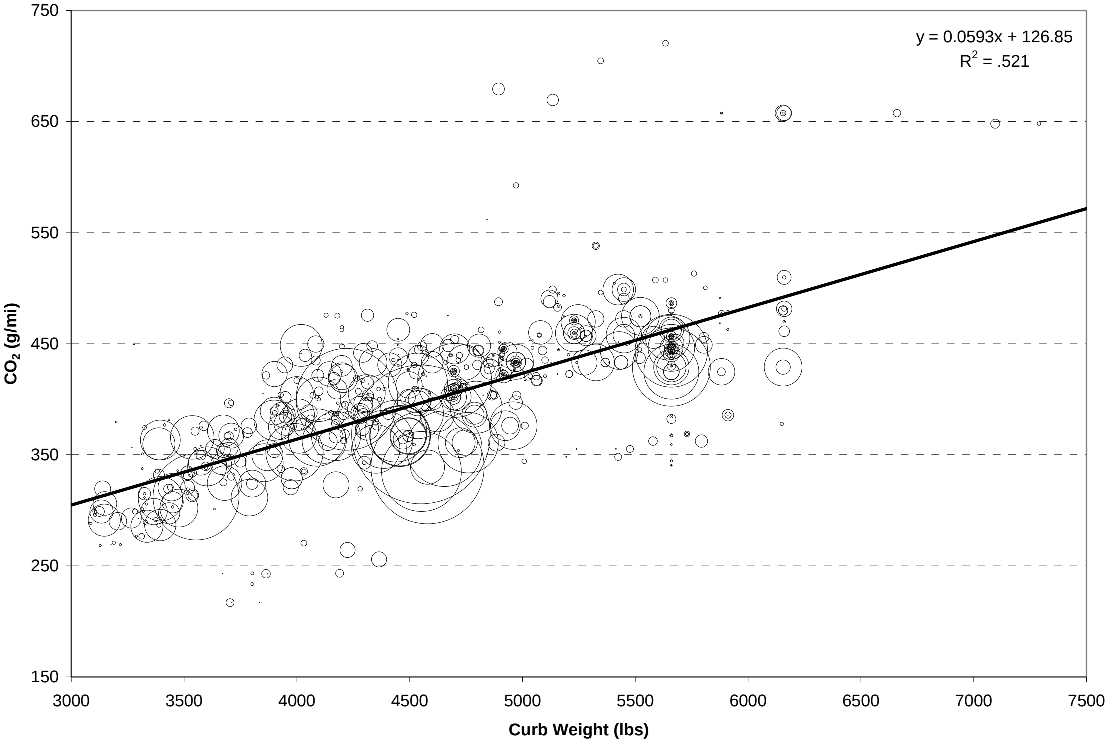

Figure 3-6 Model Year 2007 Trucks; Sales-weighted Linear Regression of CO2 Tailpipe Emissions and Curb Weight

For both cars and trucks, curb weight has a relatively high correlation with tailpipe CO2 emissions. A sales-weighted linear least squares regression determined R^2 values of 0.582 for cars and 0.521 for trucks, indicating a substantial relationship of the current fleet's curb weight and CO2 emissions.

Historically, some vehicle safety advocates have preferred weight for an attribute-based standard since a standard with a steep relationship with weight discourages down-weighting. However, with recent advances in strong, lightweight materials, occupant safety is not necessarily compromised by a reduction in vehicle weight.[47] In fact, these studies have shown that a vehicle's size is a more important factor than weight in its effect on occupant safety. In a weight-based attribute system, a lower weight would correspond to a more stringent CO2 standard. While this would discourage downsizing as a compliance strategy, it's important to recognize that weight as an attribute for determining tailpipe CO2 standards would discourage the use of lightweight materials, even though advanced lightweight materials could simultaneously reduce CO2 emissions and improve vehicle safety.

Furthermore, since a vehicle's weight is much easier to change than most other attributes, it is more likely that manufacturers could add weight to their vehicles in order to be subject to and comply with a less stringent standard. This potential is reinforced by the relatively high rate of growth of vehicle weight; it has grown 1.0 – 1.5% per year since the late 1980s.[48] This development would have negative environmental consequences by increasing overall CO2 emissions, contrary to the chief goal of section 202 (a) of the Act.

EPA also examined engine displacement as a potential attribute for determining manufacturer CO2 standards. Engine displacement is defined as the volume swept as the piston moves from top dead center to bottom dead center. Figure 3-7 and Figure 3-8 below contain sales-weighted linear regression plot of tailpipe CO2 emissions and engine displacement for 2007 cars and trucks, respectively.

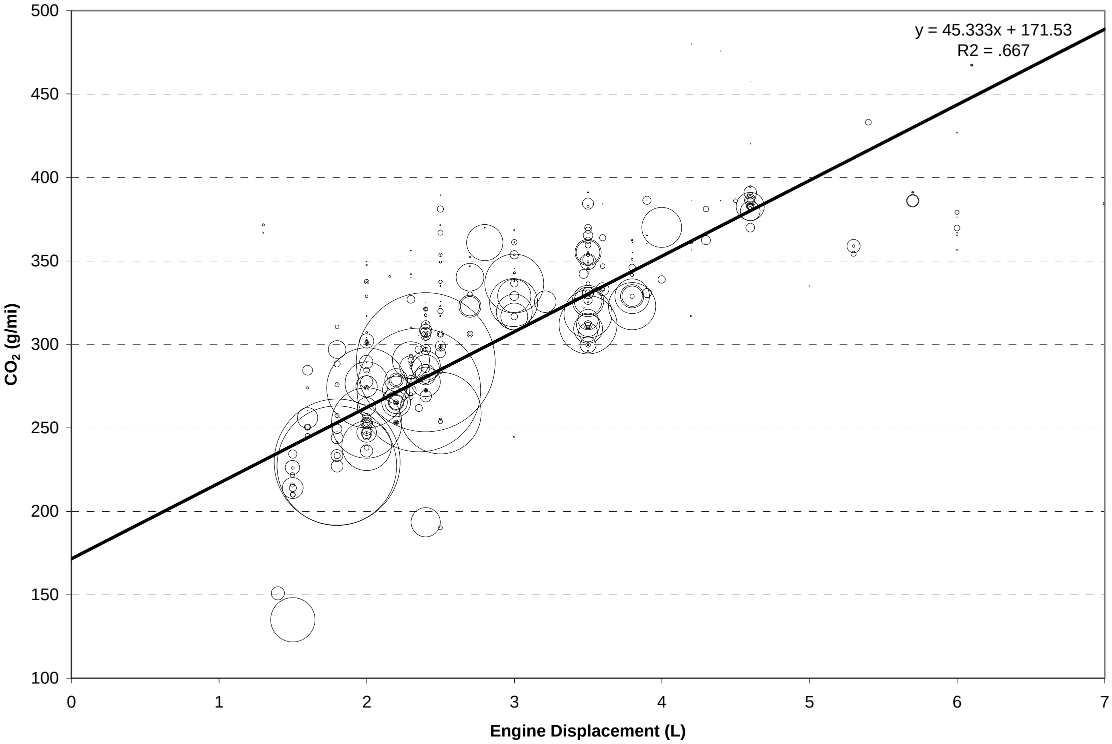

Figure 3-7 Model Year 2007 Cars; Sales-weighted Linear Regression of CO2 Tailpipe Emissions and Engine Displacement.

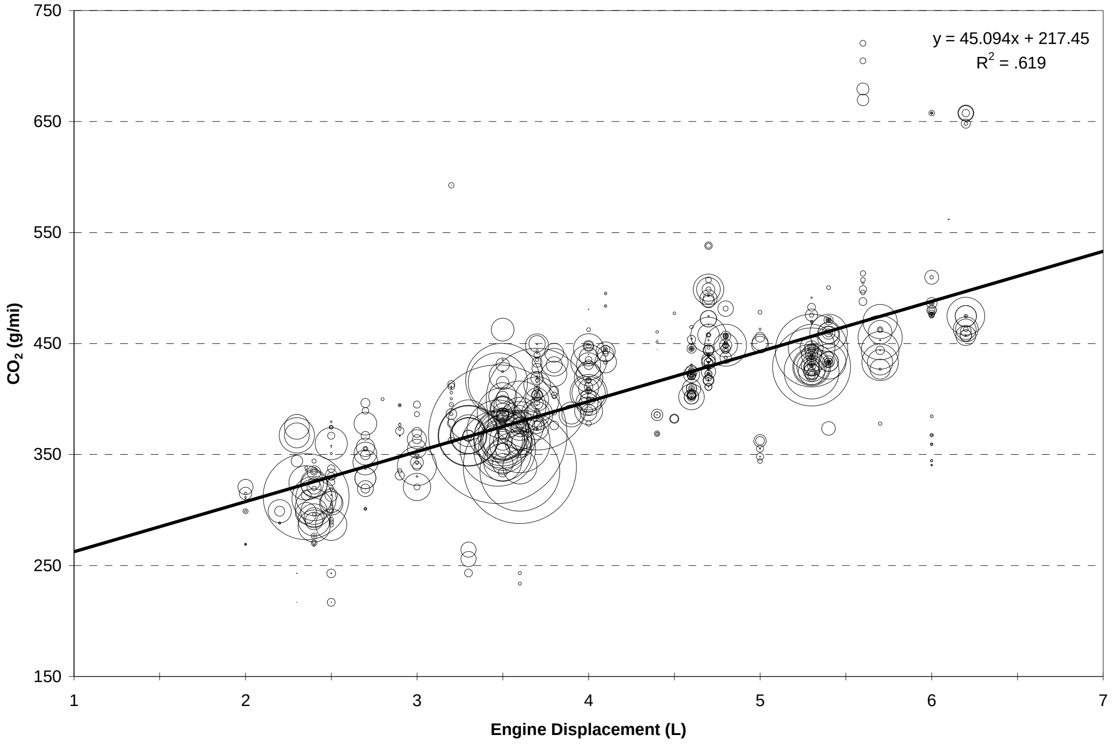

Figure 3-8 Model Year 2007 Trucks; Sales-weighted Linear Regression of CO2 Tailpipe Emissions and Engine Displacement

Engine displacement correlates well to tailpipe emissions, with R^2 values of 0.667 for cars and 0.619 for trucks. This is because increasing engine displacement typically increases the amount of fuel burned per cycle.

EPA believes that a standard based on engine displacement does not guarantee any environmental benefit because of the disincentive to add certain CO2-reducing technologies and the potential for manufacturers to adjust the sales of higher-displacement models regardless of whether or not it reflects market demand. Hypothetically, a model could have three trim lines with three different displacements: A 4-cylinder 2.0L Turbo, a 4-cylinder 2.5L, and a 6-cylinder 3.0L. Since these models would have three standards ranging from most to least stringent, correspondingly, this type of standard would be a disincentive to sell models with smaller engines or turbochargers. These strategies can dramatically reduce CO2 emissions (See RIA Section on Tech Feasibility) and are increasingly prevalent in the European market. Thus EPA believes that the use of engine displacement for establishing CO2 tailpipe standards will undermine readily achievable and feasible reductions of CO2 emissions.

EPA also examined interior volume and occupant capacity as potential attributes because they characterize vehicle utility well. Increasing interior volume creates more space for people and cargo, and increasing occupant capacity creates the potential to carry more people, both important factors consumers consider when purchasing a new vehicle. Figure 3-9 below contains a plot of interior volume and tailpipe CO2 for model year 2007 cars.

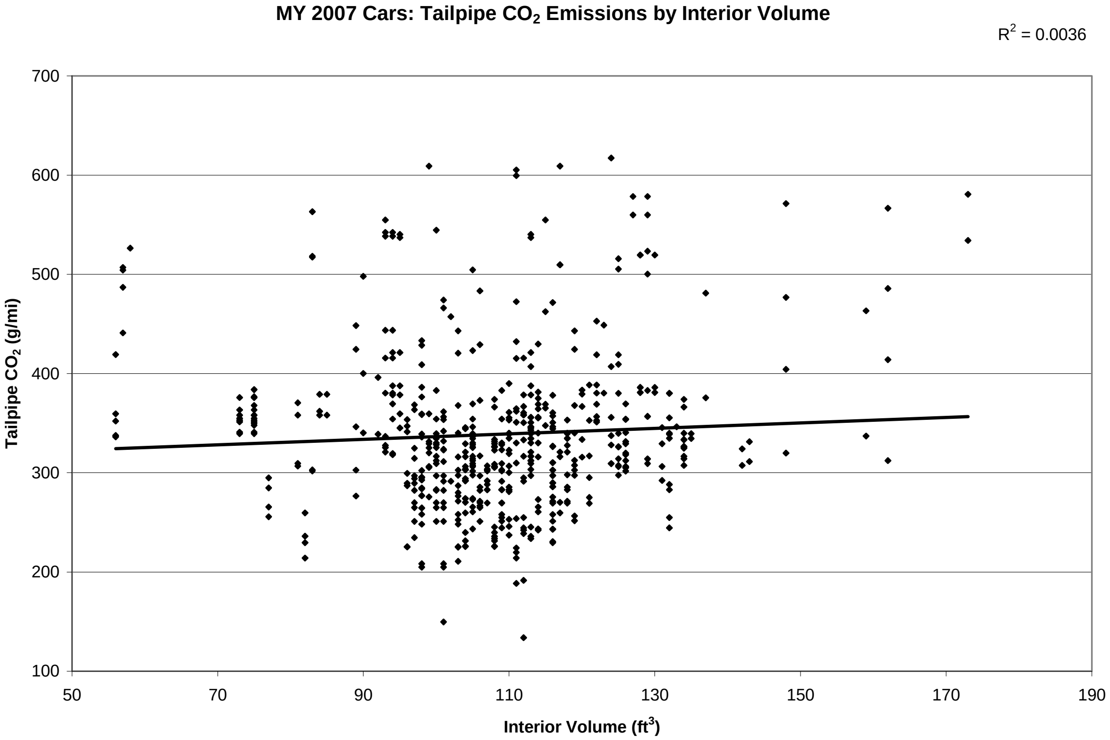

Figure 3-9 Model Year 2007 Cars; Linear Trend of CO2 Tailpipe Emissions and Engine Displacement

EPA confirmed that interior volume is not at all correlated to vehicle CO2 emissions with a R^2 value of 0.0036 for cars. The correlation of interior volume and tailpipe CO2 is worse for light trucks by definition, since cargo space for pickup trucks is a separate exterior bed. Thus, it does not make sense to have a CO2 standard for light trucks that is based on interior volume, since pick-up trucks would be required to meet a stricter CO2 standard than SUVs and minivans, which are typically regulated in the general “truck” category. For these reasons, EPA is not proposing interior volume for the standard.

Alternatively, occupant capacity does not share the same safety implications as interior volume. Furthermore, since it is difficult to game and does not discourage the use of any CO2-reducing technologies, there is significant potential for CO2 improvement. Figure 3-10 and Figure 3-11 below illustrate the breakdown of the model year 2007 fleet in terms of occupant capacity.

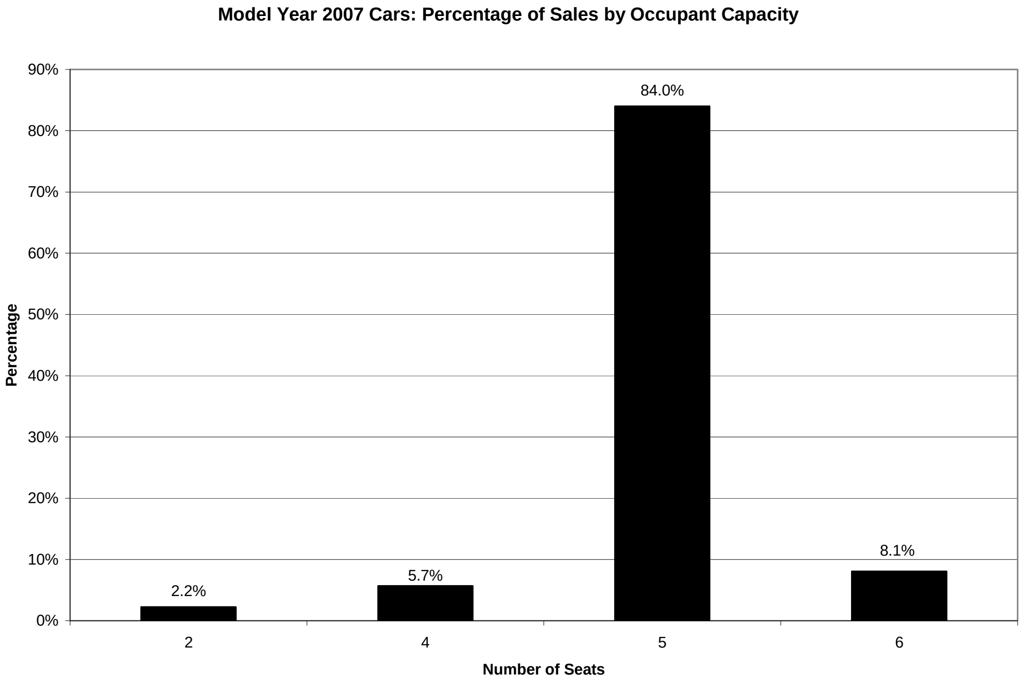

Figure 3-10 Model Year 2007 Cars; Percentage of Sales by Occupant Capacity

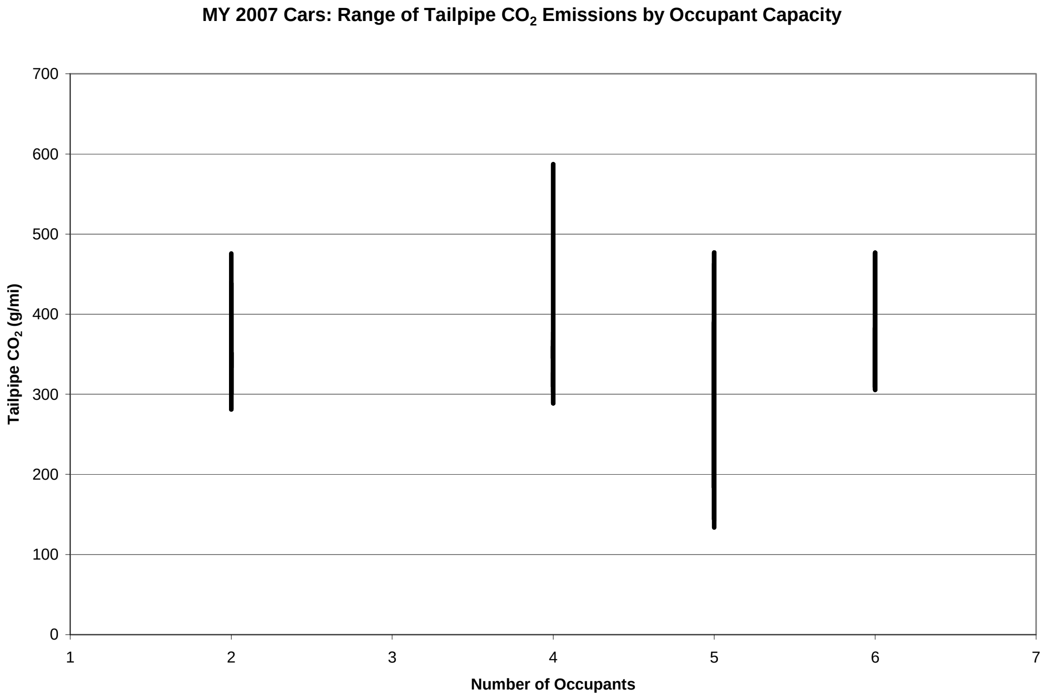

Figure 3-11 Model Year 2007 Cars; Range of Tailpipe CO2 Emissions by Occupant Capacity

However, occupant capacity and CO2 emissions do not relate well. Since 84% of the 2007 car fleet has 5 seats, an occupant-based standard would essentially result in a universal standard for a majority of vehicles. Since the car models falling into the 5-seat category have a tailpipe CO2 range of 133 to 472 g/mi, an occupancy-based standard would negate the benefits from relative equity of the attribute-based system to full line manufacturers.

3.2.3 EPA Selection of the Footprint Attribute

EPA has considered a range of potential vehicle attributes that could be used to set CO2 standards. To summarize key results from the 2007 analysis, interior volume and passenger carrying capacity have extremely poor correlation with fuel economy, and EPA is not proposing them for that reason. The three remaining attribute options—footprint, curb weight, and engine displacement—are all reasonable choices in terms of correlation with CO2 emissions levels, with weight having the best correlation to CO2 emissions levels. However, it should be noted that correlation is not the primary deciding factor for the selection of an attribute. One could easily get an excellent correlation by choosing a function that combines the effects of weight, displacement, N/v ratio (engine speed to vehicle speed ratio at top gear), and frontal area (as a product with the aerodynamic coefficient). There are many other, but these are the four variables that most define a vehicle's fuel economy[49,50] The choice of an attribute is not only an engineering decision, it also a policy decision. It is linked with the outcomes that are desired in a future fleet.

With respect to the remaining criteria, EPA believes footprint is clearly superior to both weight and engine displacement. Footprint does not inherently discourage any key CO2 control strategies (except for vehicle downsizing), while weight would discourage the use of lightweight materials. Engine displacement would discourage engine downsizing with turbocharging, a strategy increasingly popular in the United States and Europe. Footprint is somewhat less susceptible to modifications for compliance, since major changes would generally require a significant platform redesign; in contrast, it is easier for manufacturers to change weight and engine displacement.

EPA notes that the footprint attribute also correlates well with the "utility" or "usefulness" of the vehicle to the consumer. Larger footprints amount to more space inside the vehicle to carry passengers or cargo, which are important considerations for consumers. Thus, it is an additional benefit that the footprint-based approach would not discourage changes to vehicle designs that can provide more utility to consumers. EPA also recognizes that if footprint is used for the vehicle CO2 standards then the form of the standards would be compatible with NHTSA's use of footprint in their Reformed CAFE program. EPA requests comment on the proposed selection of the footprint attribute for establishing manufacturer-specific CO2 standards.

For these reasons, EPA therefore believes that the footprint attribute is the best choice of the attributes discussed, from both an engineering as well as from a public policy standpoint. EPA therefore proposes to use footprint in the CO2 standard-setting process for this rule.

EPA is proposing to implement the footprint attribute in the proposed CO2 control program via a piecewise linear function. As mentioned above, this is the equivalent to the shape selected by NHTSA for its proposed CAFE standards for light trucks for model years 2012-2016. The shape of this function with respect to CO2 is reflected in Figures I.D.3-3 and I.D.3-4 of the preamble. The difference is that it moves from low CO2 values on the left to high CO2 values on the right (see Figure 3-12 and Figure 3-13 below for example) due to its inverse relation to MPG.

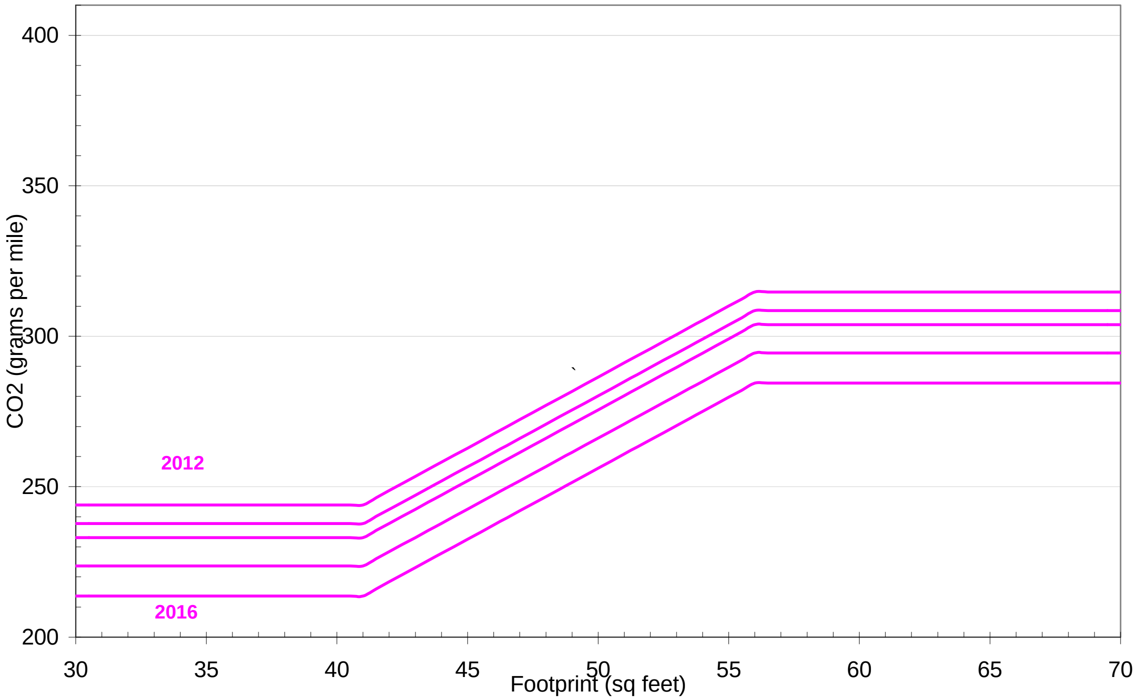

Figure 3-12 CO$_2$ (g/mi) Car standard curves

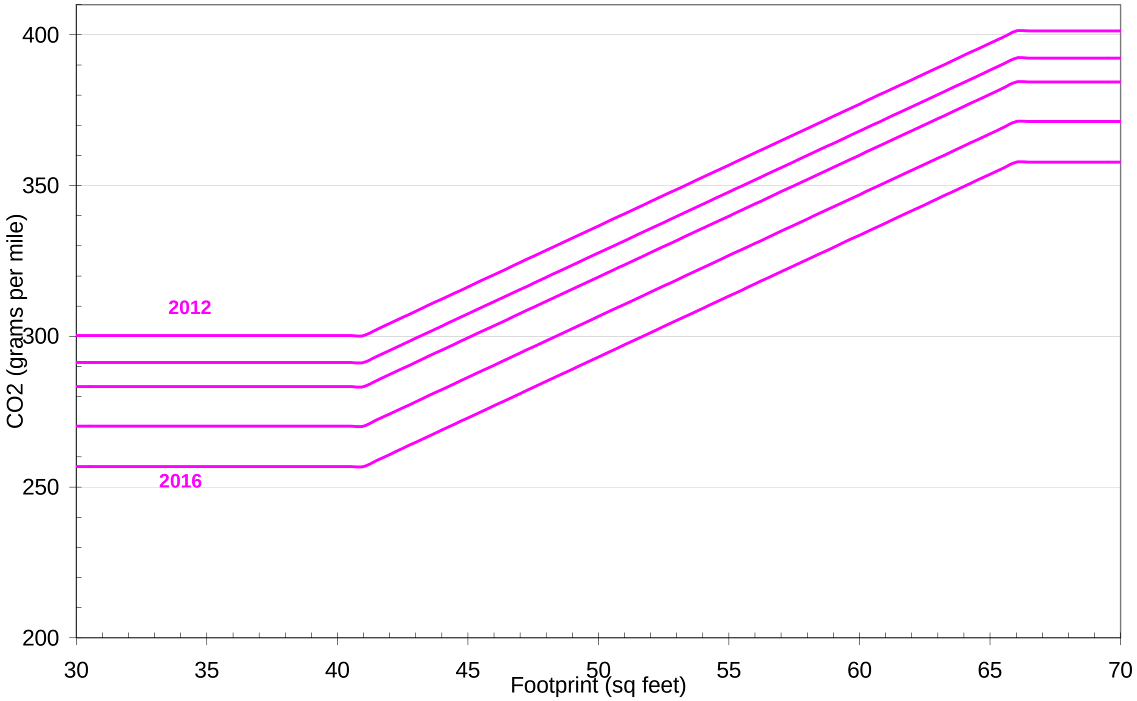

Figure 3-13 CO2 (g/mi) Truck standard curves

Implementing the proposed CO2 emission standards in this manner provides consistency with NHTSA's proposed CAFE standards.

Other forms of a footprint-based CO2 standard are possible. Examples are a logistic curve, simple straight line, a line which levels out at a certain point to discourage vehicle upsizing, etc. Section II of the preamble as well as Chapter 2 of the draft joint TSD contains more information on how EPA defined the piecewise linear CO2 target function.

3.3 Supplemental Analysis of Relative Car and Truck Standards

The methodology used to set the standards, and thus, the relative stringency of the car and truck standards is described in Chapter 2 of the draft Joint TSD. The car and truck standards were set based on achieved levels of car and truck fuel economy from NHTSA's Volpe Model under conditions where estimated net social benefits were maximized, while the application of strong hybrid and diesel technology was excluded. These achieved levels were then adjusted upwards arithmetically until the combined car-truck fleet met the CO2 levels described in Section 3.1 above. EPA and NHTSA worked jointly in that analysis and EPA believes it is a reasonable basis for determining the relative car-truck stringency for the proposed GHG standards.

In this section, a few alternative methods to setting this relative stringency are investigated. These methods use the OMEGA model, though it is expected that the results would be similar if the Volpe Model was used. EPA's OMEGA model and its use in support of this proposed rule is described in Chapter 4 of this draft RIA.

In performing these runs of the OMEGA model, the technology packages were removed which added either hybrid or diesel technology. This was done because the CO2 reduction required to meet the overall level of CO2 emissions being proposed for 2016, 250 g/mi, is generally not requiring significant levels of either hybrid or diesel technology when the potential for A/C credits is considered. This is the same approach that was used in the Volpe modeling used to develop the car and truck standards as described in Chapter 2 of the draft Joint TSD. The technology penetration of the other technologies was limited as described in Chapter 1 for MY 2016; 100% for the technologies included in package 1 for each vehicle type and 85% for the more significant technologies (any technology package number 2 or higher). In order to be comparable to the Volpe modeling, A/C related technologies were not included. Thus, the CO2 emission target was 261 g/mi in 2016. Fuel prices and the value of externalities were the same as those used to project the benefits from the proposal.

As described in greater detail in Chapter 4, the OMEGA model applies technology incrementally. It determines which vehicle receives the next step of control using the manufacturer-based net cost effectiveness metric. This metric includes the cost of the technology, the value of the fuel savings which accrues from the CO2 technology over a specified time period (here, 5 years) and the degree of CO2 emission reduction. This ranking process includes the decision of whether to apply the next level of control to a car or a truck. This allows the evaluation of car and truck CO2 control simultaneously.

In the first set of OMEGA runs used to evaluate relative car-truck stringency, all manufacturers' vehicles were combined into a single fleet. Determining manufacturer-specific CO2 standards or levels of control requires some initial assumption of relative car and truck stringency. Modeling the industry as one, single fleet avoids this. It also makes the analysis more technical in nature and focuses on the technical capability of the industry to reduce car and truck CO2 emissions efficiently, as manufacturer distinctions are eliminated. The disadvantage is that it does not reflect the fact that manufacturers vehicles differ in their fundamental level of CO2 emissions and therefore, manufacturers differ in the projected level of technology needed to meet the same footprint-based standard. With this simplification, a single run of the OMEGA model can provide an indication of the relative potential to control car and truck CO2 emissions.

We ran the OMEGA model with a CO2 emission standard which was beyond the capability of the technology available (i.e., maximum technology). The combined level of car plus truck CO2 emissions was determined, as well as for cars and trucks separately. The overall level of control was relaxed until net societal benefits were maximized. The benefits quantified included reduced externalities related to crude oil imports, upstream emissions, refueling time and CO2 emission reductions. They also included costs and benefits associated with increased VMT due to the fuel economy rebound effect (e.g., vehicle emissions, noise, congestion, value of additional driving, etc.) CO2 was valued at $20 per ton in 2007 and a 3% per annum discount rate was used. Finally, the overall CO2 emissions was increased in several steps from the maximum net benefit level to evaluate how relative car and truck emissions changed with the overall level of stringency. The results of this analysis are summarized in Table 3-9.

Table 3-9 Relative Car and Truck CO2 Emissions At Various Levels of CO2 Control – Single Industry-wide 2016 Fleet (Excludes Impact of A/C Technology)

	Car CO2 (g/mi)	Truck CO2 (g/mi)	Combined CO2 (g/mi)	Ratio of Truck/Car CO2
Maximum Application of Technology	209.4	286.6	235.3	1.37
Maximum Net Societal Benefits	210.1	286.6	235.8	1.36
+5 g/mi CO2	214.8	291.7	240.6	1.36
+10 g/mi CO2	218.6	298.3	245.3	1.36
+15 g/mi CO2	222.0	305.5	250.0	1.38
+20 g/mi CO2	222.2	318.5	254.5	1.43
+25 g/mi CO2	226.0	325.2	259.2	1.44

As can be seen, applying all the non-hybrid and non-diesel technology achieved an overall level of CO2 control of 235 g/mi. This is equivalent to a fuel economy of 37.8 mpg, since the use of diesel engines in only that in the reference fleet. (If A/C-related CO2 emission reduction of 11 g/mi were subtracted from this figure, it would decrease to 224 g/mi, equivalent to 39.6 mpg.) The ratio of car to truck CO2 emissions at this overall level of CO2 emissions is 1.37. Relaxing this level until net societal benefits reach their maximum only increased CO2 emissions by 0.5 g/mi (equivalent to a decrease in fuel economy of 0.1 mpg).

This indicates that net incremental cost of nearly all the non-hybrid, non-diesel technology packages are less than the societal benefits provided. The ratio of car to truck CO2 emissions at this overall level of CO2 emissions decreases slightly to 1.36. The ratio for the proposed truck and car standards in 2016 is 1.35 (302/224), or nearly identical.

As the overall level of CO2 control is relaxed, the ratio of truck to car emissions increases. This indicates that, on the increment, the least cost effective steps of control were applied primarily to trucks and not cars. EPA's and NHTSA's methodology for setting the relative stringency for the car and truck standards in 2012 through 2016 began with the car and truck CO2 levels where estimated social benefits were maximized and increased the CO2 levels of both cars and trucks by the same increment until the combined CO2 level was 261 g/mi. Because the cars emit less than trucks, these shifts upward increase car emissions by a greater percentage than truck emissions. Increasing the overall level of CO2 emissions based on the relative cost effectiveness of technology would increase truck emissions by a greater percentage than car emissions.

References

All references can be found in the EPA DOCKET: **EPA-HQ-OAR-2009-0472.**

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[39] Energy Information Administration. Annual Energy Outlook 2009. http://www.eia.doe.gov/oiaf/aeo/index.html

[40] NHTSA Model Year 2011 Rule. RIN 2127-AK29. Average Fuel Economy Standards. Passenger Cars and Light Trucks. Model Year 2011.

[41] NHTSA Model Year 2011 Rule. RIN 2127-AK29. Average Fuel Economy Standards. Passenger Cars and Light Trucks. Model Year 2011.

[42] NHTSA Model Year 2011 Rule. RIN 2127-AK29. Average Fuel Economy Standards. Passenger Cars and Light Trucks. Model Year 2011.

[43] See generally 71 FR at 17595-96.

[44] National Academy of Sciences, "Effectiveness and Impact of Corporate Average Fuel Economy (CAFE) Standards," National Academy Press, Washington, DC, 2002. Available for online viewing or hard copy purchase from the National Academy Press at http://books.nap.edu/openbook.php?isbn=0309076013.

[45] 71 FR at 17620-21; see also 2002 NAS Report at 24.

[46] 71 FR at 17613.

[47] 71 FR at 17596; 2002 NAS Report at 24.

[48] Light-Duty Automotive Technology and Fuel Economy Trends: 1975 through 2007," U.S. Environmental Protection Agency, EPA420-S-07-001, September 2007, "http://www.epa.gov/otaq/fetrends.htm

[49] Nam, E.K., Giannelli, R, *Fuel Consumption Modeling of Conventional and Advanced Technology Vehicles in the Physical Emission Rate Estimator (PERE)*, EPA document number EPA420-P-05-001, 2004

[50] Guidelines for Analytically Derived Fuel Economy. March 11, 2004 http://www.epa.gov/otaq/cert/dearmfr/ccd0406.pdf

CHAPTER 4: Results of Proposed and Alternative Standards

4.1 Introduction

There are many ways for a manufacturer to reduce CO_2 emissions from any given vehicle during a redesign. A manufacturer can choose from a myriad of CO_2 reducing technologies and can apply one or more of these technologies to some or all of its vehicles. Thus, for a variety of levels of CO_2 emissions control, there are an almost infinite number of technology combinations which produce the desired CO_2 reduction. EPA has created a new vehicle model, the Optimization Model for Emissions of Greenhouse gases from Automobiles (OMEGA) in order to make a reasonable estimate of how manufacturers will add technologies to vehicles in order to meet a fleet-wide CO_2 emissions level.

4.2 Model Inputs

OMEGA utilizes four basic sets of input data. The first is a description of the vehicle fleet. The key pieces of data required for each vehicle are its manufacturer, CO_2 emission level, fuel type, projected sales and footprint. The model also requires that each vehicle be assigned to one of the 19 vehicle types, which tells the model which set of technologies can be applied to that vehicle. Chapter 1 of the 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 also 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 4.2.1 of this Draft Regulatory Impact Analysis (DRIA) contains a detailed discussion of how EPA accounts for technology present in the baseline fleet in OMEGA.

The second type of input data used by the model is a description of the technologies available to manufacturers, primarily their cost and effectiveness. Note that the five vehicle classes which determine the individual technology cost and effectiveness values are not explicitly used by the model; instead, the costs and effectiveness used by the model are associated with each vehicle package, and are based on their associated vehicle types (of 19). This information was described in Chapter 1 of this DRIA 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. Several criteria can be used to develop a reasonable ordering of technologies or packages. These are described in Chapter 1 of the Draft RIA.

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

The fourth type of data describes the CO_2 emission standards being modeled. These include the CO_2 emission equivalents of the 2011 MY CAFE standards and the proposed CO_2 standards for 2016. As described in more detail in Chapter 2 of this DRIA and briefly in section 4.2.1 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 discuss in Section 4.2.1, below.

4.2.1 Representation of the CO2 Control Technology Already Applied to 2008 MY Vehicles

The market data input file utilized by OMEGA, which characterizes the vehicle fleet, is designed to account for the fact that vehicles may be equipped with one or more of the technologies available in general to reduce CO2 emissions. As described in Chapter 1 of this RIA, EPA decided to apply technologies in packages, as opposed to one at a time. However, 2008 vehicles were equipped with a wide range of technology combinations, many of which cut across the packages. Thus, EPA developed a method to account for the presence of the combinations of applied technologies in terms of their proportion of the EPA packages described in Chapter 1. This analysis can be broken down into four steps.

The first step is to develop a list of individual technologies which are either contained in each technology package, or would supplant the relevant portion of each technology package (e.g., the engine, the transmission, etc.). For example, variable intake valve timing would be associated with a downsized, turbocharged, direct injection engine. Thus, the effectiveness and cost of variable intake valve timing would be considered to be already present for any technology package which included either variable intake valve timing or included an engine technology which provided greater effectiveness. The reverse case would be an example of a technology which would supplant another technology. If a vehicle already had a downsized, turbocharged, direct injection engine, the effectiveness and cost of this technology would be considered to be already fully present when evaluating the application of a technology package which included variable intake valve timing or any other engine technology up to and including a downsized, turbocharged, direct injection engine. In either case, the effectiveness and cost present on the 2008 MY vehicle would be limited to the effectiveness and cost of the engine technology This would allow the application of non-engine related technologies also included in that package (e.g., an improved transmission) to still be applied.

A specific example would be a 2008 MY vehicle falling into EPA vehicle type 1 equipped with a dry DCT. A dry DCT is added as part of EPA's technology package number 3 for vehicle type 1. Thus, the effectiveness and cost of a dry DCT would be considered to be already present when applying the effectiveness and cost of package 3 to this vehicle. If the dry DCT contributed to 50% of the total effectiveness and 40% of the cost of package 3 over package 2 and 40% of the cost of package 3 over package 2 for this vehicle, then these percentages would be included in the market data file for this vehicle. If the level of CO2 control led to the application of technology package 3 to this vehicle in a run of the OMEGA model, the model would only apply 50% of the effectiveness of package 3 to this vehicle and 60% of the cost of this package.

If two consecutive technology packages both contain a dry DCT, packages 3 and 4, for example, the model user does not need to declare it as technology already present in the baseline. Instead, the benefit of package 4 is due to engine-related technology is considered incremental to package 3 and is contained in the technology input file. When applying package 4 to this vehicle, the OMEGA model will apply its full incremental effectiveness and cost. The same would be true for packages which replace a dry DCT with a hybrid technology equipped with variable valve timing and a 6-speed automatic transmission. The cost and effectiveness of variable valve timing would be considered to be already present for any technology packages which included the addition of variable valve timing or technologies which went beyond this technology in terms of engine related CO2 control efficiency.

Since vehicle models are grouped into vehicle types for technology addition, and there are relatively few vehicle types compared to the number of vehicle models analyzed, there may be special cases when the applicable technology packages are less effective than baseline technologies; EPA therefore limits the applicability of the relevant technology packages to the affected vehicle models by adjusting the cost and effectiveness reflected in the baseline by the same method described above. An example of a single technology which supplants several technologies would be a 2008 MY vehicle which was equipped with a diesel engine. The effectiveness of this technology would be considered to be present for technology packages which included small improvements to a gasoline engine, since the resultant gasoline engine would otherwise accrue technology packages which are not as effective at reducing CO2 than the baseline diesel engine. However, if these packages which included improvements also included improvements unrelated to the engine, like transmission improvements, only the engine related portion of the package already present on the vehicle would be considered. The transmission related portion of the package's cost and effectiveness would be allowed to be applied in order to comply with future CO2 emission standards.

Six technologies were considered to be contained in all technology packages available for all 19 vehicle types: low viscosity lubrication, improved engine friction, low rolling resistance tires, high efficiency accessories, electric power steering and improved automatic transmission controls and lock-up. The total effectiveness and cost estimates for every technology package described in Chapter 1 includes the effectiveness and cost of these five technologies. Thus, their presence on a 2008 MY vehicle must be deducted from the effectiveness of any package added in the modeling.

All the packages described in Chapter 1 which are numbered 2 or higher (i.e., all packages other than the initial package available to each vehicle type) contain at least dual cam phasing and a 6-speed automatic transmission. Thus, the followed technologies were considered to be contained in all technology packages numbered 2 and above for all 19 vehicle types: intake valve timing, coupled cam phasing, dual cam phasing, 6-speed (or higher) automatic or manual transmission, or a continuously variable transmission. In addition, the following technologies supplant either dual cam phasing or a 6-speed automatic transmission: variable valve lift and timing, cylinder deactivation, diesel combustion, dual clutch transmission, and IMA, power-split and 2-mode hybridization. Thus, the effectiveness and cost of these technologies were also included when determining the percentages of the effectiveness and cost of each package number 2 or higher which was already utilized on each 2008 MY vehicle.

All the packages described in Chapter 1 which are numbered 2 or also include conversion to direct injection gasoline combustion, except for package 2 for vehicle type 1. Thus, the effectiveness and cost of direct injection gasoline combustion was also included when determining the percentages of the effectiveness and cost of each package number 2 or higher which was already utilized on each 2008 MY vehicle, with the exception of package number 2 for vehicle type 1.

Table 4-1 depicts the packages which first turbocharge an engine.

Table 4-1 Technology Packages Which Initially Include Turbocharging

Vehicle Type	Technology Package	Vehicle Type	Technology Package
1	4	12	5
3	4	13	5
4	2	14	5
5	4	15	4
6	4	16	3
7	5	17	5
8	5	18	5
9	4	19	5
10	5		

Thus, the effectiveness and cost of turbocharging was included when determining the percentages of the effectiveness and cost of each package shown in Table 4-1 or higher within each vehicle type which was already utilized on each 2008 MY vehicle.

Table 4-2 depicts the packages which first add start-stop technology to a vehicle.

Table 4-2 Technology Packages Which Initially Add Start-Stop

Vehicle Type	Technology Package	Vehicle Type	Technology Package
1	3	11	4
2	3	12	4
3	3	13	4
4	3	14	4
5	3	15	3
6	3	16	3
7	4	17	4
8	4	18	4
9	4	19	4
10	4		

Thus, the effectiveness and cost of start-stop technology was included when determining the percentages of the effectiveness and cost of each package shown in Table 4-2 or higher within each vehicle type which was already utilized on each 2008 MY vehicle.

The second step in this process is to determine the total cost and CO2 effectiveness of the technologies already present and relevant to each available package. Determining the total cost usually simply involves adding up the costs of the individual technologies present. In order to determine the total effectiveness of the technologies already present on each vehicle, the lumped parameter model described above is used. Because the specific technologies present on each 2008 vehicle are known, the applicable synergies and dis-synergies can be fully accounted for.

The third step in this process is to divide the total cost and CO2 effectiveness values determined in step 2 by the total cost and CO2 effectiveness of the relevant technology packages. These fractions are capped at a value of 1.0 or less, since a value of 1.0 causes the OMEGA model to not change either the cost or CO2 emissions of a vehicle when that technology package is added.

The fourth step is to combine the fractions of the cost and effectiveness of each technology package already present on the individual 2008 vehicles models for each vehicle type. 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 vehicle type. For effectiveness, the individual percentages are combined by weighting them by both sales and base CO2 emission level. This appropriately weights vehicle models with either higher sales or CO2 emissions within a vehicle type. 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 2011 MY CAFE standards and the proposed CO2 standards.

Table 4-3 and Table 4-4 show the degree to which the baseline fleet, adjusted for sales in 2016, includes the effectiveness and cost of the various technology packages by vehicle type.

Table 4-3 Presence of Technology on 2008 MY Vehicles In Terms of CO2 Effectiveness (Weighted Average Across Car and Truck Sales in 2016)

	Technology Package Number					
Vehicle Type	1	2	3	4	5	6
1	6.50%	19.70%	2.30%	0.00%	N/A*	N/A
2	13.20%	28.10%	12.60%	N/A	N/A	N/A
3	11.80%	21.70%	0.50%	24.30%	N/A	N/A
4	2.80%	35.30%	0.00%	0.00%	N/A	N/A
5	11.40%	38.30%	3.70%	1.00%	N/A	N/A
6	2.20%	47.70%	1.60%	4.10%	N/A	N/A
7	8.30%	22.10%	19.40%	0.10%	0.00%	0.00%
8	0.00%	0.00%	0.00%	0.00%	0.00%	N/A
9	0.50%	0.00%	0.00%	0.00%	0.00%	N/A
10	0.50%	4.70%	0.60%	0.00%	0.00%	N/A
11	1.40%	0.00%	0.00%	0.00%	N/A	N/A
12	7.50%	13.00%	2.40%	0.00%	0.00%	N/A
13	22.90%	6.80%	57.40%	0.00%	0.00%	N/A
14	0.00%	33.70%	0.00%	0.00%	0.00%	N/A
15	0.00%	0.00%	0.00%	0.00%	0.00%	N/A
16	5.60%	31.30%	3.30%	0.00%	N/A	N/A
17	4.00%	57.70%	9.40%	0.00%	0.00%	N/A
18	19.40%	15.80%	0.00%	0.00%	0.00%	N/A
19	17.80%	47.40%	0.00%	0.00%	0.00%	N/A

* N/A: No such package for that vehicle type

Table 4-4 Presence of Technology on 2008 MY Vehicles In Terms of Cost (Weighted Average Across Car and Truck Sales in 2016)

	Technology Package Number					
Vehicle Type	1	2	3	4	5	6
1	1.40%	16.50%	1.90%	0.00%	N/A	N/A
2	7.60%	23.20%	16.40%	N/A	N/A	N/A
3	8.10%	15.40%	3.40%	5.70%	N/A	N/A
4	2.00%	31.90%	0.00%	0.00%	N/A	N/A
5	10.90%	22.40%	3.40%	0.20%	N/A	N/A
6	0.70%	33.80%	2.40%	3.00%	N/A	N/A
7	6.20%	19.90%	27.90%	0.20%	0.20%	0.00%
8	0.00%	0.00%	0.00%	0.00%	0.00%	N/A
9	0.10%	0.00%	0.00%	0.00%	0.00%	N/A
10	0.10%	2.60%	0.60%	0.00%	0.00%	N/A
11	0.20%	0.00%	0.00%	0.00%	N/A	N/A
12	1.30%	3.10%	2.40%	0.00%	0.00%	N/A
13	3.30%	2.80%	58.20%	0.10%	0.10%	N/A
14	0.00%	8.70%	0.00%	0.00%	0.00%	N/A
15	0.00%	0.00%	0.00%	0.00%	0.00%	N/A
16	1.80%	22.90%	6.90%	0.00%	N/A	N/A
17	1.40%	46.90%	12.00%	9.50%	0.00%	N/A
18	12.60%	11.10%	0.00%	0.00%	0.00%	N/A
19	2.70%	26.60%	0.00%	0.00%	0.00%	N/A

As mentioned above for the market data input file utilized by OMEGA, which characterizes the vehicle fleet, the modeling must and does account for the fact that many 2008 MY vehicles are already equipped with one or more of the technologies discussed in the Draft TSD Chapter 3. Because EPA chose to apply technologies in packages, and 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 CO2 effectiveness requires careful, detailed analysis. The first step in this analysis is to develop a list of individual technologies which are either contained in each technology package, or would supplant the addition of the relevant portion of each technology package. An example would be a 2008 MY vehicle equipped with variable valve timing and a 6-speed automatic transmission. The cost and effectiveness of variable valve timing would be considered to be already present for any technology packages which included the addition of variable valve timing or technologies which went beyond this technology in terms of engine related CO2 control efficiency.

An example of a technology which supplants several technologies would be a 2008 MY vehicle which was equipped with a diesel engine. The effectiveness of this technology would be considered to be present for technology packages which included improvements to a gasoline engine, since the resultant gasoline engines have a lower CO2 control efficiency than the diesel engine. However, if these packages which included improvements also included improvements unrelated to the engine, like transmission improvements, only the engine related portion of the package already present on the vehicle would be considered. The transmission related portion of the package's cost and effectiveness would be allowed to be applied in order to comply with future CO2 emission standards.

4.2.2 Technology Package Approach

Consistent with its streamlined redesign cycle approach, EPA designed OMEGA to allow the user to add GHG-reducing technologies in packages that would reasonably and likely be added by manufacturers within a redesign cycle. In addition, the user can combine similar vehicle models into "vehicle type" groups which are likely to receive the same list of technology packages. For each vehicle type, the user must rank the technology packages in order of how OMEGA should add them to that specific vehicle type. This approach puts some onus on the user to develop a reasonable sequence of technologies. However, the model also produces information which helps the user determine when a particular technology or bundle of technologies might be "out of order". The approach also simplifies the model's calculations and enables synergistic effects among technology packages to be included to the fullest degree possible.

When technology is sufficiently new, or the lead time available prior to the end of the redesign cycle is such that it is not reasonable to project that the technology could be applied to all vehicle models that are of the same specific vehicle type, the user can limit the technology application through the use of a market penetration cap ("market cap") of less than 100%. This cap can vary by redesign cycle. When a technology package is applied to fewer than 100% of the sales of a vehicle model due to the market cap, the effectiveness of the technology group is simply reduced proportionately to reflect the total net effectiveness of applying that technology package to that vehicle's sales. Most of the technologies for the analysis conducted in this rule had a market cap of 85%, though hybrids were restricted to 15% for reasons described in the preamble. A small number of technologies had a 100% phase in cap. These include: low friction lubricants, electric power steering, improved accessories, and low rolling resistance tires. These simple to apply technologies may be implemented outside of a vehicle's normal redesign schedule.

OMEGA does not create a new vehicle with the technology package and retain the previous vehicle which did not receive the technology package, splitting sales between the old and new vehicles. If subsequent technology packages can be applied to the vehicle, the user must consider whether in reality the new technology would likely be applied to those vehicles which received the previous technology or those which did not, or a combination of the two. The effectiveness of adding the subsequent technology may depend on which vehicles are receiving it.

In OMEGA, the costs and effectiveness of technologies are assumed to be the same for all vehicle models that belong to the sale vehicle type category. There may be cases when a vehicle model in the baseline may already contain some CO2-reducing technology; OMEGA considers this when determining whether a technology can or cannot be applied to it. In the inputs to the model, the user can limit the volume of a specific vehicle model's sales which can receive a technology package by indicating the fraction of its baseline that already contains some effectiveness and cost of each specific technology package. In addition, as described above, the volume of a given vehicle type's sales which can receive a specific technology package can also be limited in an input file with a market penetration "cap", if desired. The effectiveness and application limits of each technology package can vary over time, if desired.

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 the effectiveness of the current technology package and the denominator serves to "back out" any effectiveness that is present in the baseline. CAP refers to the market penetration cap, 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.

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

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 the baseline.

$$IncrementalCost = TechCost * (CAP - CEB)$$

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

EPA's OMEGA model calculates the new CO2 and average vehicle cost after each technology package has been added. To simplify the model's algorithm, EPA has chosen to input the package costs and effectiveness values on a step-wise basis. This is not the same "incremental" approach implemented in the Volpe model because each step in OMEGA has incorporated several technologies. However, for simplification in the core model calculations, the user must enter into the technology input file the technology costs which are incremental to the technology package immediately preceding it. In the case of the first technology package, this is simply the full technology package cost, since it is going on a baseline vehicle and since any technology in the baseline is considered in the equations, as described in the equations above.

4.3 Modeling Process

In order to determine the technology costs associated with this proposed rule, EPA performed two separate modeling exercises. The first was to determine the costs associated with meeting any existing regulation of CO2 or MPG. The latest regulation that has been promulgated is NHTSA's CAFE program for MY 2011, directed under the Energy Independence and Security Act (EISA). EPA considers the MY 2011 CAFE regulations to constitute the "reference case" for calculating the costs and benefits of this GHG proposal. 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 proposed rule alone, EPA seeks to subtract out any costs associated with meeting any existing standards related to GHG emissions. EPA ran OMEGA a second time to calculate the cost of meeting the EPA's proposed standards in 2016, and then subtracted the results of the reference case model run to determine the costs of this proposed GHG program.

Conceptually, OMEGA begins by determining the specific CO2 emission standard applicable for each manufacturer and its vehicle class (i.e., car or truck). Since the proposed rule allows for averaging across a manufacturer's cars and trucks, the model determines the CO2 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 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 would govern credit trading between these two vehicle classes. For both the 2011 CAFE and 2016 CO2 standards, these standards are a function of each manufacturer's sales of cars and truck and their footprint values. When evaluating the 2011 MY CAFE standards, the car-truck trading was limited to 1.2 mpg. When evaluating the proposed CO2 standards, the OMEGA model was run only for MY 2016. OMEGA is designed to evaluate technology addition over a complete redesign cycle and 2016 represents the final year of a redesign cycle starting with the first year of the proposed CO2 standards, 2012. Estimates of the technology and cost for the interim model years are developed from the model projections made for 2016. This process is discussed in Chapter 6 of EPA's DRIA to this proposed rule. When evaluating the 2016 standards using OMEGA, the proposed CO2 standard which manufacturers would otherwise have to meet to account for the anticipated level of A/C credits generated was adjusted. On an industry wide basis, the projection shows that manufacturers would generate 11 g/mi of A/C credit in 2016. Thus, the 2016 CO2 target for the fleet evaluated using OMEGA was 261 g/mi instead of 250 g/mi.

The cost of the improved A/C systems required to generate the 11 g/mi credit was estimated separately. This is consistent with the proposed A/C credit procedures, which would grant manufacturers A/C credits based on their total use of improved A/C systems, and not on the increased use of such systems relative to some base model year fleet. Some manufacturers may already be using improved A/C technology. However, this represents a small fraction of current vehicle sales. To the degree that such systems are already being used, EPA is over-estimating both the cost and benefit of the addition of improved A/C technology relative to the true reference fleet to a small degree.

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

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:

$$ManufCostEff = \frac{TechCost - \sum_{i=1}^{PP}\left[dFS_i \times VMT_i\right] \times \frac{1}{(1-Gap)}}{\sum_{i}^{i+35}\left[\left[dCO2\right] \times VMT_i\right] \times \frac{1}{\left(1-Gap\right)}}$$

Where

ManufCostEff = Manufacturer-Based Cost Effectiveness (in dollars per kilogram CO_2),

TechCost = Marked up cost of the technology (dollars),

PP = 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,

dFS_i = Difference in fuel consumption due to the addition of technology times fuel price in year i,

dCO_2 = Difference in CO_2 emissions due to the addition of technology

VMTi = product of annual VMT for a vehicle of age i and the percentage of vehicles of age i still on the road,

1- Gap = Ratio of onroad fuel economy to two-cycle (FTP/HFET) fuel economy

When calculating the fuel savings, 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 proposal, 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.

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. It is reasonable to estimate that the added technology to improve CO_2 level and fuel economy would retain this same percentage of value when the vehicle is five years old. However, it is less clear whether first purchasers, and thus, manufacturers would consider this residual value when ranking technologies and making vehicle purchases, respectively. For this proposal, this factor was not included in the determination of manufacturer-based net cost-effectiveness in the analyses performed in support of this proposed rule. Comments are requested on the benefit of including an increase in the vehicle's residual value after five years in the calculation of effective cost.

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. EPA requests comment on the use of manufacturer-based net cost-effectiveness to rank CO_2 emission reduction technologies in the context of evaluating alternative fleet average standards for this rule. EPA believes this manufacturer-based net cost-effectiveness metric is appropriate for ranking technology in this proposed program because it considers effectiveness values that may vary widely among technology packages when determining the order of technology addition. Comments are requested on this option and on any others thought to be appropriate.

4.4 Modeling of CAA Compliance Flexibilities

EPA's proposed rule incorporates several compliance flexibilities. Three of these flexibilities, the credit for air conditioning system improvements, car-truck credit trading, and FFV credits, are expected to be used extensively by manufacturers and have been factored into our estimates of the cost of the proposed CO2 standards. OMEGA was designed to be able to address the first two types of flexibilities directly through the appropriate specification of model inputs and scenario definition. However, for several reasons, the expected impact of A/C credits was handled outside of OMEGA. The impact of car-truck credit trading was accomplished in a slightly more complex fashion than will be the case with future versions of the model. OMEGA was not originally designed to include FFV credits in terms of miles per gallon. The methods used to account for these three flexibilities are described below.

OMEGA is capable of including both the impact of air conditioning use on CO2 emissions from the tailpipe (indirect A/C emissions) and refrigerant emissions (direct A/C emissions). The current approach to specifying refrigerant emissions in the Market file and the effectiveness of refrigerant emission control in the Technology file allows for the straightforward accounting of EPA's current approach to estimating both of these factors. As described in Chapter 2 above, EPA currently estimates the same base level of direct A/C emissions from cars and a distinct level of emissions from trucks. These levels can be input directly into Column AD of the Market file. The reduction in direct A/C emissions associated with improved A/C systems can be input into Column U of the Technology file.

Accounting for indirect A/C emissions, consistent with our approach to estimating these emissions in Chapter 2, however, is more difficult. In Chapter 2, we estimate a single level of 14 g/mi CO2 from A/C usage and a potential reduction of 40% for a high efficiency A/C design (maximum A/C credit of 5.7 g/mi CO2). OMEGA currently combines all sources of CO2 tailpipe emissions (i.e., those measured over the 2-cycle compliance test and those from A/C usage). Adding 14 g/mi CO2 from A/C usage to the base emission level of all vehicles could be easily accomplished. However, specifying a consistent 40% reduction of this incremental emission level would not be. The CO2 effectiveness of technologies included in the Technology file applies to all sources of CO2 emissions. Since the base 2-cycle CO2 emission level of vehicles varies, the additional 14 g/mi of indirect A/C emissions would represent a different percentage of total CO2 emissions of each vehicle. A single effectiveness value for the benefit of high efficiency A/C systems would therefore produce a slightly different CO2 emission reduction for each vehicle.

In addition, OMEGA is currently designed to include both indirect and direct A/C emissions in the accounting of emissions towards compliance with the specified standards. This means that the 14 g/mi of indirect A/C emissions and 17-21 g/mi of direct A/C emissions are included in the base level of vehicles' emissions. Their remaining levels after the application of technology are considered when determining whether a manufacturer is in compliance with the specified standards. However, this is not consistent with the design of the proposed A/C credit system. Neither direct nor indirect A/C emissions are included in the compliance determination towards the proposed CO2 emission standards. Compliance is determined based on CO2 emissions measured over the 2-cycle test procedure which does not include these A/C emissions. Then, reductions in A/C emissions are essentially subtracted from the measured 2-cycle CO2 emissions.

With the current OMEGA model design, it was more straightforward to determine the total A/C credit applicable to each manufacturer in 2016 and adjust their proposed CO2 emission standards accordingly. Thus, the effective 2016 proposed car and truck standards were increased by 10.2 g/mi and 11.5 g/mi, respectively. OMEGA was then run to determine the level of non-A/C technology needed to meet the proposed standards after accounting for A/C credits. After modeling, EPA then added a uniform AC cost of $60 per vehicle to each manufacturer's per vehicle technology cost.

With respect to car-truck trading, OMEGA was originally designed to allow the trading of car-truck credits on a vehicle-g/mi CO2 basis. For example, if a manufacturer over-complies with its applicable CO2 standard for cars by 3 g/mi and it sells 1,000,000 cars, it generates 3,000,000 vehicle-g/mi CO2 worth of credits. If these credits are used to compensate for under-compliance towards the truck CO2 standard and truck sales are 500,000, the manufacturer's truck CO2 emission level could be as much as 6 g/mi CO2 above the standard. This is the credit trading approach used in EPA's Tier 2 light-duty vehicle emission control program.

As described in section III.B.4 of the Preamble to this proposed rule, EPA is proposing to trade car and truck credits on a lifetime CO2 emission basis. In the above example, cars are assumed to have a lifetime VMT of 152,000 miles. Therefore, the value of the 3 g/mi over-compliance is multiplied by 1,000,000 vehicles and 190,971 miles and converted to metric tons, or 573,000 metric tons of CO2. If these credits are used to compensate for under-compliance towards the truck CO2 standard and truck sales are again 500,000, the manufacturer's truck CO2 emission level could only be as much as 5.2 g/mi CO2 above the standard, as the lifetime VMT of trucks is 221,199 miles.

In order to simulate trading on a lifetime emission basis, we ran the OMEGA model with a single vehicle fleet (i.e., as if cars and trucks were being regulated identically). We adjusted the base CO2 emissions of trucks (in g/mi) to account for their higher lifetime VMT by multiplying them by 1.158 (the ratio of 221,199 to 190,971). We also adjusted the proposed CO2 emission standard applicable to each manufacturer in 2016 to account for these higher truck emissions. Because each manufacturer has a different car-truck sales split, the degree to which their standards were increased varied. Thus, each manufacturer's standard was specified as a universal or flat standard in the Scenario file (each manufacturer's compliance was evaluated separately). This universal standard was essentially determined by applying the proposed 2016 car standard to each manufacturer's cars and 1.158 times the proposed 2016 truck standard to each manufacturer's trucks. The OMEGA input and output files using the latest version of the model, including the adjusted truck base CO2 levels and adjusted standards can be found under "EPA OMEGA Model" in the docket to this rule.

Under the proposal, FFV credits are only available through model year 2015. Since we use the OMEGA model directly to evaluate technical feasibility and costs only for the 2016 model year, FFV credits are not a factor. (FFV credits use in earlier years is accounted for in projecting the cost of technology for 2012-2015 below.) However, as discussed above, some manufacturers' 2008 baseline fleets (adjusted for projected sales in 2011) do not meet the 2011 CAFE standards which comprise the reference case for this analysis. FFV credits are available under this program and expected be used at the maximum allowable level by Chrysler, Ford and General Motors for both their cars and trucks and by Nissan for their trucks. Under the current CAFE program, FFV credits are limited to 1.2 mpg in 2011. Car-truck trading is also allowed under this program, up to 1.0 mpg in 2011. However, our reference case is a 2016 vehicle fleet complying with the 2011 CAFE standards. In 2016, the limit on FFV credits is reduced to 0.8 mpg and car-truck trading is increased to 1.5 mpg. We use these latter levels here.

Because fuel economy is the inverse of fuel consumption, a specified change in fuel economy (e.g., either the limit on FFV credits or car-truck trading) represents a varying change in fuel consumption (and CO2 emissions) depending on the initial level of fuel economy. For example, for a manufacturer whose truck standard is 22.5 mpg, its trucks could be as low as 21 mpg if the manufacturer generated sufficient credits from its car fleet. These two fuel economy levels represent CO2 emission levels of 395 and 423 g/mi, respectively, assuming all the vehicles are fueled with gasoline, a difference of 28 g/mi CO2. If the manufacturer's truck standard is 24 mpg, its trucks could be as low as 23 mpg if the manufacturer generated sufficient credits from its car fleet. These two fuel economy levels represent CO2 emission levels of 363 and 386 g/mi, respectively, a difference of 23 g/mi CO2. In both cases, the difference in terms of mpg is 1.5.

However, the difference in terms of CO2 emissions decreases as the base fuel economy increases.

As mentioned above, the OMEGA model is not designed to incorporate a credit which is specified in terms of mpg. Since the effect in terms of CO2 emissions changes with the level of fuel economy standard and the footprint-based 2011 CAFE standards impose a different effective fuel economy standard on each manufacturer, these credits cannot be simulated in an OMEGA model run which represents the CO2 standard as a footprint-based standard. Thus, as was the case with the proposed 2016 standards, we determined the effective flat standard applicable to each manufacturer's sales in 2011 after accounting for expected use of FFV credits. The 2011 CAFE standards for cars and trucks were converted to CO2 emissions assuming that all vehicles were fueled with gasoline (i.e., 8887/mpg). Truck emissions were again increased by a factor of 1.158 and the car and truck standards for each manufacturer were sales weighted after again increasing the truck standard by this same factor. An exception was made for those manufacturers which traditionally pay CAFEE fines in lieu of compliance. For these manufacturers, we substituted the achieved fuel economy levels from NHTSA's Volpe Model evaluations of the 2011 CAFEE standards for these manufacturers' CAFEE standards. These manufacturers were BMW, Daimler, Porsche, Tata and Volkswagen. Also, several manufacturers were not run through the model, as their 2008 vehicles already complied with both 2011 car and truck CAFE standards: Honda, Kia, Mazda, and Toyota.

This approach allows unlimited trading of car-truck credits to occur. This is consistent with the proposal for 2016, but not 2011. In order to determine whether the 1.5 mpg car-truck trading limit had been exceeded, EPA converted the final car and truck CO2 emissions levels for each manufacturer to their fuel economy equivalents and compared these values to the applicable 2011 CAFE standards. If the fuel economy of the vehicle class which under-complied with its standard exceeded 1.5 mpg, the shortfall was reduced to 1.5 mpg and the fuel economy of the over-complying class decreased. The OMEGA model was then run for cars and trucks separately to determine the overall cost of these trading limited manufacturers. Only two manufacturers were found to exceed the trading limit in the unlimited trading runs, Daimler and Hyundai. The impact of limiting trading on projected technology costs in 2011 was very small, $8 and $3 per vehicle, respectively. Hyundai's 2008 vehicles complied with the 2011 CAFEE standards with unlimited trading (i.e., zero compliance cost). However, limited trading required Hyundai to apply technology to their trucks. The OMEGA input and output files using the latest version of the model, including the adjusted truck base CO2 levels and adjusted standards can be found under "EPA OMEGA Model" in the docket to this rule.

4.5 Per Vehicle Costs 2012-2016

As described above, the per-vehicle technology costs for this program alone must account for any cost that incurred by compliance with existing vehicle programs. EPA first used OMEGA to calculate costs reflected in the existing CAFE program. OMEGA estimates that, on average, manufacturers will need to spend $78 per vehicle to meet the current MY 2011 CAFE standards.[L] Reference case costs are provided in Table 4-5 below.

Table 4-5 Incremental Technology Cost of the Reference Case

	Cars	Trucks	Combined
BMW	$ 319	$ 479	$ 361
Chrysler	$ 7	$ 125	$ 59
Daimler	$ 431	$ 632	$ 495
Ford	$ 28	$ 211	$ 109
General Motors	$ 28	$ 136	$ 73
Honda	$ 0	0	$ 0
Hyundai	$ 0	$ 76	$ 14
Kia	$ 0	$ 48	$ 8
Mazda	$ 0	$ 0	$ 0
Mitsubishi	$ 96	$ 322	$ 123
Nissan	$ 0	$ 19	$ 6
Porsche	$ 535	$ 1,074	$ 706
Subaru	$ 64	$ 100	$ 77
Suzuki	$ 99	$ 231	$ 133
Tata	$ 691	$ 1,574	$ 1,161
Toyota	$ 0	$ 0	$ 0
Volkswagen	$ 269	$ 758	$ 354
Overall	$ 47	$ 141	$ 78

EPA then used OMEGA to calculate the costs of meeting the proposed 2016 standards, which are displayed in Table 4-6 below, and two alternative scenarios for sensitivity. In Table 4-13 and Table 4-14, EPA presents the per-vehicle cost for these scenarios, respectively. EPA has accounted for the cost to meet the standards in the reference case. In other words, the following tables contain results of the OMEGA control case runs after the reference case values have been subtracted.

[L] It should be noted that the latest version of OMEGA projects slightly different costs than those shown here. This is usually due to an error when the model eliminates over-compliance which occurs with the last step of technology addition. The costs presented here reflect the correction of this error. The latest version of the model also reflects several improvements to the model's algorithms when selecting between car and truck control. These revisions generally only change the projected cost by a dollar or two per vehicle and do not affect the overall conclusions of this analysis.

Table 4-6 Incremental Technology Cost of the Proposed 2016 CO2 Standards

	Cars	Trucks	All
BMW	$1,701	$1,665	$1,691
Chrysler	$1,331	$1,505	$1,408
Daimler	$1,631	$1,357	$1,543
Ford	$1,435	$1,485	$1,457
General Motors	$969	$1,782	$1,311
Honda	$606	$695	$633
Hyundai	$739	$1,680	$907
Kia	$741	$1,177	$812
Mazda	$946	$1,030	$958
Mitsubishi	$1,067	$1,263	$1,090
Nissan	$1,013	$1,194	$1,064
Porsche	$1,549	$666	$1,268
Subaru	$903	$1,329	$1,057
Suzuki	$1,093	$1,263	$1,137
Tata	$1,270	$674	$952
Toyota	$600	$436	$546
Volkswagen	$1,626	$949	$1,509
Overall	$968	$1,214	$1,051

EPA estimates that the additional technology required for manufacturers to meet the GHG standards in this proposed rule will cost on average $1051/vehicle.

The majority of manufacturers representing the vast majority of sales in 2016 are projected to comply with the proposed 2016 standards with the addition of technology under the penetration limits described above. However, several smaller volume manufacturers (at least with respect to U.S. sales) are projected to fall short of compliance. The CO2 standards applicable to each manufacturer based on its distribution of sales and vehicle footprints are shown in Table 4-7 along with the projected achieved level of CO2 emissions from the OMEGA model.

Table 4-7 CO2 Standards and Projected Achieved Levels in 2016

	Car		Truck	
Manufacturer	Standard	Achieved CO2	Standard	Achieved CO2
BMW *	237.1	245.8	295.2	339.7
Chrysler	241.7	220.1	312.2	334.1
Daimler *	244.1	246	305.6	363
Ford	238.5	225.1	326	353.6
General Motors	238.5	221.2	333.9	349.4
Honda	231.6	186.3	292.7	302.8
Hyundai	231.8	196.8	290.4	308
Kia	233.7	191.6	300.7	310.5
Mazda	230.5	205.6	283.4	285.4
Mitsubishi	227.5	212.4	281.7	319.7
Nissan	235.3	212.5	315.7	351.5
Porsche *	214.8	247.8	298.7	398.5
Subaru	224.7	208.3	279.1	270.7
Suzuki	216.8	197.4	283.7	312.1
Tata *	258.6	270.6	287.1	397.4
Toyota	230	188.1	303.2	307.3
Volkswagen *	227.2	240.6	304.8	394.9
Overall	234	208.8	314	334.6

4.6 Technology Penetration

The major technologies chosen by OMEGA are described in the Table 4-8 through Table 4-11 below for the reference case and control case cars and trucks. The values in the table containing the control case technology are for that alone – EPA has subtracted out the impact of the reference case.

Table 4-8 2016 Technology Penetration in the Reference Case-Cars

Cars	VVT	VVTL	GDI	GDI Deac	GDI Turbo	Diesel	6 Spd Auto	Wet DCT	Dry DCT	42 S-S	IMA	Power Split	2-Mode	EPS
BMW	85.9%	11.9%	8.9%	9.0%	0.0%	0.0%	88.5%	9.0%	0.0%	9.0%	0.0%	0.2%	0.0%	0.0%
Chrysler	48.0%	0.0%	0.0%	0.0%	0.0%	0.0%	23.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	2.9%
Daimler	47.0%	0.0%	5.2%	15.2%	0.0%	1.6%	45.1%	31.9%	0.0%	15.2%	0.0%	0.0%	0.0%	0.0%
Ford	12.7%	0.0%	0.0%	0.0%	0.0%	0.0%	36.8%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	3.6%
General Motors	54.9%	0.0%	5.6%	0.0%	0.0%	0.0%	13.2%	0.0%	0.0%	0.2%	0.0%	0.0%	0.1%	0.0%
Honda	0.0%	100.0%	0.0%	0.0%	0.0%	0.0%	5.9%	0.0%	0.0%	0.0%	3.0%	0.0%	0.0%	0.0%
Hyundai	29.9%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Kia	24.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.8%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	2.5%
Mazda	96.0%	3.3%	13.4%	0.0%	0.0%	0.0%	36.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.6%
Mitsubishi	77.8%	0.0%	0.0%	0.0%	0.0%	0.0%	77.4%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	4.9%
Nissan	99.8%	0.0%	5.1%	0.0%	0.0%	0.0%	26.6%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1.9%
Porsche	31.1%	0.0%	0.0%	14.8%	16.3%	0.0%	0.0%	31.1%	0.0%	14.8%	0.0%	0.0%	0.0%	0.0%
Subaru	48.7%	3.3%	0.0%	0.0%	0.0%	0.0%	26.9%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Suzuki	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Tata	64.4%	0.0%	31.1%	33.4%	0.0%	0.0%	31.1%	33.4%	0.0%	33.4%	0.0%	0.0%	0.0%	0.0%
Toyota	99.7%	0.0%	7.1%	0.0%	0.0%	0.0%	35.7%	0.0%	0.0%	0.0%	0.0%	15.8%	0.0%	63.8%
Volkswagen	16.8%	0.7%	41.0%	4.7%	0.0%	0.0%	73.6%	17.9%	0.0%	4.7%	0.0%	0.0%	0.0%	0.0%
Overall	53.0%	15.0%	5.6%	1.0%	0.1%	0.0%	27.8%	2.0%	0.0%	1.0%	0.4%	3.1%	0.0%	13.3%

Table 4-9 2016 Technology Penetration in the Reference Case-Trucks

Trucks	VVT	VVTL	GDI	GDI Deac	GDI Turbo	Diesel	6 Spd Auto	Wet DCT	Dry DCT	42 S-S	IMA	Power Split	2-Mode	EPS
BMW	97.0%	0.0%	3.0%	16.9%	0.0%	0.0%	80.1%	16.9%	0.0%	16.9%	0.0%	0.0%	0.0%	0.0%
Chrysler	4.8%	0.0%	0.1%	0.0%	0.0%	0.1%	34.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	2.9%
Daimler	92.9%	0.0%	40.3%	0.0%	44.7%	16.1%	47.3%	44.7%	0.0%	44.7%	0.0%	0.0%	0.0%	0.0%
Ford	37.7%	0.0%	1.3%	0.0%	0.0%	0.0%	17.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	3.6%
GeneralMotors	24.6%	0.0%	0.0%	0.0%	0.0%	0.0%	14.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%
Honda	0.0%	100.0%	4.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Hyundai	28.6%	0.0%	0.0%	0.0%	0.0%	0.0%	27.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Kia	98.8%	0.0%	0.0%	0.0%	0.0%	0.0%	1.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	2.5%
Mazda	49.9%	0.0%	2.5%	0.0%	0.0%	0.0%	43.5%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.6%
Mitsubishi	100.0%	0.0%	0.0%	18.4%	0.0%	0.0%	64.9%	18.4%	0.0%	18.4%	0.0%	0.0%	0.0%	4.9%
Nissan	100.0%	49.5%	49.5%	0.0%	0.0%	0.0%	50.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1.9%
Porsche	91.6%	0.0%	0.0%	47.0%	38.0%	0.0%	0.0%	85.0%	0.0%	85.0%	0.0%	0.0%	0.0%	0.0%
Subaru	32.6%	0.0%	0.0%	0.0%	0.0%	0.0%	32.6%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Suzuki	100.0%	0.0%	17.8%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Tata	85.0%	0.0%	0.0%	85.0%	0.0%	0.0%	0.0%	85.0%	0.0%	85.0%	0.0%	0.0%	0.0%	0.0%
Toyota	85.5%	0.0%	8.1%	0.0%	0.0%	0.0%	20.0%	0.0%	0.0%	0.0%	0.0%	6.6%	0.0%	63.8%
Volkswagen	99.3%	0.0%	100.0%	17.3%	67.7%	0.7%	0.0%	85.0%	0.0%	85.0%	0.0%	0.0%	0.0%	0.0%
Overall	48.6%	16.0%	9.0%	1.6%	2.2%	0.3%	20.5%	3.8%	0.0%	3.8%	0.0%	1.3%	0.0%	13.3%

Table 4-10 2016 Technology Penetration in the Control Case-Cars

Cars	VVT	VVTL	GDI	GDI Deac	GDI Turbo	Diesel	6 Spd Auto	Wet DCT	Dry DCT	42 S-S	IMA	Power Split	2-Mode	EPS
BMW	97.8%	2.0%	4.9%	37.2%	44.1%	0.0%	14.8%	65.5%	5.7%	71.0%	0.0%	3.9%	10.3%	100.0%
Chrysler	46.2%	44.3%	59.0%	19.1%	0.8%	0.0%	24.2%	18.0%	44.3%	62.2%	0.0%	0.0%	0.0%	100.0%
Daimler	89.2%	0.0%	3.4%	42.0%	39.9%	1.6%	9.4%	60.8%	14.2%	72.5%	0.0%	3.2%	9.3%	100.0%
Ford	51.9%	27.0%	27.0%	37.7%	12.2%	0.0%	11.1%	46.0%	27.0%	73.0%	0.0%	0.0%	0.0%	100.0%
General Motors	43.5%	37.2%	40.6%	11.0%	2.9%	0.0%	5.0%	13.4%	37.2%	50.6%	0.0%	0.0%	0.1%	100.0%
Honda	0.0%	100.0%	24.0%	0.0%	0.0%	0.0%	5.8%	0.0%	24.0%	24.0%	3.0%	0.0%	0.0%	100.0%
Hyundai	16.9%	31.3%	34.1%	1.8%	0.8%	0.0%	2.8%	2.6%	31.3%	33.9%	0.0%	0.0%	0.0%	100.0%
Kia	4.5%	35.6%	35.6%	0.0%	0.0%	0.0%	0.0%	0.0%	35.6%	35.6%	0.0%	0.0%	0.0%	100.0%
Mazda	64.3%	28.4%	61.3%	1.5%	11.6%	0.0%	34.5%	13.1%	28.2%	41.3%	0.0%	0.0%	0.0%	100.0%
Mitsubishi	21.8%	65.5%	74.1%	0.0%	0.0%	0.0%	22.6%	0.0%	65.5%	65.5%	0.0%	0.0%	0.0%	100.0%
Nissan	63.8%	36.2%	36.2%	22.6%	3.2%	0.0%	33.3%	25.8%	36.2%	60.5%	0.0%	1.0%	0.0%	100.0%
Porsche	100.0%	0.0%	2.6%	27.2%	57.8%	0.0%	7.8%	70.0%	0.0%	70.0%	0.0%	0.0%	15.0%	100.0%
Subaru	14.6%	42.5%	42.4%	3.5%	6.6%	0.0%	0.4%	10.1%	42.4%	52.6%	0.0%	0.0%	0.0%	100.0%
Suzuki	0.0%	76.2%	76.2%	0.0%	0.0%	0.0%	0.0%	0.0%	76.2%	76.2%	0.0%	0.0%	0.0%	100.0%
Tata	100.0%	0.0%	3.6%	81.4%	0.0%	0.0%	13.7%	70.0%	0.0%	70.0%	0.0%	3.6%	11.4%	100.0%
Toyota	64.9%	34.8%	41.6%	2.3%	0.0%	0.0%	31.2%	26.5%	21.1%	23.4%	0.0%	15.8%	0.0%	100.0%
Volkswagen	87.4%	0.1%	7.7%	25.2%	58.4%	0.0%	11.9%	72.0%	0.0%	70.0%	0.0%	1.4%	13.5%	100.0%
Overall	47.0%	40.3%	33.2%	13.8%	8.0%	0.0%	15.6%	24.3%	27.1%	46.4%	0.4%	3.4%	1.2%	100.0%

Table 4-11 2016 Technology Penetration in the Control Case-Trucks

Trucks	VVT	VVTL	GDI	GDI Deac	GDI Turbo	Diesel	6 Spd Auto	Wet DCT	Dry DCT	42 S-S	IMA	Power Split	2-Mode	EPS
BMW	99.5%	0.0%	0.5%	29.0%	56.0%	0.0%	15.0%	70.0%	0.0%	70.0%	0.0%	0.0%	15.0%	100.0%
Chrysler	81.6%	4.1%	41.1%	39.3%	4.6%	0.1%	52.5%	33.5%	4.1%	37.6%	0.0%	0.0%	0.0%	100.0%
Daimler	92.9%	0.0%	2.4%	47.8%	37.2%	16.1%	15.0%	70.1%	0.0%	70.1%	0.0%	0.0%	14.9%	100.0%
Ford	84.5%	6.1%	32.3%	39.6%	13.2%	0.0%	28.6%	53.2%	5.7%	58.6%	0.0%	0.0%	0.0%	100.0%
General Motors	83.1%	3.5%	24.3%	45.6%	13.0%	0.0%	23.0%	58.6%	3.5%	62.1%	0.0%	0.0%	0.1%	100.0%
Honda	30.7%	69.3%	24.4%	3.5%	7.9%	0.0%	19.3%	11.5%	4.5%	16.0%	0.0%	0.0%	0.0%	100.0%
Hyundai	89.3%	0.0%	0.0%	8.5%	76.5%	0.0%	4.0%	85.0%	0.0%	85.0%	0.0%	0.0%	0.0%	100.0%
Kia	77.3%	0.0%	42.7%	0.0%	33.0%	0.0%	42.7%	33.0%	0.0%	33.0%	0.0%	0.0%	0.0%	100.0%
Mazda	92.9%	7.0%	9.9%	5.8%	40.8%	0.0%	7.2%	46.6%	7.0%	53.6%	0.0%	0.0%	0.0%	100.0%
Mitsubishi	90.3%	0.0%	0.0%	18.4%	55.2%	0.0%	16.7%	73.6%	0.0%	73.6%	0.0%	0.0%	0.0%	100.0%
Nissan	98.6%	1.4%	11.8%	36.0%	8.4%	0.0%	34.1%	44.4%	1.4%	45.9%	0.0%	0.0%	0.0%	100.0%
Porsche	85.0%	15.0%	15.0%	53.7%	31.3%	0.0%	15.0%	70.0%	0.0%	70.0%	0.0%	0.0%	15.0%	100.0%
Subaru	34.4%	57.0%	51.5%	5.8%	27.7%	0.0%	0.0%	69.3%	15.7%	49.2%	0.0%	0.0%	0.0%	100.0%
Suzuki	85.0%	0.0%	35.7%	17.8%	31.6%	0.0%	35.7%	49.3%	0.0%	49.3%	0.0%	0.0%	0.0%	100.0%
Tata	100.0%	0.0%	4.1%	80.9%	0.0%	0.0%	15.0%	70.0%	0.0%	70.0%	0.0%	4.1%	10.9%	100.0%
Toyota	93.6%	0.0%	27.4%	2.1%	0.0%	0.0%	28.2%	2.1%	0.0%	2.1%	0.0%	6.6%	0.0%	100.0%
Volkswagen	87.9%	11.9%	15.0%	29.2%	55.8%	0.7%	15.0%	70.0%	0.0%	70.0%	0.0%	0.0%	15.0%	100.0%
Overall	80.7%	11.8%	24.5%	27.3%	14.0%	0.3%	25.0%	40.6%	3.1%	43.1%	0.0%	1.3%	1.1%	100.0%

As can be seen, the overall reduction in vehicle weight is projected to be 4%. This reduction varies across the two vehicle classes and vehicle base weight. For cars below 2950 pounds curb weight, the reduction is 2.3% (62 pounds), while it was 4.4% (154 pounds) for cars above 2950 curb weight. For trucks below 3850 pounds curb weight, the reduction is 3.5% (119 pounds), while it was 4.5% (215 pounds) for trucks above 3850 curb weight. Splitting trucks at a higher weight, for trucks below 5000 pounds curb weight, the reduction is 3.3% (140 pounds), while it was 6.7% (352 pounds) for trucks above 5000 curb weight. These results are tabulated below in Table 4-12.

Table 4-12 Breakdown of Weight Reduction in Modeling Results

	Weight Category	% Weight Reduction	Average Weight Reduction
Cars	< 2950 lbs	2.3%	62 lbs
	> 2950 lbs	4.4%	154 lbs
Trucks with 3850 lb break point	< 3850 lbs	3.5%	119 lbs
	> 3850 lbs	4.5%	215 lbs
Trucks with 5000 lb break point	< 5000 lbs	3.3%	140 lbs
	> 5000 lbs	6.7%	352 lbs

4.7 Manufacturer-Specific Standards

As described in Section 3.2, in any attribute-based regulatory structure, manufacturers are bound to have different overall GHG targets, since they are based on the size and sales mix of each manufacturer. The fleet-wide averages calculated for the proposed 2016 model year are presented in Table 4-13.

Table 4-13 2016 Projected Standards by Manufacturer

	Standards		
	Cars	Trucks	Combined
BMW	226.9	283.7	241.8
Chrysler	231.5	300.7	262.1
Daimler	233.9	294.1	253.2
Ford	228.3	314.5	266.5
General Motors	228.3	322.4	267.9
Honda	221.4	281.2	239.2
Hyundai	221.6	278.9	231.8
Kia	223.5	289.2	234.2
Mazda	220.3	271.9	227.7
Mitsubishi	217.3	270.2	223.5
Nissan	225.1	304.2	247.5
Porsche	204.6	287.2	230.8
Subaru	214.5	267.6	233.7
Suzuki	206.6	272.2	223.4
Tata	248.4	275.6	262.8
Toyota	219.8	291.7	243.5
Volkswagen	217.0	293.3	230.3
Overall	223.8	302.5	250.2

These car and truck standards average out to an overall industry CO2 stringency of 250 g/mi, consistent with President Obama's announcement on May 19, 2009.

4.8 Alternative Program Stringencies

EPA analyzed the technology cost of two alternative stringency scenarios: 4%/year and 6%/year. With the reference case the same as that described above in Section 4.1, the costs of the two alternative control cases along with the technology penetrations and the manufacturer-specific standards are presented in Table 4-14 through Table 4-19, below. The manufacturers's CO2 targets for these alternative standards are presented in Table 4-20 and Table 4-21.

Table 4-14 2016 Technology Cost in the 4% sensitivity case

	Cars	Trucks	All
BMW	$ 1,701	$ 1,665	$ 1,691
Chrysler	$ 1,167	$ 1,505	$ 1,316
Daimler	$ 1,631	$ 1,357	$ 1,543
Ford	$ 1,339	$ 1,417	$ 1,373
General Motors	$ 850	$ 1,769	$ 1,237
Honda	$ 606	$ 460	$ 563
Hyundai	$ 685	$ 1,505	$ 832
Kia	$ 741	$ 738	$ 741
Mazda	$ 819	$ 1,030	$ 849
Mitsubishi	$ 1,004	$ 1,263	$ 1,034
Nissan	$ 910	$ 1,194	$ 991
Porsche	$ 1,549	$ 666	$ 1,268
Subaru	$ 903	$ 1,131	$ 985
Suzuki	$ 1,093	$ 1,026	$ 1,076
Tata	$ 1,270	$ 674	$ 952
Toyota	$ 479	$ 436	$ 465
Volkswagen	$ 1,626	$ 949	$ 1,509
Overall	$ 893	$ 1,154	$ 980

Table 4-15 2016 Technology Cost in the 6% sensitivity case

	Cars	Trucks	All
BMW	$ 1,701	$ 1,665	$ 1,691
Chrysler	$ 1,642	$ 2,211	$ 1,893
Daimler	$ 1,631	$ 1,357	$ 1,543
Ford	$ 2,175	$ 2,396	$ 2,273
General Motors	$ 1,718	$ 2,158	$ 1,903
Honda	$ 777	$ 1,580	$ 1,016
Hyundai	$ 1,275	$ 1,680	$ 1,347
Kia	$ 1,104	$ 1,772	$ 1,213
Mazda	$ 1,321	$ 1,293	$ 1,317
Mitsubishi	$ 1,495	$ 2,065	$ 1,563
Nissan	$ 1,654	$ 2,274	$ 1,830
Porsche	$ 1,549	$ 666	$ 1,268
Subaru	$ 1,440	$ 1,615	$ 1,503
Suzuki	$ 1,718	$ 2,219	$ 1,846
Tata	$ 1,270	$ 674	$ 952
Toyota	$ 755	$ 1,182	$ 895
Volkswagen	$ 1,626	$ 949	$ 1,509
Overall	$ 1,381	$ 1,866	$ 1,544

Table 4-16 2016 Technology Penetration in the 4% sensitivity case- Cars

Cars	VVT	VVTL	GDI	GDI Deac	GDI Turbo	Diesel	6 Spd Auto	Wet DCT	Dry DCT	42 S-S	IMA	Power Split	2-Mode	EPS
BMW	97.8%	2.0%	4.9%	37.2%	44.1%	0.0%	14.8%	65.5%	5.7%	71.0%	0.0%	3.9%	10.3%	100.0%
Chrysler	33.3%	44.3%	51.7%	13.6%	0.8%	0.0%	16.9%	12.4%	44.3%	56.7%	0.0%	0.0%	0.0%	100.0%
Daimler	89.2%	0.0%	3.4%	42.0%	39.9%	1.6%	9.4%	60.8%	14.2%	72.5%	0.0%	3.2%	9.3%	100.0%
Ford	50.0%	27.0%	36.1%	26.8%	12.2%	0.0%	16.2%	39.0%	27.0%	66.1%	0.0%	0.0%	0.0%	100.0%
General Motors	56.1%	23.8%	40.3%	10.6%	2.9%	0.0%	17.6%	13.4%	23.8%	37.3%	0.0%	0.0%	0.1%	100.0%
Honda	0.0%	100.0%	24.0%	0.0%	0.0%	0.0%	5.8%	0.0%	24.0%	24.0%	3.0%	0.0%	0.0%	100.0%
Hyundai	17.4%	31.3%	31.3%	0.0%	0.8%	0.0%	0.0%	0.8%	31.3%	32.1%	0.0%	0.0%	0.0%	100.0%
Kia	4.5%	35.6%	35.6%	0.0%	0.0%	0.0%	0.0%	0.0%	35.6%	35.6%	0.0%	0.0%	0.0%	100.0%
Mazda	40.7%	28.4%	37.7%	1.5%	11.6%	0.0%	10.9%	13.1%	28.2%	41.3%	0.0%	0.0%	0.0%	100.0%
Mitsubishi	29.2%	58.2%	74.1%	0.0%	0.0%	0.0%	29.9%	0.0%	58.2%	58.2%	0.0%	0.0%	0.0%	100.0%
Nissan	63.8%	36.2%	42.3%	16.6%	0.0%	0.0%	41.9%	16.6%	36.2%	52.8%	0.0%	1.0%	0.0%	100.0%
Porsche	100.0%	0.0%	2.6%	27.2%	57.8%	0.0%	7.8%	70.0%	0.0%	70.0%	0.0%	0.0%	15.0%	100.0%
Subaru	14.6%	42.5%	42.4%	3.5%	6.6%	0.0%	0.4%	10.1%	42.4%	52.6%	0.0%	0.0%	0.0%	100.0%
Suzuki	0.0%	76.2%	76.2%	0.0%	0.0%	0.0%	0.0%	0.0%	76.2%	76.2%	0.0%	0.0%	0.0%	100.0%
Tata	100.0%	0.0%	3.6%	81.4%	0.0%	0.0%	13.7%	70.0%	0.0%	70.0%	0.0%	3.6%	11.4%	100.0%
Toyota	82.0%	17.7%	24.5%	2.3%	0.0%	0.0%	31.2%	43.6%	4.0%	6.3%	0.0%	15.8%	0.0%	100.0%
Volkswagen	87.4%	0.1%	7.7%	25.2%	58.4%	0.0%	11.9%	72.0%	0.0%	70.0%	0.0%	1.4%	13.5%	100.0%
Overall	51.3%	34.8%	30.7%	11.4%	7.7%	0.0%	18.3%	25.6%	21.6%	39.0%	0.4%	3.4%	1.2%	100.0%

Table 4-17 2016 Technology Penetration in the 4% sensitivity case- Trucks

Trucks	VVT	VVTL	GDI	GDI Deac	GDI Turbo	Diesel	6 Spd Auto	Wet DCT	Dry DCT	42 S-S	IMA	Power Split	2-Mode	EPS
BMW	99.5%	0.0%	0.5%	29.0%	56.0%	0.0%	15.0%	70.0%	0.0%	70.0%	0.0%	0.0%	15.0%	100.0%
Chrysler	81.6%	4.1%	41.1%	39.3%	4.6%	0.1%	52.5%	33.5%	4.1%	37.6%	0.0%	0.0%	0.0%	100.0%
Daimler	92.9%	0.0%	2.4%	47.8%	37.2%	16.1%	15.0%	70.1%	0.0%	70.1%	0.0%	0.0%	14.9%	100.0%
Ford	84.5%	2.8%	29.9%	38.7%	13.2%	0.0%	31.1%	51.9%	2.8%	54.7%	0.0%	0.0%	0.0%	100.0%
General Motors	82.0%	3.5%	23.1%	45.6%	13.0%	0.0%	21.8%	58.6%	3.5%	62.1%	0.0%	0.0%	0.1%	100.0%
Honda	10.3%	69.3%	11.9%	3.5%	0.0%	0.0%	6.8%	3.5%	4.5%	8.1%	0.0%	0.0%	0.0%	100.0%
Hyundai	84.0%	0.0%	7.8%	8.5%	63.5%	0.0%	11.8%	71.9%	0.0%	71.9%	0.0%	0.0%	0.0%	100.0%
Kia	34.6%	0.0%	7.7%	0.0%	25.3%	0.0%	7.7%	25.3%	0.0%	25.3%	0.0%	0.0%	0.0%	100.0%
Mazda	92.9%	7.0%	9.9%	5.8%	40.8%	0.0%	7.2%	46.6%	7.0%	53.6%	0.0%	0.0%	0.0%	100.0%
Mitsubishi	90.3%	0.0%	0.0%	18.4%	55.2%	0.0%	16.7%	73.6%	0.0%	73.6%	0.0%	0.0%	0.0%	100.0%
Nissan	98.6%	1.4%	11.8%	36.0%	8.4%	0.0%	34.1%	44.4%	1.4%	45.9%	0.0%	0.0%	0.0%	100.0%
Porsche	85.0%	15.0%	15.0%	53.7%	31.3%	0.0%	15.0%	70.0%	0.0%	70.0%	0.0%	0.0%	15.0%	100.0%
Subaru	61.5%	29.9%	51.5%	5.8%	27.7%	0.0%	27.1%	57.9%	0.0%	33.5%	0.0%	0.0%	0.0%	100.0%
Suzuki	85.0%	0.0%	59.5%	17.8%	7.7%	0.0%	59.5%	25.5%	0.0%	25.5%	0.0%	0.0%	0.0%	100.0%
Tata	100.0%	0.0%	4.1%	80.9%	0.0%	0.0%	15.0%	70.0%	0.0%	70.0%	0.0%	4.1%	10.9%	100.0%
Toyota	93.6%	0.0%	27.4%	2.1%	0.0%	0.0%	28.2%	2.1%	0.0%	2.1%	0.0%	6.6%	0.0%	100.0%
Volkswagen	87.9%	11.9%	15.0%	29.2%	55.8%	0.7%	15.0%	70.0%	0.0%	70.0%	0.0%	0.0%	15.0%	100.0%
Overall	77.6%	10.7%	22.1%	27.1%	12.6%	0.3%	24.0%	38.7%	2.2%	40.6%	0.0%	1.3%	1.1%	100.0%

Table 4-18 2016 Technology Penetration in the 6% Sensitivity Case-Cars

Cars	VVT	VVTL	GDI	GDI Deac	GDI Turbo	Diesel	6 Spd Auto	Wet DCT	Dry DCT	42 S-S	IMA	Power Split	2-Mode	EPS	We Redu
BMW	97.8%	2.0%	4.9%	37.2%	44.1%	0.0%	14.8%	65.5%	5.7%	71.0%	0.0%	3.9%	10.3%	100.0%	
Chrysler	43.7%	48.5%	48.5%	33.6%	2.9%	0.0%	3.7%	36.2%	48.5%	84.7%	0.0%	0.0%	0.0%	100.0%	
Daimler	89.2%	0.0%	3.4%	42.0%	39.9%	1.6%	9.4%	60.8%	14.2%	72.5%	0.0%	3.2%	9.3%	100.0%	
Ford	79.3%	7.6%	13.3%	35.8%	35.8%	0.0%	5.5%	41.1%	32.0%	73.1%	1.6%	5.5%	4.8%	100.0%	
General Motors	53.8%	39.4%	40.2%	42.7%	2.9%	0.0%	8.1%	39.5%	39.4%	78.9%	0.0%	0.0%	0.1%	100.0%	
Honda	5.7%	86.5%	41.1%	0.0%	0.0%	0.0%	11.0%	0.0%	35.4%	35.4%	3.0%	0.0%	0.0%	100.0%	
Hyundai	39.8%	35.2%	43.4%	9.3%	17.8%	0.0%	8.2%	27.1%	35.2%	62.3%	0.0%	0.0%	0.0%	100.0%	
Kia	35.2%	35.6%	56.8%	0.0%	13.2%	0.0%	21.3%	13.2%	35.6%	48.7%	0.0%	0.0%	0.0%	100.0%	
Mazda	32.5%	67.3%	68.5%	1.5%	11.6%	0.0%	2.7%	13.1%	67.2%	80.3%	0.0%	0.0%	0.0%	100.0%	
Mitsubishi	28.1%	64.2%	66.8%	4.3%	13.9%	0.0%	6.9%	7.1%	74.1%	81.2%	1.9%	1.2%	0.8%	100.0%	
Nissan	61.8%	38.2%	46.5%	19.3%	19.2%	0.0%	10.8%	21.7%	53.6%	75.3%	4.3%	5.7%	0.7%	100.0%	
Porsche	100.0%	0.0%	2.6%	27.2%	57.8%	0.0%	7.8%	70.0%	0.0%	70.0%	0.0%	0.0%	15.0%	100.0%	
Subaru	14.6%	75.0%	74.9%	3.5%	6.6%	0.0%	0.4%	17.6%	67.4%	77.6%	0.0%	0.0%	0.0%	100.0%	
Suzuki	85.0%	0.0%	1.5%	7.2%	76.2%	0.0%	0.0%	7.2%	76.2%	83.5%	0.0%	1.5%	0.0%	100.0%	
Tata	100.0%	0.0%	3.6%	81.4%	0.0%	0.0%	13.7%	70.0%	0.0%	70.0%	0.0%	3.6%	11.4%	100.0%	
Toyota	54.4%	45.3%	52.2%	2.3%	0.0%	0.0%	31.2%	2.3%	45.3%	47.6%	0.0%	15.8%	0.0%	100.0%	
Volkswagen	87.4%	0.1%	7.7%	25.2%	58.4%	0.0%	11.9%	72.0%	0.0%	70.0%	0.0%	1.4%	13.5%	100.0%	
Overall	52.8%	39.7%	37.9%	19.1%	14.8%	0.0%	13.4%	24.9%	38.1%	62.8%	1.1%	4.7%	2.0%	100.0%	

Table 4-19 2016 Technology Penetration in the 6% Sensitivity Case-Trucks

Trucks	VVT	VVTL	GDI	GDI Deac	GDI Turbo	Diesel	6 Spd Auto	Wet DCT	Dry DCT	42 S-S	IMA	Power Split	2-Mode	EPS	We Redu
BMW	99.5%	0.0%	0.5%	29.0%	56.0%	0.0%	15.0%	70.0%	0.0%	70.0%	0.0%	0.0%	15.0%	100.0%	
Chrysler	81.6%	4.1%	4.1%	70.1%	10.8%	0.1%	5.1%	80.9%	4.1%	85.0%	0.0%	0.0%	0.0%	100.0%	
Daimler	92.9%	0.0%	2.4%	47.8%	37.2%	16.1%	15.0%	70.1%	0.0%	70.1%	0.0%	0.0%	14.9%	100.0%	
Ford	90.7%	0.0%	2.2%	38.0%	45.0%	0.0%	2.6%	71.0%	5.0%	76.1%	0.0%	3.1%	5.8%	100.0%	
General Motors	87.0%	1.7%	1.7%	68.5%	14.8%	0.0%	2.1%	81.5%	3.5%	85.0%	0.0%	0.0%	0.1%	100.0%	
Honda	54.0%	46.0%	31.6%	3.5%	50.4%	0.0%	0.0%	54.0%	31.0%	85.0%	0.0%	0.0%	0.0%	100.0%	
Hyundai	89.3%	0.0%	0.0%	8.5%	76.5%	0.0%	4.0%	85.0%	0.0%	85.0%	0.0%	0.0%	0.0%	100.0%	
Kia	85.4%	1.1%	1.1%	0.0%	83.9%	0.0%	0.0%	83.9%	1.1%	85.0%	0.0%	0.0%	0.0%	100.0%	
Mazda	63.4%	36.5%	41.3%	5.8%	40.8%	0.0%	9.0%	76.2%	7.0%	53.6%	0.0%	0.0%	0.0%	100.0%	
Mitsubishi	90.3%	0.0%	3.2%	24.9%	56.9%	0.0%	5.3%	60.6%	9.4%	70.0%	0.0%	5.3%	9.7%	100.0%	
Nissan	100.0%	0.0%	0.8%	9.8%	74.4%	0.0%	3.7%	59.2%	17.7%	76.9%	0.0%	4.6%	3.6%	100.0%	
Porsche	85.0%	15.0%	15.0%	53.7%	31.3%	0.0%	15.0%	70.0%	0.0%	70.0%	0.0%	0.0%	15.0%	100.0%	
Subaru	34.4%	57.0%	51.5%	5.8%	27.7%	0.0%	0.0%	33.5%	51.5%	85.0%	0.0%	0.0%	0.0%	100.0%	
Suzuki	85.0%	0.0%	3.1%	26.5%	55.4%	0.0%	0.0%	70.0%	0.0%	70.0%	0.0%	3.1%	11.9%	100.0%	
Tata	100.0%	0.0%	4.1%	80.9%	0.0%	0.0%	15.0%	70.0%	0.0%	70.0%	0.0%	4.1%	10.9%	100.0%	
Toyota	82.0%	3.2%	15.0%	17.6%	34.2%	0.0%	13.6%	51.8%	3.2%	55.0%	0.0%	6.6%	0.0%	100.0%	
Volkswagen	87.9%	11.9%	15.0%	29.2%	55.8%	0.7%	15.0%	70.0%	0.0%	70.0%	0.0%	0.0%	15.0%	100.0%	
Overall	83.4%	8.1%	9.2%	33.8%	39.0%	0.3%	5.3%	67.0%	8.5%	75.2%	0.0%	2.3%	2.7%	100.0%	

Table 4-20 2016 Standards by Manufacturer in the 4% Sensitivity Case

	Standards		
	Cars	Trucks	Combined
BMW	230.3	288.3	245.5
Chrysler	235.0	305.3	266.0
Daimler	237.4	298.7	257.0
Ford	231.7	319.0	270.4
General Motors	231.8	327.0	271.8
Honda	224.8	285.8	242.9
Hyundai	225.0	283.5	235.4
Kia	226.9	293.8	237.8
Mazda	223.7	276.5	231.3
Mitsubishi	220.7	274.7	227.1
Nissan	228.5	308.7	251.3
Porsche	208.0	291.8	234.6
Subaru	217.9	272.2	237.5
Suzuki	210.0	276.8	227.1
Tata	251.8	280.1	266.9
Toyota	223.2	296.3	247.3
Volkswagen	220.5	297.8	233.9
Overall	227.2	307.1	254.0

Table 4-21 2016 Standards by Manufacturer in the 6% Sensitivity Case

	Standards		
	Cars	Trucks	Combined
BMW	208.7	259.4	222.0
Chrysler	213.4	276.4	241.2
Daimler	215.8	269.8	233.1
Ford	210.2	290.1	245.6
General Motors	210.2	298.1	247.2
Honda	203.2	256.9	219.2
Hyundai	203.4	254.6	212.6
Kia	205.4	264.9	215.1
Mazda	202.1	247.6	208.7
Mitsubishi	199.1	245.8	204.7
Nissan	207.0	279.8	227.6
Porsche	186.4	262.9	210.7
Subaru	196.3	243.3	213.3
Suzuki	188.5	247.9	203.6
Tata	230.2	251.2	241.4
Toyota	201.7	267.4	223.3
Volkswagen	198.9	268.9	211.1
Overall	205.7	278.2	230.0

4.9 Assessment of Manufacturer Differences

The levels of requisite technologies shown above differ significantly across the various manufacturers. This is to be expected for universal, or flat fuel economy or CO2 standards, since manufacturers' sales mixes differ dramatically in average size. However, use of footprint-based standards should eliminate the effect of vehicle size, and thus, market mix, on the relative stringency of a standard across manufacturers. Yet, large differences remain in the level of technology projected to be required for various manufacturers to meet the proposed standards. Therefore, several analyses were performed to ascertain the cause of these differences. Because the baseline case fleet consists of 2008 MY vehicle designs, these analyses were focused on these vehicles, their technology and their CO_2 emission levels.

Manufacturers' average CO_2 emissions vary for a wide range of reasons. In addition to widely varying vehicle styles, designs, and sizes, manufacturers have implemented fuel efficient technologies to varying degrees, as indicated in Table 4-22 below.

Table 4-22 Penetration of Technology in 2008 Vehicles with 2016 Sales: Cars and Trucks

	GDI	GDI+ Deac	GDI+ Turbo	Diesel	6 Speed or CV Trans	Dual Clutch Trans	Start-Stop	Hybrid
BMW	6.70%	0.00%	0.00%	0.00%	98.80%	0.80%	0.00%	0.10%
Chrysler	0.00%	0.00%	0.00%	0.00%	27.90%	0.00%	0.00%	0.00%
Daimler	6.20%	0.00%	0.00%	6.20%	74.70%	11.40%	0.00%	0.00%
Ford	0.60%	0.00%	0.00%	0.00%	28.10%	0.00%	0.00%	0.00%
General Motors	3.30%	0.00%	0.00%	0.00%	13.70%	0.00%	0.10%	0.10%
Honda	1.20%	0.00%	0.00%	0.00%	4.20%	0.00%	0.00%	2.10%
Hyundai	0.00%	0.00%	0.00%	0.00%	4.90%	0.00%	0.00%	0.00%
Kia	0.00%	0.00%	0.00%	0.00%	0.90%	0.00%	0.00%	0.00%
Mazda	11.80%	0.00%	0.00%	0.00%	37.10%	0.00%	0.00%	0.00%
Mitsubishi	0.00%	0.00%	0.00%	0.00%	76.10%	0.00%	0.00%	0.10%
Nissan	17.70%	0.00%	0.00%	0.00%	33.30%	0.00%	0.00%	0.00%
Porsche	0.00%	0.00%	0.00%	0.00%	3.90%	0.00%	0.00%	0.00%
Subaru	0.00%	0.00%	0.00%	0.00%	29.00%	0.00%	0.00%	0.00%
Suzuki	0.00%	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%
Tata	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Toyota	7.50%	0.00%	0.00%	0.00%	30.60%	0.00%	0.00%	12.80%
Volkswagen	52.20%	0.00%	0.00%	0.10%	82.80%	10.90%	0.00%	0.00%
Overall	6.40%	0.00%	0.00%	0.10%	27.10%	0.60%	0.00%	2.80%

Once significant levels of technology are added to these vehicles in order to comply with future standards, the impact of existing technology diminishes dramatically. Manufacturers which did not utilize much technology in 2008 essentially catch up to those which did. The exception is the use of hybrid technology in 2008, since hybrids are not projected to be needed by most manufacturers to meet the proposed standards. This primarily affects Toyota, and to a lesser extent, Honda. Their use of hybrid technology in their 2008 fleet will continue to provide relatively greater CO2 reductions even in the 2016 projections. As long as the vehicle designs of various manufacturers would produce the same level of CO2 emissions if their CO2 reducing technology was removed, for the most part, difference in the application of technology in 2008 will not affect the level of technology needed in 2016.

In addition, as mentioned above, differences in CO2 emissions due to differences the distribution of sales by vehicle size should be largely eliminated by the use of a footprint-based standard. Thus, just because a manufacturer produces larger vehicles than another manufacturer does not explain the differences in required technology seen above.

In order to focus this analysis on the 2008 MY fleet, it would be helpful to remove the effect of differences in vehicle size and the use of CO2 reducing technology, so that the other causes of differences can be highlighted. EPA used the EPA lumped parameter model described in Chapter 1 to estimate the degree to which technology present on each 2008 MY vehicle was improving fuel efficiency. The effect of this technology was then removed from each vehicle to produce CO_2 emissions which did not reflect any differences due to the use of CO2 reducing technology. This set of adjusted CO2 emission levels is referred to as "no technology" emissions.

The differences in the relative sizes of vehicles sold by each manufacturer were accounted for by determining the difference between the sales-weighted average of each manufacturer's "no technology" CO_2 levels and their required CO_2 emission level under the proposed 2016 standards. This difference is the total reduction in CO2 emissions required for each manufacturer relative to a "no technology" baseline. The same difference for the industry as a whole is 71 g/mi CO2 for cars and 1.7 g/mi CO2 for trucks. This industry-wide difference was subtracted from each manufacturer's difference to highlight which manufacturers had lower and higher CO2 emission reduction requirements. The results are shown in Figure 4-1.

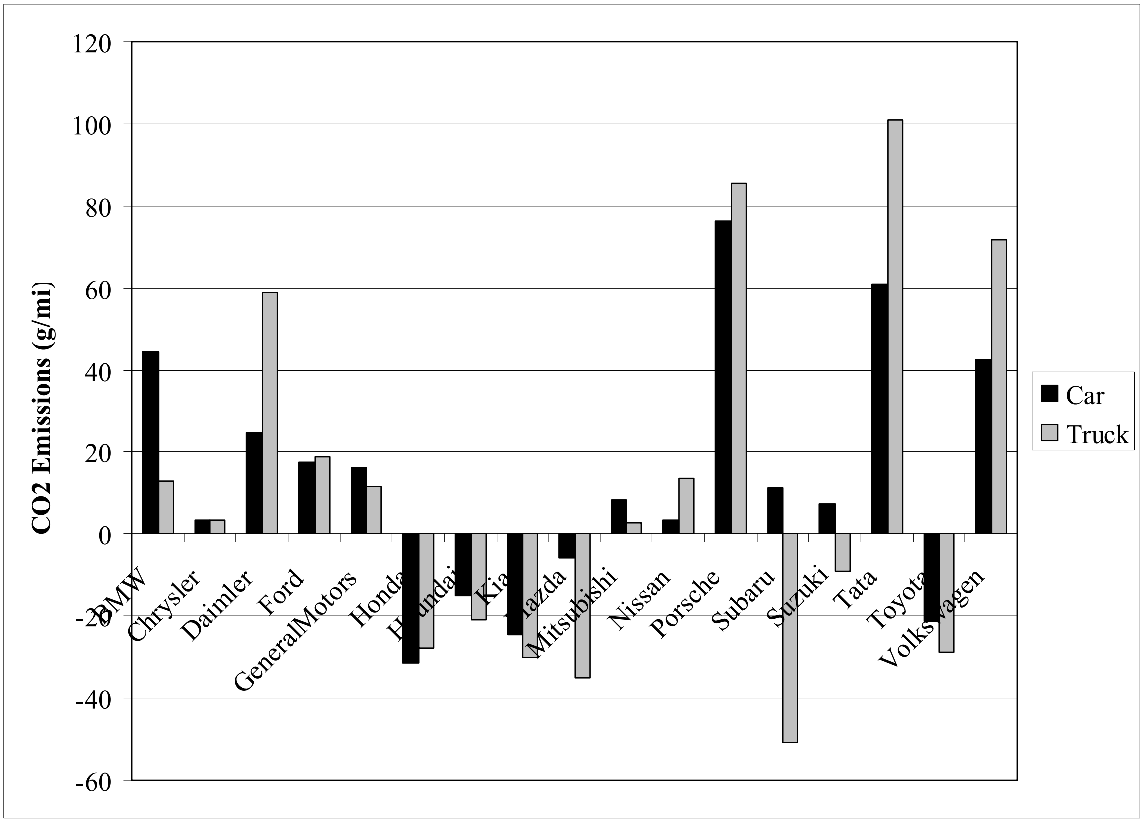

Figure 4-1 CO2 Emissions Relative to Fleet Adjusted for Technology and Footprint

As can be seen, the manufacturers projected in Table 4-22 to require the greatest levels of technology also show the highest offsets relative to the industry. The greatest offset shown in Figure 4-1 is for Tata's trucks (Land Rover). These vehicles are estimated to have 100 g/mi greater CO_2 emissions than the average 2008 MY truck after accounting for differences in the use of fuel saving technology and footprint. The lowest adjustment is for Subaru's trucks, which have 50 g/mi CO_2 lower emissions than the average truck.

While this comparison confirms the differences in the technology penetrations shown in Table 4-22, it does not yet explain why these differences exist. Two well known factors affecting vehicle fuel efficiency are vehicle weight and performance. The footprint-based form of the proposed CO_2 standard accounts for most of the difference in vehicle weight seen in the 2008 MY fleet. However, even at the same footprint, vehicles can have varying weights. Also, higher performing vehicles also tend to have higher CO_2 emissions over the two-cycle test procedure. So manufacturers with higher average performance levels will tend to have higher average CO_2 emissions for any given footprint. Table 4-23 shows each manufacturer's average ratios of weight to footprint and horsepower to weight.

Table 4-23 Vehicle Weight to Footprint and Performance

	Car		Truck	
Manufacturer	Weight / Footprint (lb/sq ft)	Horsepower/ Weight (hp/lb)	Weight / Footprint (lb/sq ft)	Horsepower/ Weight (hp/lb)
BMW	78	0.073	94	0.059
Chrysler	74	0.054	85	0.053
Daimler	73	0.068	97	0.057
Ford	77	0.057	84	0.052
General Motors	76	0.057	83	0.059
Honda	67	0.051	83	0.055
Hyundai	70	0.052	84	0.056
Kia	67	0.05	79	0.057
Mazda	73	0.05	80	0.055
Mitsubishi	74	0.052	83	0.056
Nissan	72	0.059	80	0.058
Porsche	82	0.106	96	0.073
Subaru	73	0.057	79	0.054
Suzuki	70	0.049	81	0.062
Tata	78	0.077	110	0.057
Toyota	71	0.054	80	0.062
Volkswagen	80	0.059	108	0.052
Overall	73	0.056	83	0.058

The impact of these two factors on each manufacturer's "no technology" CO_2 emissions was estimated. First, the "no technology" CO_2 emissions levels were statistically analyzed to determine the average impact of weight and the ratio of horsepower to weight on CO_2 emissions. Both factors were found to be statistically significant at the 95 percent confidence level. The results of the statistical analysis are summarized in Table 4-24.

Table 4-24 Effect of Weight and Performance on "No Technology" Vehicle CO2

	Intercept (g/mi CO2)	Effect of weight (g/mi CO2/lb)	Effect of Horsepower / Weight (g/mi CO2*lb/hp)	R-Square
Car	-45.8	0.0819	1590	0.82
Truck	-21	0.0782	1838	0.71

Together, these two factors explain over 80 percent of the variability in vehicles' CO_2 emissions for cars and over 70 percent for trucks. These relationships were then used to adjust each vehicle's "no technology" CO_2 emissions to the average weight for its footprint value and to the average horsepower to weight ratio of either the car or truck fleet, as follows:

For Cars:

CO2 Emissions adjusted for weight and performance = "No Technology" CO2 -

(Vehicle Weight - Vehicle Footprint * 73) * 0.0819 –

(Vehicle hp/wt – 0.056) * 1590

For Truck:

CO2 Emissions adjusted for weight and performance = "No Technology" CO2 -

(Vehicle Weight - Vehicle Footprint * 83) * 0.0782 –

(Vehicle hp/wt – 0.058) * 1838

We then recomputed the difference between the sales-weighted average of each manufacturer's adjusted "no technology" CO_2 levels and their required CO_2 emission level under the proposed 2016 standards and subtracted the difference for the industry as a whole. The results are shown in Figure 4-2.

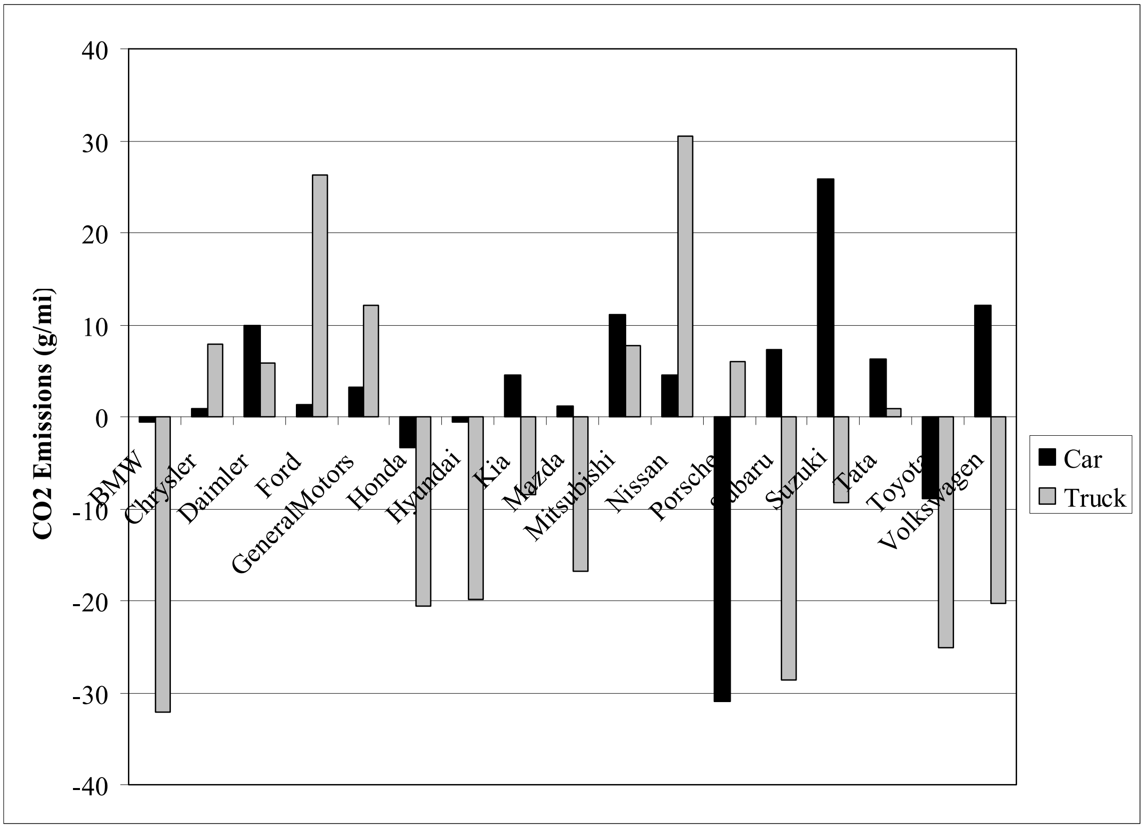

Figure 4-2 CO2 Emissions Relative to Fleet Adjusted for Technology, Footprint, Weight at Footprint, and Performance

First, note that the scale in Figure 4-2 is much smaller by a factor of 3 than that in Figure 4-1. In other words, accounting for differences in vehicle weight (at constant footprint) and performance dramatically reduces the differences in various manufacturers' CO_2 emissions. Most of the manufacturers with high offsets in Figure 4-1 now show low or negative offsets. For example, BMW's and VW's trucks show very low CO_2 emissions. Tata's emissions are very close to the industry average. Daimler's vehicles are no more than 10 g/mi above the average for the industry. This analysis indicates that the primary reasons for the differences in technology penetrations shown for the various manufacturers in Table 4-24 are weight and performance. EPA has not determined why some manufacturer's vehicle weight is relatively high for its footprint value, nor whether this weight provides additional utility for the consumer. Performance is more straightforward. Some consumers desire high performance and some manufacturers orient their sales towards these consumers. However, the cost in terms of CO_2 emissions is clear. Producing relatively heavy or high performance vehicles increases CO_2 emissions and will require greater levels of technology in order to meet the proposed CO_2 standards.

CHAPTER 5: Emissions Impacts

5.1 Overview

The domestic transportation sector emits approximately 28% of total U.S. greenhouse gas (GHG) emissions in 2010 based on the standard accounting methodology used by EPA in compiling the inventory of U.S. GHG emissions pursuant to the United Nations Framework Convention on Climate Change. This number is potentially even higher, as the standard methodology excludes upstream transportation fuel emissions associated with extraction, shipping, refining, and distribution from the emissions of the transportation sector. Within the transportation sector, emissions from light duty vehicles such as passenger cars, passenger trucks, and light duty commercial trucks account for 18% of total US GHG emissions, or approximately 1,300 million metric tons (MMT) of CO_2 equivalent (CO_2 EQ) greenhouse gas emissions in calendar year 2010.

Today's proposal quantifies anticipated impacts from the EPA vehicle CO_2 emission standards. The emissions from the GHGs carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and hydrofluorocarbons (HFCs) were quantified. In addition to reducing the emissions of greenhouse gases, today's proposal would also influence the emissions of "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 air toxics (hazardous air pollutants, including benzene, 1,3-butadiene, formaldehyde, acetaldehyde, and acrolein).

Downstream (tailpipe) emission impacts were developed using a spreadsheet analysis based on data from two EPA models. Computation algorithms and achieved CO_2 levels were derived from EPA's Optimization Model for reducing Emissions of Greenhouse gases from Automobiles (OMEGA) and were coupled with non-CO_2 emission rates from EPA's Motor Vehicle Emission Simulator (MOVES).

Upstream (fuel production and distribution) emission changes resulting from the decreased fuel consumption predicted by the downstream models were calculated using a spreadsheet model based on emission factors from GREET.[51] Based on these analyses, the control programs proposed in this chapter would account for 325 MMT CO_2EQ of annual GHG reduction by the year 2030 and 519 MMT per year by 2050. Fuel savings resulting from the GHG standards are projected at 42.6 billion gallons of fuel savings in Calendar Year 2050 (Table 5-1).

Table 5-1 - Impacts of Proposed Program on GHG Emissions and Fuel Savings

CALENDAR YEAR	ANNUAL GHG REDUCTION (CO_2 EQ MMT)	FUEL SAVINGS (MILLION BARRELS PER DAY OF GASOLINE EQUIVALENT)	ANNUAL FUEL SAVINGS (BILLION GALLONS OF GASOLINE EQUIVALENT)
2020	165.2	0.9	13.4
2030	324.6	1.7	26.2
2040	417.5	2.2	33.9
2050	518.5	2.8	42.6

The emissions of non-GHG air pollutants due to light duty vehicles are also expected to be affected by today's proposal. These effects are largely due to changes in fuel production, but are also driven by changes in driver behavior.[M] The delta values shown here include both upstream and downstream contributions.

Table 5-2 - Impacts of Proposed Program on Non-GHG Emissions (Short Tons per year)

POLLUTANT	CALENDAR YEAR 2020	% CHANGE VS. 2020 REFERENCE	CALENDAR YEAR 2030	% CHANGE VS. 2030 REFERENCE
Δ 1,3-Butadiene	11.5	0.07%	36.8	0.22%
Δ Acetaldehyde	16.8	0.037%	60.6	0.134%
Δ Acrolein	0.2	0.00%	1.8	0.03%
Δ Benzene	-83.6	-0.04%	-77.5	-0.04%
Δ Carbon Monoxide	70,614	0.13%	227,832	0.38%
Δ Formaldehyde	-28.3	-0.03%	-15.7	-0.02%
Δ Oxides of Nitrogen	-17,206	-0.14%	-27,726	-0.23%
Δ Particulate Matter (below 2.5 micrometers)	-2,856	-0.08%	-5,431	-0.16%
Δ Oxides of Sulfur	-16,307	-0.18%	-31,965	-0.34%
Δ Volatile Organic Compounds	-73,739	-0.60%	-142,347	-1.17%

We also analyzed the emission reductions over the full model year lifetime of the 2012-2016 model year cars and trucks affected by today's proposal. These results, including both upstream and downstream GHG contributions, are presented below (Table 5-3).

[M] A rebound of 10% is used in this analysis. See section 5.3.3.1.1 for a brief definition of rebound, and the joint Technical Support Document for a more complete discussion.

Table 5-3 - Model Year Lifetime Fuel Savings and GHG Reductions

Model Year	Lifetime GHG Reduction (MMT CO2 EQ)	Lifetime Fuel Savings (Billion Gallons Of Gasoline Equivalent)	Lifetime Fuel Savings (Million Barrels of Gasoline Equivalent)
2012	81	6.6	157
2013	125	10.0	239
2014	174	13.9	331
2015	243	19.5	463
2016	323	26.3	626
Total Program Benefit	**947**	**76.2**	**1,815**

5.2 Introduction

5.2.1 Scope of Analysis

Today's program proposes new standards for the greenhouse gas (GHG) emissions of light duty vehicles from model year 2012 through model year 2016. The proposed program affects light duty gasoline and diesel fueled vehicles. Most passenger vehicles such as cars, sport utility vehicles, vans, and pickup trucks are light duty vehicles. Such vehicles are used for both commercial and personal uses and are significant contributors to the total United States (U.S.) GHG emission inventory. Today's proposal will significantly decrease the magnitude of these emissions. Because of anticipated changes to driving behavior and fuel production, a number of co-pollutants would also be affected by today's proposal.

This chapter describes the development of inventories for emissions of the gaseous pollutants impacted by the proposed rule. These pollutants are divided into greenhouse gases, or gases that in an atmosphere absorb and emit radiation within the thermal infrared range, and non-greenhouse gases. Such impacts may occur "upstream" in the agricultural sector and fuel production and distribution processes, or "downstream" in direct emissions from the transportation sector. Table 5-4 presents the processes considered in each domain. This analysis presents the projected impacts of today's proposal on greenhouse gases in calendar years 2020, 2030, 2040 and 2050. Non-greenhouse gases are shown in 2020 and 2030. The program was quantified as the difference in mass emissions between the proposed standards and a reference case as described in Section 5.3.2.2.

Table 5-4 - Processes Considered

PROCESS	UPSTREAM / DOWNSTREAM
Crude Oil Extraction	Upstream
Crude Oil Transport	Upstream
Oil Refining	Upstream
Fuel Transport and Distribution	Upstream
Fuel Tailpipe Emissions	Downstream
Air Conditioning System Leakage	Downstream

Delta inventories for the four greenhouse gases carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and hydrofluorocarbons (HFC) are presented herein. The sole HFC discussed in this inventory is R-134a, which is the refrigerant in most current vehicle air conditioning systems. Delta inventories for the non-ghg pollutants 1,3-butadiene, acetaldehyde, acrolein, benzene, carbon monoxide (CO), formaldehyde, oxides of nitrogen (NOx), particulate matter below 2.5 micrometers, oxides of sulfur (SO_x), and volatile organic compounds (VOC) are also presented.

5.2.2 Downstream Contributions

The largest source of GHG reductions from today's proposal is new standards for tailpipe emissions produced during vehicle operation (termed "downstream" emissions). Absolute reductions from tailpipe GHG standards are projected to grow over time as the fleet turns over to vehicles affected by the standards, meaning the benefit of the program will continue to grow as long as the older vehicles in the fleet are replaced by newer, lower CO_2 emitting vehicles.

As described herein, the downstream reductions in greenhouse gases due to the proposed program are anticipated to be achieved through improvements to both fuel economy and air conditioning system operation. Improvements to air conditioning systems can be further separated into reducing leakage of HFCs (direct improvement) and reducing fuel consumption by increasing the efficiency of the air conditioning system (indirect).

Due to the rebound effect, improving fuel economy is anticipated to increase total vehicle miles traveled, which has impacts on both GHG and non-GHG emissions. These impacts are detailed in Section 5.3.3.1.1

5.2.3 Upstream Contributions

In addition to downstream emission reductions, reductions are expected in the emissions associated with the processes involved in getting petroleum to the pump, including the extraction and transportation of crude oil, and the production and distribution of finished gasoline (termed "upstream" emissions). Changes are anticipated in upstream emissions due to the expected reduction in the volume of fuel consumed. Less gasoline consumed means less gasoline transported, less gasoline refined, and less crude oil extracted and transported to refineries. Thus, there should be reductions in the emissions associated with each of these steps in the gasoline production and distribution process.

HFC manufacture is not considered a significant source of upstream emissions and is not considered in this analysis.[52]

5.2.4 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 5-5). 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 GWPs used in this chapter are drawn from publications by the Intergovernmental Panel on Climate Change (IPCC).[53,N]

Table 5-5 - 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

5.3 Program Analysis and Modeling Methods

5.3.1 Models Used

The inventories presented in this document were developed from established EPA models.

Downstream inventories were generated using algorithms from EPA's Optimization Model for reducing Emissions of Greenhouse gases from Automobiles (OMEGA). Broadly

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[N] The global warming potentials (GWP) used in the NPRM inventory analysis are consistent with Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4). At this time, the IPCC Second Assessment Report (SAR) global warming potential values have been agreed upon as the official U.S. framework for addressing climate change. The IPCC SAR GWP values are used in the official U.S. greenhouse gas inventory submission to the United Nations climate change framework. When inventories are recalculated for the final rule, changes in GWP used may lead to adjustments.

speaking, OMEGA is used to determine 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 benefits analyses 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 benefits (emission reductions, monetized co-benefits) of the analyzed program

Inputs to the OMEGA post-processor were updated with emission rates from EPA's Motor Vehicle Emission Simulator (MOVES).[5455] CO_2 emission and fuel consumption rates are drawn from OMEGA results, with all co-pollutant emission rates derived from the Draft MOVES emission rate database. [O,56] Air conditioning inventories (including HFC and CO_2 contributions) were separately calculated in spreadsheet analyses, and are based on previous EPA research.[57] Both MOVES and OMEGA are established models and continue to be actively developed. [58,59]

Upstream emissions were calculated using the same tools as were used for the Renewable Fuel Standard 2 (RFS2) proposed rule analysis,[60] but for the current analysis it was assumed that all impacts are related to changes in volume of gasoline produced and consumed, with no changes in volumes of other petroleum-based fuels, ethanol, or other renewable fuels. The estimate of emissions associated with production of gasoline from crude oil is based on emission factors in the GREET model developed by DOE's Argonne National Lab.[61, 62] The actual calculation of the emission inventory impacts of the decreased gasoline production is done in EPA's spreadsheet model for upstream emission impacts. This model uses the decreased volumes of the crude based fuels and the various crude production and transport emission factors from GREET to estimate the net emissions impact. As just noted, the analysis for today's proposal assumes that all changes in volumes of fuel used affect only gasoline, with no effects on use of other petroleum-based fuels, ethanol, or other renewable fuels.

The following sections provide an in-depth description of the inputs and methodology used in each analysis.

5.3.2 Description of Scenarios

One reference and one control scenario are modeled in this proposal, and each is described below.[63] The two scenarios shown are differentiated by their regulatory CO_2 emission standards. The reference scenario CO_2 emissions are based upon the National Highway Traffic Safety Administration (NHTSA) Model Year 2011 Corporate Average Fuel Economy (CAFE) standards,[64] while the control scenario CO_2 emissions are based upon the program proposed herein. Otherwise, the scenarios share fleet composition, sales, base vehicle miles traveled (VMT), and all other relevant aspects. Vehicles are modeled as compliant with Tier 2 criteria emission standards.

[O] Two tables were updated in the Draft MOVES database. These tables are available in the docket.

Ethanol use was modeled at the volumes projected in AEO2007 for the reference and control case; thus no changes are projected in upstream emissions related to ethanol production and distribution. However, due to the decreased gasoline volume associated with today's proposal, a greater market share of E10 is expected relative to E0, which would be expected to have some effect on fleetwide average non-GHG emission rates. The increased market share of ethanol blended gasoline, which is likely small relative to the other effects considered here, has not been accounted for in the downstream emission modeling conducted for today's proposal, but is planned to be addressed in the final rule air quality analysis, for which localized impacts could be more significant. Due to the lower energy content of ethanol blended gasoline, the increase in ethanol market share is also projected to decrease the fuel savings predicted by this analysis by approximately 1-2%. A more comprehensive analysis of the impacts of different ethanol and gasoline volume scenarios is being prepared as part of EPA's RFS2 rulemaking package.[P]

5.3.2.1 Sales and Fleet Composition

Fleet composition has a significant effect upon the impacts of the proposed rule. Consequently, it is significant that the cars and trucks in this analysis are defined differently than their historic EPA classifications. Passenger Automobiles (PA), as used herein, are defined as classic cars and two-wheel drive SUVs below 6,000 lbs. gross vehicle weight. The remaining light duty fleet is defined as Non-Passenger Automobiles (NPA). The NPA classification includes most classic light duty trucks such as four-wheel drive SUVs, pickup trucks, and similar vehicles.

As shown in Table 5-6, the vehicle classifications used herein are consistent with the definitions used by the National Highway Safety Transit Association in the MY 2011 CAFE standards.[65] While the formal definitions are lengthy, brief summaries of the classifications are shown here.

Table 5-6 -Definitions of Vehicle Classes

REGULATOR	CAR DEFINITION	TRUCK DEFINITION
National Highway Traffic Safety Administration CAFE Program (pre-MY 2011)	Classic Car – Passenger Car	Classic Truck – Light Duty Trucks 1-4 and Medium Duty Passenger Vehicles.
EPA Program (MY 2012+)	Passenger Automobile – PC + 2 wheel drive SUVs below 6,000 GVW	Non-Passenger Automobile – Remaining light duty fleet

Based on EPA analysis of the projected MY 2012-2016 fleet,[66] approximately 22% of the classic truck fleet is anticipated to be reclassified as Passenger Automobiles under the new standards. Projected sales of classic cars and trucks for calendar years 2012-2030 were drawn from the Energy Information Administration Annual Energy Outlook (AEO) April 2009 projection.[67] The AEO 2009 sales projections, based on the classic fleet, were then

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[P] XX [Insert RFS2 NPRM reference, since FRM will not be available in time for GHG NPRM.]

reclassified using PA and NPA definitions. For calendar years 2030-2050, which are beyond the scope of AEO's projections, 0.76% annual growth in the sales of cars and trucks was assumed.

Table 5-7 – Projected Total Vehicle Sales and Car Fractions

	Model Year 2012	Model Year 2013	Model Year 2014	Model Year 2015	Model Year 2016
Total Light Duty Sales	14,850,955	15,653,713	16,216,393	16,575,580	16,581,055
Classic Car Fraction	51.8%	52.9%	54.3%	55.8%	57.1%
PA Fraction	62.6%	63.6%	64.3%	65.6%	66.5%
PAs Sold	8,235,204	9,255,624	9,977,341	10,479,350	10,890,967

5.3.2.2 Proposed Standards

Individual PA and NPA tailpipe CO_2 fleet average emission standards are shown for reference and control scenarios along with an anticipated fleet average combined standard. Rather than an absolute standard, the values referred to here as standards are the production weighted average standard predicted by the coefficients of the relevant equation. As documented in Preamble section II, under both reference and control scenarios, each manufacturer has a unique fleet average standard based on their vehicle footprints and production.

Fleet average standards are calculated here by weighting the individual PA and NPA standards by the respective proportions of anticipated production (Section 5.3.2.1). These CO_2 emission values are unadjusted values (i.e. in CAFE space), so they are lower than the anticipated on-road emissions. In all scenarios, vehicles are assumed to maintain model year 2016 emissions for post-2016 vehicles. Because the fleet composition continues to change post-MY 2016, the fleet average emission level continues to vary

5.3.2.2.1 Reference Case

5.3.2.2.1.1 CO_2 Emission Standards

The reference scenario standards were derived from the NHTSA model year 2011 Corporate Average Fuel Economy (CAFE) standards applied to the MY 2012-2016 reference fleet (see chapter 1 of the draft joint TSD and chapter 4 of this DRIA).[68] Average car and truck fuel economy standards were calculated from the coefficients in the MY 2011 rule and EPA analysis of the projected MY 2012-2016 fleet.[69,70] Average fuel economy levels were calculated for each manufacturer's fleet, and then combined based on projected sales.

A ratio of 8887 grams of CO_2 emitted per gallon of gasoline was used to convert to the calculated fuel economy standards to CO_2 (gram/mile) emission factors. The basic derivation of the 8887 factor can be seen in previous EPA publications.[71]

CO_2 emission standards were calculated by applying the CAFE coefficients to the footprint of each model, and calculating fleet averages based on projected model sales. Minor changes in the emission standard are expected due to projected changes in the average new vehicle footprint between 2012 and 2016 (Table 5-8).

Table 5-8 – Reference Case Average Emission Standards (grams/mile CO_2)

MODEL YEAR	PA EMISSION LEVEL	NPA EMISSION LEVEL	MY EMISSION LEVEL
2012	291	366	319
2013	291	366	319
2014	291	368	319
2015	291	368	318
2016	291	368	317

5.3.2.2.1.2 Achieved CO_2 Emission Levels

The emission standards shown in Table 5-8 do not reflect the impact of several program flexibilities in CAFE, nor do they account for manufacturer overcompliance. Projected achieved emission levels include the effects of manufacturers who pay fines rather than comply with the emission standards, as well as a number of credit programs under EPCA/EISA that allow manufacturers to emit more than the standard seemingly requires. Additionally, some manufacturers overcomply with the standards, and this overcompliance is not reflected in the CAFE standards.

While the CAFE program is complex, the most significant portions of the program flexibilities are accounted for. In this analysis, manufacturer overcompliance, credit trading, FFV credits, and fine paying manufacturers were accounted for. Banked credits from the calculation of achieved standards were excluded.

In general, achieved emission levels were estimated by beginning with the more stringent of either (A) manufacturer's CAFE score (in CO_2 space) or (B) estimated achieved MY 2008 CO_2 level based on the EPA fleet data file. Using that starting point, each manufacturer's emissions was increased by the impact of the credits of which is anticipated that they will take advantage. Consistent with the use of the MY 2011 standards, the credits and trading levels available for MY 2011 are assumed available in all years of the reference case. Manufacturers were always assumed to perform at least as well as they did in 2008.

Overcompliance and Credit Trading

Using the EPA fleet file, the fleet mix was estimated by manufacturer for model year 2012 through model year 2016. For each model year, the CAFE score (in CO_2 space) was calculated by manufacturer for PA and NPA separately. To estimate the effects of overcompliance, each manufacturer's achieved 2008 PA/NPA emissions were compared against the PA/NPA emissions required by CAFE in 2011.

The overcompliance on either PA or NPA could be "traded" within a manufacturer in order to make up a shortfall in the remaining vehicle class. Credits are generated on a sales and VMT weighted basis, and traded between vehicle classes. The MY 2011 CAFE cap on credit trading of 1.0 mpg was used. This trading of the overcompliance credit negates some, but not all of the overcompliance anticipated. Certain manufacturers, such as Toyota and Honda, overcomply by a great deal more than they are able to trade between vehicle classes.

Flex Fueled vehicle Credits

The 2007 Energy Independence and Security Act allows for CAFE credits due to production of "flex-fueled" vehicles. Under the model year 2011 standards, such credits can be used to meet up to 1.2 MPG of the CAFE standard. The manufacturers General Motors, Chrysler and Ford were assumed to take advantage of this credit for both cars and trucks, while Nissan was assumed to utilize this credit solely for trucks.

Fines

In this analysis, EPA used estimates of fine paying manufacturers from NHTSA's Volpe model. That model supplied projected maximum stringencies that a manufacturer would meet before it was more cost effective to pay a non-compliance fine. The manufacturers who are projected to pay fines are Tata, Daimler, BMW, Porsche, and Volkswagen.

The projected impacts of these program flexibilities on the standards, achieved levels based on program flexibilities and manufacturer overcompliance are shown in Table 5-10.

Table 5-9 - Impacts of credits (grams/mile CO2 EQ)

MODEL YEAR	OVERCOMPLIANCE, CREDITS AND TRADING	FFV	FINES	NET
2012	-6.1	6.7	0.7	1.2
2013	-6.4	6.7	0.2	0.5
2014	-6.8	6.7	0.1	0.0
2015	-7.1	6.5	0.1	-0.5
2016	-7.3	6.4	0.0	-0.9

Table 5-10 – Reference Case Achieved Emissions (grams/mile CO_2)

MODEL YEAR	ANTICIPATED PA EMISSION LEVEL	ANTICIPATED NPA EMISSION LEVEL	ANTICIPATED MY EMISSION LEVEL
2012	284	382	320
2013	283	382	319
2014	283	383	319
2015	282	384	317
2016	282	384	316

5.3.2.2.2 Control Case

5.3.2.2.2.1 CO_2 Emission Standards

Similar to the reformed CAFE program, EPA is proposing to establish a footprint attribute based function in order to determine the CO_2 (gram/mile) emission standard for a given vehicle. The piecewise linear function used by EPA is documented in Section II of the preamble. Based on this function, and the same vehicle fleet as was used in the reference scenario, EPA calculated projected PA and NPA fleet average emission standards for the MY2012-2016 vehicles. Average PA and NPA fuel economy standards were calculated by applying this function to the EPA fleet file (Table 5-11).[72]

Table 5-11 - Control Case Average Emission Standards (grams/mile CO2)

MODEL YEAR	PA EMISSION LEVEL	NPA EMISSION LEVEL	PROJECTED MY EMISSION STANDARD LEVEL
2012	261	351	295
2013	253	341	286
2014	246	332	276
2015	235	317	263
2016	223	302	250

5.3.2.2.2.2 Achieved CO_2 Emission Levels

Just as with the reference scenario, the emission standards (Table 5-11) do not include the effect of several program flexibilities built into the EPA program.

The same basic methodology was used to calculate achieved fleet standards for the control case. In general, achieved standards were estimated by beginning with the more stringent of either (A) manufacturer's calculated footprint-based emission standard or (B) estimated achieved CO_2 level based on the EPA fleet data file. Using that starting point, each manufacturer's emissions were increased by the impact of the credits of which were anticipated that they will take advantage. Manufacturers were always assumed to perform at least as well as they did in 2008.

Overcompliance and Trading

Using the EPA fleet file, the fleet mix was estimated by manufacturer for model year 2012 through model year 2016. For each model year, the GHG standard was calculated by manufacturer for PA and NPA separately. To estimate the effects of overcompliance, each manufacturer's achieved PA/NPA emissions was compared against the PA/NPA emissions required by CAFE.

The achieved overcompliance on either PA or NPA could be "traded" within a manufacturer in order to make up a shortfall in the remaining vehicle class. Credits are generated on a sales and VMT weighted basis, and traded between vehicle classes. Under the EPA proposed program, there are no limits on such trading. This trading of the overcompliance credit negates nearly all of the overcompliance anticipated in the early years.

Under the unlimited within-fleet trading allowed under the EPA program, manufacturers can potentially invest in their fleet differently than the precise achieved levels described here. Because the credit trading is VMT weighted, the resulting changes will be essentially environmentally neutral on both GHG and criteria pollutants.

Flex Fueled Vehicles

The flex fueled vehicle credit, per the discussion in the preamble (Section III), is set at 1.2 MPG for MY 2012-2014, 1.0 MPG for MY 2015, and 0 MPG for MY 2016+. As in the reference case, it was assumed that the manufacturers General Motors, Chrysler and Ford would take advantage of this credit for both cars and trucks, while Nissan would utilize this credit solely for trucks.

A/C

Indirect A/C credits were set at 5.7 grams CO_2 per mile for the fleet, while direct A/C credits were set at 6.9 grams CO_2 per mile for PA and 8.6 grams CO_2 per mile for NPA). EPA assumed market penetration of the technology according to Table 5-16. A more complete discussion of the A/C credit program and inventories is provided in section 5.3.3.2, as well as DRIA chapter 2.

Temporary Lead Time Allowance Alternative Standards (TLAAS)

We assumed that every potentially eligible manufacturer took advantage of the temporary lead time allowance. Each qualifying manufacturer was assumed to use the full vehicle allocation according to the default production schedule shown in Preamble Section III. The allocation was split evenly between cars and trucks for each manufacturer. This vehicle allocation was assumed to emit as much CO_2 per mile as the highest emitting car or truck in each manufacturer's fleet. These vehicles were then proportionally averaged into the manufacturer's GHG score. For more on the TLAAS program, please see Appendix A to this RIA chapter.

The aggregate impacts of these program flexibilities are listed in Table 5-12.

Table 5-12 – Estimated Impacts of Proposed Program Flexibilities (grams/mile CO2 EQ)

MODEL YEAR	OVERCOMPLIANCE, CREDITS AND TRADING	FFV	DIRECT A/C	INDIRECT A/C	TLAAS	NET
2012	0.1	6.0	1.9	1.4	0.3	**9.6**
2013	-0.3	5.7	3.0	2.3	0.2	**10.9**
2014	0.0	5.4	4.1	3.1	0.2	**12.7**
2015	0.0	4.1	5.6	4.3	0.1	**14.0**
2016	0.0	0.0	6.3	4.8	0.0	**11.1**

Based on these impacts, the achieved emission level by PA, NPA and fleet are displayed in Table 5-13. Please note that the achieved emission levels include the increase in test procedure emissions due to the use of the A/C credit. The impacts of A/C improvements are discussed in section 5.3.3.2.

Table 5-13 – Federal GHG Program Anticipated Emission Levels (grams/mile CO2)

MODEL YEAR	ANTICIPATED PA EMISSION LEVEL	ANTICIPATED NPA EMISSION LEVEL	ANTICIPATED MY EMISSION LEVEL
2012	266	368	304
2013	261	359	297
2014	256	349	289
2015	246	335	277
2016	234	314	261

Table 5-13 differs slightly from the OMEGA cost-side model results in 2016. OMEGA assumes environmentally neutral trading between PA and NPA within a manufacturer's fleet in order to minimize technology costs. Consequently, the distribution of fleet emission reductions differs slightly between cars and trucks from that which is shown here. However, because the trading is VMT weighted, it is environmentally neutral and has no GHG emissions impacts.

OMEGA also predicts slight undercompliance in 2016 for several manufacturers, while the results presented here assume full compliance. Based on preliminary analysis, the OMEGA cost-side results are estimated to produce approximately 0.5% less GHG benefit.

5.3.3 Calculation of Downstream Emissions

The fleet inputs (achieved CO_2 emission levels by model year and vehicle sales) described above were incorporated into a spreadsheet along with emission rates derived from Draft MOVES 2009 and benefits calculations from the OMEGA post-processor. The resulting spreadsheet projects emission impacts in each calendar year. The effects of the program grow over time as the fleet turns over to vehicles subject to the more stringent new standards.

A model year lifetime analysis, considering only the five model years regulated underneath the program, is shown in Section 5.6. In contrast to the calendar year analysis, the model year lifetime analysis shows the lifetime impacts of the program on each MY fleet over the course of that fleet's existence.

5.3.3.1 Tailpipe GHG Emissions

Two basic elements feed into OMEGA's calculation of vehicle tailpipe emissions. These elements are VMT and emission rates.

$$\text{Total Emissions} = \text{VMT}_{\text{miles}} * \text{Emission rate}_{\text{grams/mile}}$$

Equation 3 - 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 are applied to each model year within the calendar year. Emissions are then summed across all model years.

The following sections describe the VMT and emission factor components of this analysis.

5.3.3.1.1 Base VMT

The downstream analysis is based upon a "bottom-up" estimate of total VMT and vehicle population. The VMT inputs are documented more fully in draft joint TSD chapter 4, but a description of their use in the emissions calculations are provided below.

The analysis spreadsheet contains MY-specific estimates of per vehicle VMT by vehicle age, as well as the fractions of new vehicles still on the road as a function of age. The total VMT for vehicles in a specific model year during a specific calendar year is determined by multiplying 1) new vehicle sales for that model year, 2) the fraction of new vehicles remaining on the road according to the age of those vehicles in that calendar year and 3) the annual VMT for that model year, age, and vehicle class.

Future vehicle sales were drawn from AEO 2009 (as discussed in Section 5.3.2.1), while historic vehicle sales are drawn from the Transportation Energy Data Book,[73] Post MY 2011 vehicles were reclassified in order to correspond to the PA/NPA definitions.

As described in the draft technical support document, mileage accumulation by age was calculated using inputs from the NHTSA "Vehicle Survivability and Travel Mileage Schedules" and additional inputs unique to this analysis.[74,75] In brief, a 1.15% per vehicle annual VMT growth rate was assumed, but additional factors such as achieved fuel efficiency and the price of gasoline also contributed to the precise schedule for each MY.

The survival schedule was taken without emendation from "Vehicle Survivability and Travel Mileage Schedules." While adjustments may be necessary to this schedule to accommodate the change between classic cars/trucks and PA/NPA, EPA is unaware of any extant data supporting specific adjustments. Because of the lack of data, the survival rates from "Vehicle Survivability and Travel Mileage Schedules" were used without further adjustment (Table 5-14).[76]

Table 5-14 - Survival Fraction by Age

AGE	PA SURVIVAL FRACTION	NPA SURVIVAL FRACTION
0	0.9950	0.9950
1	0.9900	0.9741
2	0.9831	0.9603
3	0.9731	0.9420
4	0.9593	0.9190
5	0.9413	0.8913
6	0.9188	0.8590
7	0.8918	0.8226
8	0.8604	0.7827
9	0.8252	0.7401
10	0.7866	0.6956
11	0.7170	0.6501
12	0.6125	0.6042
13	0.5094	0.5517
14	0.4142	0.5009
15	0.3308	0.4522
16	0.2604	0.4062
17	0.2028	0.3633
18	0.1565	0.3236
19	0.1200	0.2873
20	0.0916	0.2542
21	0.0696	0.2244
22	0.0527	0.1975
23	0.0399	0.1735
24	0.0301	0.1522
25	0.0227	0.1332
26	0.0000	0.1165
27	0.0000	0.1017
28	0.0000	0.0887
29	0.0000	0.0773
30	0.0000	0.0673
31	0.0000	0.0586
32	0.0000	0.0509
33	0.0000	0.0443
34	0.0000	0.0385
35	0.0000	0.0334

A complete discussion of the derivation of the MY specific VMT schedules is provided in draft joint TSD chapter 4.

5.3.3.1.2 Rebound

The tailpipe CO_2 standards are expected to result in greater fuel efficiency. Per the discussion of the rebound effect in the draft joint TSD chapter 4, improved fuel efficiency is expected to lead to a proportional increase in VMT. Consequently, the VMT differs between the reference and control cases.

The rebound effect is formally defined as the ratio of the percentage change in VMT to the percentage change in incremental driving cost, which is typically assumed to be the incremental cost of fuel consumed per mile. Since VMT increases with a reduction in fuel consumption, the sign of the rebound effect is negative. The percentage increase in VMT for a given change in fuel consumption per mile is calculated as follows:

$$\Delta\%VMT_{reb} = -REB * \frac{\left(FleetFC_{old} - FleetFC_{new}\right)}{FleetFC_{old}}$$

Equation 4 - VMT Rebound

As fuel consumption changes by model year, each model year's vehicles reflect a different change in VMT In OMEGA, this change in VMT is assumed to continue throughout the life of the vehicle, which is consistent with the assumption that fuel economy is constant throughout vehicle life.

This analysis assumes a 10% rebound effect; the analysis behind 10% is explored in greater depth in Chapter 4 of the draft joint TSD.

5.3.3.1.3 Emission Factors

The derivation of the emission factors used in this analysis is documented in chapter 4 of the technical support document. Briefly, CO_2 emission rates are derived from the achieved vehicle emission levels in Table 5-10 & Table 5-13, SO_2 emission rates are derived from fuel sulfur levels, and the emission rates for the remaining pollutants are derived from the draft MOVES 2009 database. For a more complete discussion of these emission rates, please see the draft joint TSD chapter 4.[77]

EPA is not projecting any reductions in tailpipe CH_4 or N_2O emissions as a result of these proposed emission caps, which are meant to prevent emission backsliding and to bring diesel vehicles equipped with advanced technology aftertreatment into alignment with current gasoline vehicle emissions. Similar to other pollutants, there are emission impacts due to reduced fuel production and increased driving (rebound).

5.3.3.1.4 Tailpipe CO2 Emissions from Vehicles

CO_2 emission rates were derived from the achieved levels in Table 5-10 & Table 5-13. Previous EPA analysis has shown that an approximately 20% gap exists between CAFE space fuel economy and on-road fuel economy.[78] The on-road gap is more fully documented in the draft joint TSD chapter 4.

The 20% gap, while approximate, includes average effects of fuel efficiency contributors such as road roughness, wind, and high acceleration events. The gap also reflects the different energy content between certification fuel and real world fuel (which frequently contains some oxygenate or ethanol.), as well as the fuel consumption impacts of running a mobile vehicle air conditioning system. In this analysis, CO_2 emissions are assumed to remain constant throughout the vehicle's lifetime.

By dividing a CAFE-space CO_2 emission rate by (1-on-road gap), one can approximate the actual on-road CO_2 emissions experienced by drivers.

On road tailpipe CO_2 emissions =
Achieved CO_2 Emission Level /(1-on-road gap) x VMT including rebound

Equation 5- Tailpipe CO2 Emissions Excluding A/C

Based on Equation 5, the baseline CO_2 emissions and change in tailpipe emissions due to the new control program were calculated. Emissions due to rebound were also calculated. The contributions of the A/C control program are excluded from this table.

Table 5-15 - Tailpipe CO_2 Emissions including Baseline A/C Usage (MMT)

	2020	2030	2040	2050
Tailpipe CO_2 Emissions (Reference)	1,209	1,373	1,662	2,069
Δ CO_2 Emissions (Control) including 10% rebound	-108	-212	-274	-344
Δ CO_2 Emissions due to 10% rebound	11	21	27	33

5.3.3.2 Air Conditioning Emissions

Outside of the tailpipe CO_2 emissions directly attributable to driving, EPA has analyzed how new control measures might be developed for air conditioning ("A/C")-related emissions of HFCs and CO_2. With regard to air conditioning-related emissions, significant opportunity exists to reduce HFC emissions from refrigerant leakage (direct emissions) and CO_2 from A/C induced engine loads (indirect emissions).

Over 95% of the new cars and light trucks in the U.S. are equipped with A/C systems. There are two mechanisms by which A/C systems contribute to the emissions of GHGs. The first is through direct leakage of refrigerant (currently the HFC compound R134a) into the air. Based on the high GWP of HFCs (Table 5-5), a small leakage of the refrigerant has a greater global warming impact than a similar amount of emissions from other mobile source GHGs. Leakage can occur slowly through seals, gaskets, hose permeation and even small failures in the containment of the refrigerant, or more quickly through rapid component deterioration, vehicle accidents or during maintenance and end of-life vehicle scrappage (especially when refrigerant capture and recycling programs are less efficient). The leakage emissions can be reduced through the choice of leak-tight, durable components, or the global warming impact of leakage emissions can be addressed by using an alternative refrigerant with lower GWP. These options are described more fully in DRIA Chapter 2.

EPA's analysis indicates that together, these A/C- related emissions account for approximately 8% of the GHG emissions from cars and light trucks. EPA is proposing credit provisions which we expect all manufacturers to utilize which are expected to reduce direct leakage emissions by 50% and to reduce the incremental increase of A/C related CO_2 emissions by 40% in model year 2016 vehicles, with a gradual phase-in starting in model year 2012. It is appropriate to separate the discussion of these two categories of A/C-related emissions because of the fundamental differences in the emission mechanisms and the methods of emission control. Refrigerant leakage control is akin in many respects to past EPA fuel evaporation control programs in that containment of a fluid is the key control feature, while efficiency improvements are more similar to the vehicle-based control of CO_2 in that they would be achieved through specific hardware and controls.

The anticipated phase-in of air conditioning controls is shown in Table 5-16. The market penetration is based upon analysis from the OMEGA model. OMEGA projections show improved A/C technology market penetration at 85% of the market in 2016. This 85% cap is then roughly linearized across the five year period (Table 5-16). Because HFC leakage is somewhat independent of vehicle miles traveled, HFC reduction % is based on the proportion of new vehicles that have HFC leakage containment technology. By contrast, indirect A/C reduction % is dependent upon the travel fraction, and is proportional to the VMT attributable to vehicles with the control technology.

Table 5-16 – AC Control by Model Year (Reduction from Base Emissions)

	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016+
Market Penetration of technology	25%	40%	55%	75%	85%
HFC Reduction %	-13%	-21%	-28%	-38%	-43%
Indirect Reduction %	-10%	-16%	-22%	-30%	-34%

The penetrations of A/C control technology and HFC reductions shown in this section differ slightly from those shown in DRIA chapter 2, and in Preamble section III. The HFC credits discussed in this section are slightly larger (9%) than the proposed program credits, while the penetration schedule of the credits is slightly lower. The net effect is a less than 1%

overstatement of total program GHG related benefits. EPA will address this issue in the final rulemaking.

5.3.3.2.1 Direct A/C (HFC) Emissions

The projected HFC baseline inventories are derived from previous EPA analyses.[79]

HFC emissions are a leakage type emission, similar to other evaporative emissions from a vehicle.[80] Consequently, HFC emissions are tied more closely to vehicle stock than to VMT.

To calculate HFC emissions, the per-vehicle per-year emission contribution of the current vehicle fleet was determined using averaged 2005 and 2006 registration data from the Transportation Energy Databook (TEDB)[81] and 2005 and 2006 mobile HFC leakage estimates from the EPA Emissions and Sinks report. This per-vehicle per-year contribution was then scaled to the projected vehicle fleet in each future year using data from the emission modeling analysis. This analysis assumes that the leakage rates of the current fleet remain constant into the future. Preliminary EPA estimates suggest that air conditioner charge size is decreasing, which implies that the current analysis may somewhat overstate the HFC emission inventory.

The resulting HFC inventory is a combination top-down/bottom up inventory and includes leakage, maintenance/servicing, and disposal/end of life phases of HFC. The proposed EPA program is expected to impact only two of these phases of the HFC inventory by reducing leakage and reducing need for servicing.

The vehicle population model from the emission analysis was used to calculate the penetration of the technology into the market by calendar year. The equation used for calculating the reductions in HFC is shown below (Equation 6).

Emissions Reductions = Reduction % by Calendar Year x Total CY inventory
Reduction % by CY = $\sum_{\text{Calendar Year}}$ (Reduction % by MY x Vehicle Population by MY)/Total Vehicle Population

Equation 6 - HFC Inventory Calculation

Table 5-17 shows the calculated penetration of technology into the vehicle fleet and consequent reduction from baseline HFC Inventory.

Table 5-17 - HFC (Direct A/C) Emissions

Calendar Year	Baseline HFC (MMT CO2EQ)	Penetration of Technology (Population Based)	Reduction From Baseline (%)	Reduction from Baseline (MMT CO2EQ)
2010	55.0	0%	0%	0.0
2020	61.5	43%	-21%	-13.5
2030	70.5	76%	-38%	-27.2
2040	76.4	84%	-42%	-32.1
2050	82.1	85%	-42%	-34.9

5.3.3.2.2 Indirect A/C (CO2) Emissions

By adding an additional load to the powertrain, A/C indirectly causes an increase in tailpipe CO_2 emissions. Thus, where HFC inventory is proportional to penetration of the technology into the vehicle population, the indirect A/C emission inventory is proportional to VMT of those vehicles. Because newer vehicles are assumed to be driven more, indirect A/C control technology benefits the fleet more quickly than HFC control technology.

The emission rates for indirect A/C usage were taken from the EPA analysis documented in DRIA chapter 2. There, indirect A/C usage is calculated to add 14.25 grams of CO_2 emissions to the certification emissions of either cars or trucks. The indirect A/C controls proposed in the rule are estimated to remove up to 40% of the emission impact of air conditioning systems, or 5.7 grams per mile.

The OMEGA post processor was used to calculate the contribution the indirect A/C program to the overall inventory. Reference and Control scenario emissions due to anticipated improvements to indirect A/C systems are shown in Table 5-18.

Table 5-18 –Indirect A/C Emissions

Calendar Year	Baseline Indirect A/C (MMT CO2EQ)	Reduction From Baseline (%)	Reduction from Baseline (MMT CO2EQ)
2010	52.9	-0%	0
2020	55.2	-20%	-11.0
2030	65.9	-32%	-21.1
2040	80.6	-34%	-27.2
2050	100.5	-34%	-34.1

It should be noted that the baseline indirect A/C emissions are included within the on-road adjustment factor. The baseline inventory is not double counted when aggregating the components of this program.

5.3.3.3 Tailpipe Co-pollutant Emissions

Due to the rebound effect, the downstream emissions of several co-pollutants are anticipated to increase. These inventories are calculated in a similar manner to the CO_2 emissions. Rebound VMT, which is the additional driving, is broken into distribution by vehicle age. VMT by each age was then multiplied by the appropriate emission factor. These emissions by age were then summed by calendar year (Equation 7,Table 5-19).

The EPA reference fleet assumes a small number of diesel vehicles are sold in each year (~20 thousand out of ~13-16 million). For the criteria emission analysis, it was assumed that 0.5% of new light duty vehicles sold were diesels. Because diesel fueled vehicles are subject to the same Tier 2 emission standards as gasoline fueled vehicles, the emission rates of criteria pollutants are similar.[Q]

$$\text{Emissions}_{\text{Calendar Year}} = \sum_{\text{Calendar Year}} (\text{Rebound VMT by Age} * \text{Emission Factor by Age})$$

Equation 7 - Emissions by Calendar Year

Table 5-19 - Delta GHG Emissions Due to Rebound (Metric Tons)

	CALENDAR YEAR			
	2020	**2030**	**2040**	**2050**
Gasoline Fueled Vehicles				
Δ CH_4	307	644	857	1079
Δ N_2O	134	284	377	3475
Diesel Fueled Vehicles				
Δ CH_4	0.13	0.25	0.32	0.40
Δ N_2O	0.20	0.40	0.52	0.66

[Q] Emissions rates between tier 2 gasoline and diesel vehicles are similar but not identical due to the particulars of operations of the engine types. Diesel and gasoline engines emit differently during start, as well as during the various modes of operation.

Table 5-20 - Delta Downstream non-GHG Emissions (Short Tons)

	CALENDAR YEAR	
	2020	2030
Gasoline Fueled Vehicles		
Δ 1,3-Butadiene	13.08	39.75
Δ Acetaldehyde	24.58	74.86
Δ Acrolein	1.22	3.72
Δ Benzene	79.27	241.26
Δ CO	77,648.80	241,314.67
Δ Formaldehyde	31.08	94.43
Δ NO_x	5,128.09	15,110.31
Δ $PM_{2.5}$	217.31	569.82
Δ SO_2	-2,502.6	-4,905.6
Δ VOC	1,678.90	5,442.80
Diesel Fueled Vehicles		
Δ 1,3-Butadiene	0.17	0.44
Δ Acetaldehyde	0.23	0.60
Δ Acrolein	0.07	0.17
Δ Benzene	0.37	0.98
Δ CO	174.13	624.39
Δ Formaldehyde	0.72	1.89
Δ NO_x	225.72	449.95
Δ $PM_{2.5}$	0.88	1.87
Δ SO_2	Attributed to Gasoline	
Δ VOC	19.33	51.03

In general, downstream emissions are predicted to increase a small amount due to rebound driving. The one exception is sulfur emissions (SO_2), which are predicted to decrease as a result of the decrease in fuel consumption. As shown in section 5.3.4, the increases in non-ghg pollutants are generally less than the projected decreases on the upstream side. The exceptions are in those pollutants, such as carbon monoxide (CO), where a relatively small of US emissions comes from upstream sources.

5.3.3.4 Fuel Savings

The proposed EPA program is anticipated to create significant fuel savings as compared to the reference case. Projected fuel savings are shown in Table 5-21. Fuel savings can be calculated from total tailpipe CO_2 avoided (including CO_2 due to driving and indirect

A/C use) using a conversion factor of 8887 grams of CO_2 per gallon of gasoline. All fuel saved is considered 100% gasoline without any oxygenate.[R,82]

Fuel savings were calculated from total tailpipe CO_2 avoided (including CO_2 due to driving and indirect A/C) using a conversion factor of 8887 grams of CO_2 per gallon of gasoline. [83]

Table 5-21 - Downstream Fuel Consumption Changes by Calendar Year

(Billions of Gallons of Gasoline Equivalent)

	2020	**2030**	**2040**	**2050**
Fuel Consumption (Reference)	142.2	161.9	196.2	244.1
Δ Total Fuel Consumption due to EPA Program	-13.4	-26.2	-33.9	-42.6
Δ Fuel Consumption due to 10% rebound	1.2	2.3	3.0	3.8
Δ Fuel Consumption due to A/C controls	-1.2	-2.4	-3.1	-3.8

5.3.4 Calculation of Upstream Emissions

The term "upstream emissions" refers to air pollutant emissions generated from all crude oil extraction, transport, refining, and finished fuel transport, storage, and distribution. As shown above in Table 5-4 this includes all the stages prior to the final filling of vehicle fuel tanks at retail service stations. The details of the assumptions, data sources, and calculations that were used to estimate the emission impacts presented here can be found in the Technical Support Document and the docket memo, "Calculation of Upstream Emissions for the GHG Vehicle Rule."[84]

5.4 Greenhouse Gas Emission Inventory

This section presents total program calendar year impacts by sector (Table 5-22, Table 5-23,Table 5-24). Upstream, downstream, and total program impact are presented.

[R] Based on the documentation of the on-road gap, it would be justifiable to assume an ethanol percentage of 0.8%. This volume of ethanol would result in a total energy difference of less than 0.5%. See the fuel labeling rule technical support document, EPA420-R-06-017, for further details.

Table 5-22 – Downstream GHG and Fuel Consumption Changes vs. Reference Case

	2020	2030	2040	2050
Δ CO2 (Metric Tons)	-118,682,739	-232,643,716	-301,498,777	-378,287,357
Δ CH4 (Metric tons)	308	645	857	1,080
Δ N2O (Metric tons)	134	284	378	476
Δ HFC (Metric tons)	-9,429	-18,987	-22,420	-24,407
Δ GHG (MMT CO2 EQ)	**-132.1**	**-259.7**	**-333.4**	**-413.0**
Δ Fuel Consumption (billion gallons per year)	**-13.4**	**-26.2**	**-33.9**	**-42.6**

Table 5-23 – Upstream GHG Change vs. Reference Case

	2020	2030	2040	2050
Δ CO2 (Metric Tons)	-28,857,236	-56,566,395	-73,308,230	-91,979,068
Δ CH4 (Metric tons)	-163,638	-320,765	-415,701	-521,576
Δ N2O (Metric tons)	-464	-909	-1,178	-1,478
Δ GHG (MMT CO2 EQ)	**-33.1**	**-64.9**	**-84.1**	**-105.5**

Table 5-24 – Total GHG and Fuel Consumption Changes vs. Reference Case

	2020	2030	2040	2050
Δ CO2 (Metric Tons)	-147,539,975	-289,210,111	-374,807,007	-470,266,424
Δ CH4 (Metric tons)	-163,330	-320,120	-414,844	-520,496
Δ N2O (Metric tons)	-329	-625	-800	-1,002
Δ HFC (Metric tons)	-9,429	-18,987	-22,420	-24,407
Δ GHG (MMT CO2 EQ)	**-165.2**	**-324.6**	**-417.5**	**-518.5**
Δ Fuel Consumption (billion gallons per year)	**-13.4**	**-26.2**	**-33.9**	**-42.6**

5.4.1 Impact on US and Global GHG Inventory

As stated in the introduction, climate change is widely viewed as the most significant long-term threat to the global environment. According to the Intergovernmental Panel on Climate Change, anthropogenic emissions of greenhouse gases are very likely (90 to 99 percent probability) the cause of most of the observed global warming over the last 50 years. All mobile sources emitted 31.5 percent of all US GHG in 2006, and have been the fastest - growing source of US GHG since 1990. Light-duty vehicles are responsible for nearly 60 percent of all mobile source GHGs. For light-duty vehicles, CO2 emissions represent about 95 percent of all greenhouse emissions, and the CO2 emissions measured over the EPA tests used for fuel economy compliance represent over 90 percent of total light-duty vehicle greenhouse gas emissions.

This action is an important step towards curbing steady growth of GHG emissions from cars and light trucks. In the absence of control, GHG emissions worldwide and in the U.S. are projected to continue steady growth; U.S. GHGs are estimated to make up roughly 15 percent of total worldwide emissions, and the contribution of direct emissions from cars and light-trucks to this U.S. share is growing over time, reaching an estimated 20 percent of U.S. emissions by 2030 in the absence of control.

As discussed elsewhere in this proposal, this steady rise in GHG emissions is associated with numerous adverse impacts on human health, food and agriculture, air quality, and water and forestry resources.

5.5 Non-Greenhouse Gas Emission Inventory

The reference case emission inventories used for this proposed rule are obtained from different sources depending on sector.

For stationary/area sources and aircraft, 2020 projections were used from the 2002 National Emissions Inventory (NEI), Version 3. The development of these inventories is documented in the November 27, 2007, memo titled, "Approach for Developing 2002 and Future Year National Emission Summaries," from Madeleine Strum to Docket EPA-HQ-OAR-2007-0491. That memo summarizes the methodologies and additional reference documents for criteria air pollutants (CAP) and mobile source air toxics (MSATs). The effects of the Clean Air Interstate rule are not included here.

For onroad mobile sources, the MOVES Draft 2009 model was used that estimates emissions from light-duty and heavy-duty gasoline and diesel vehicles, except for motorcycles. For motorcycles, the MOBILE6.2 model was used as run using the NMIM platform that applies county specific fuel properties and temperatures. For the MOVES model runs the Vehicle Miles Traveled (VMT) of light-duty gasoline vehicles was adjusted to account for factors related to this proposal, such as the ten percent rebound effect as described above in Sections 5.3.3.1.1 and 5.3.3.1.2.

Most nonroad equipment was modeled with NONROAD2005d using NMIM, which is a version of the NONROAD that includes the benefits of the two nonroad regulations published in 2008 (the locomotive and marine diesel rule and the small spark-ignition and recreational marine engine rule).[85, 86]

Inventories for locomotives and commercial marine vessels are not covered by the NONROAD model, and they have been updated since the 2002 NEI and its future year projections were completed. Thus the more recent inventory projections published in the regulatory impact analyses of their respective recent rulemakings were used.[85, 87] Locomotives and C1/C2 commercial marine vessel inventories come from the spring 2008 final rule, and the C3 commercial marine emission inventory is from the base case inventories in the June 2009 proposed rule.

Table 5-25 and Table 5-26 show the total 2020 and 2030 mobile and non-mobile source inventory projections that were used as the reference case against which impacts of the rule were applied. The impacts, expressed as percentages, are presented below in Sections 5.5.1 through 5.5.3.

Table 5-25. 2020 Reference Case Emissions by Sector (annual short tons)

	VOC	**CO**	**NOX**	**PM10**	**PM2.5**	**SO2**
Onroad Gasoline	1,973,180	29,211,716	1,934,488	96,380	58,990	30,922
Onroad Diesel	129,321	260,238	1,353,773	32,733	40,071	4,218
Nonroad SI[a]	1,289,918	14,286,250	242,828	53,092	49,019	15,413
Other Nonroad[b]	234,870	1,424,643	3,389,761	230,553	210,509	943,226
Stationary/Area	8,740,057	11,049,239	5,773,927	3,194,610	3,047,714	7,864,681
Total	12,367,346	56,232,087	12,694,778	3,607,368	3,406,303	8,858,459

TABLE 5-25 CONTINUED	**BENZENE**	**1,3-BUTADIENE**	**ACETAL-DEHYDE**	**FORMAL-DEHYDE**	**ACROLEIN**
Onroad Gasoline	60,742	7,518	14,604	18,716	903
Onroad Diesel	1,571	830	3,743	10,010	475
Nonroad SI[a]	36,862	5,895	4,768	10,240	584
Other Nonroad[b]	3,760	929	9,542	22,324	1,013
Stationary/Area	111,337	1,847	13,118	23,846	3,412
Total	214,273	17,019	45,777	85,136	6,387

[a] Nonroad gasoline, LPG, and CNG engines plus portable fuel containers
[b] Nonroad diesel engines and all locomotive, aircraft, and commercial marine

Table 5-26. 2030 Reference Case Emissions by Sector (annual short tons)

	VOC	CO	NOX	PM10	PM2.5	SO2
Onroad Gasoline	1,800,856	32,038,635	1,504,390	110,796	67,416	36,011
Onroad Diesel	140,959	219,594	1,120,656	34,746	26,498	5,478
Nonroad SI[a]	1,198,679	15,815,805	243,515	55,011	50,816	17,270
Other Nonroad[b]	238,652	1,411,393	3,427,832	253,572	229,183	1,426,994
Stationary/Area	8,740,057	11,049,239	5,773,927	3,194,610	3,047,714	7,864,681
Total	12,119,203	60,534,666	12,070,321	3,648,735	3,421,628	9,350,433

Table 5-26 continued	Benzene	1,3-Butadiene	Acetal-dehyde	Formal-dehyde	Acrolein
Onroad Gasoline	55,692	6,840	13,354	17,071	812
Onroad Diesel	1,706	915	4,050	10,903	517
Nonroad SI[a]	39,871	6,279	5,118	11,229	629
Other Nonroad[b]	3,764	979	9,579	22,487	1,055
Stationary/Area	111,337	1,847	13,118	23,846	3,412
Total	212,371	16,859	45,220	85,536	6,425

[a] Nonroad gasoline, LPG, and CNG engines plus portable fuel containers

[b] Nonroad diesel engines and all locomotive, aircraft, and commercial marine

5.5.1 Downstream Impacts of Program

As described in the introduction, downstream inventories were generated using algorithms from EPA's Optimization Model for reducing Emissions of Greenhouse gases from Automobiles (OMEGA). The OMEGA benefits post-processor produces a national scale analysis of the benefits (emission reductions, monetized co-benefits) of the analyzed program. The non-GHG emission results shown here (Table 5-27) were calculated in a spreadsheet analysis using algorithms from the Draft MOVES 2009 emission database and algorithms from the OMEGA post-processor.

Table 5-27. Downstream Emission Changes of Proposed Program

POLLUTANT	CALENDAR YEAR 2020		CALENDAR YEAR 2030	
	Short Tons	Percent Change in US Total	Short Tons	Percent Change in US Total
Δ 1,3-Butadiene	13.2	0.078%	40.2	0.238%
Δ Acetaldehyde	25	0.054%	75	0.167%
Δ Acrolein	1.29	0.020%	3.89	0.061%
Δ Benzene	80	0.037%	242	0.114%
Δ Carbon Monoxide	77,823	0.138%	241,939	0.400%
Δ Formaldehyde	32	0.037%	96	0.113%
Δ Oxides of Nitrogen	5,354	0.042%	15,560	0.129%
Δ Particulate Matter (below 2.5 micrometers)	218	0.006%	572	0.017%
Δ Oxides of Sulfur	-2,503	-0.028%	-4,906	-0.052%
Δ Volatile Organic Compounds	1,698	0.014%	5,494	0.045%

5.5.2 Upstream Impacts of Program

Fuel production and distribution emission impacts of the proposed program were estimated in conjunction with the development of life cycle GHG emission impacts, and the GHG emission inventories discussed above. The basic calculation is a function of fuel volumes in the analysis year and the emission factors associated with each process or subprocess.

In general this life cycle analysis uses the same methodology as the Renewable Fuel Standard (RFS2) proposed rule. It relies partially on the "Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation" (GREET) model, developed by the Department of Energy's Argonne National Laboratory (ANL), but takes advantage of additional information and models to significantly strengthen and expand on the GREET analysis.

Updates and enhancements to the GREET model assumptions include updated crude oil and gasoline transport emission factors that account for recent EPA emission standards and modeling, such as the Tier 4 diesel truck standards published in 2001 and the locomotive and commercial marine standards finalized in 2008. In addition, GREET does not include air toxics. Thus emission factors for the following air toxics were added: benzene, 1,3-butadiene, formaldehyde, acetaldehyde, and acrolein. These upstream toxics emission factors were calculated from the 2002 National Emissions Inventory (NEI), a risk and technology review for petroleum refineries, speciated emission profiles in EPA's SPECIATE database, or the Mobile Source Air Toxics rule (MSAT) inventory for benzene; these pollutant tons were divided by refinery energy use or gasoline distribution quantities published by the DOE Energy Information Administration (EIA) to get emission factors in terms of grams per million BTU of finished gasoline. The resulting emission factors are presented in Chapter 4 of the draft joint TSD for today's proposed rule.

Results of these emission inventory impact calculations relative to the reference case for 2020 and 2030 are shown in Table 5-28 for the criteria pollutants and individual air toxic pollutants.

The proposed program is projected to provide reductions in all pollutants associated with gasoline production and distribution as the projected fuel savings reduce the quantity of gasoline needed.

Table 5-28. Upstream Emission Changes of Proposed Program

POLLUTANT	CALENDAR YEAR 2020		CALENDAR YEAR 2030	
	Short Tons	Percent Change in US Total	Short Tons	Percent Change in US Total
Δ 1,3-Butadiene	-1.8	-0.010%	-3.4	-0.020%
Δ Acetaldehyde	-8	-0.017%	-15	-0.033%
Δ Acrolein	-1	-0.017%	-2	-0.032%
Δ Benzene	-163	-0.076%	-320	-0.151%
Δ Carbon Monoxide	-7,209	-0.013%	-14,107	-0.023%
Δ Formaldehyde	-60	-0.071%	-112	-0.131%
Δ Oxides of Nitrogen	-22,560	-0.178%	-43,286	-0.359%
Δ Particulate Matter (below 2.5 micrometers)	-3,075	-0.090%	-6,003	-0.175%
Δ Oxides of Sulfur	-13,804	-0.156%	-27,060	-0.289%
Δ Volatile Organic Compounds	-75,437	-0.610%	-147,841	-1.220%

5.5.3 Total Program Impact

Table 5-29 shows the combined impacts of downstream and upstream aspects of the proposed program. The fuel production and distribution impacts of the proposed program on VOC, NOx, PM2.5, and SOx are mainly due to reductions in emissions associated with gasoline production and distribution as the projected fuel savings of the program reduce the quantity of gasoline needed. Increases in CO are driven by the rebound effect on VMT, which are only partially offset by upstream reductions.

Air toxic emission impacts depend on the relative reductions from upstream emissions versus increases due to rebound on the downstream emissions. Relative to 2030 US total reference case emissions, formaldehyde and benzene emissions are projected to decrease by 0.02 to 0.04 percent, but 1,3-butadiene, acetaldehyde, and acrolein emissions would increase by 0.03 to 0.22 percent.

Table 5-29. Total Non-GHG Emission Changes of Proposed Program

POLLUTANT	CALENDAR YEAR 2020		CALENDAR YEAR 2030	
	Short Tons	Percent Change in US Total	Short Tons	Percent Change in US Total
Δ 1,3-Butadiene	11.5	0.07%	36.8	0.22%
Δ Acetaldehyde	17	0.04%	61	0.13%
Δ Acrolein	0.2	0.00%	1.8	0.03%
Δ Benzene	-84	-0.04%	-77	-0.04%
Δ Carbon Monoxide	70,614	0.13%	227,832	0.38%
Δ Formaldehyde	-28	-0.03%	-16	-0.02%
Δ Oxides of Nitrogen	-17,206	-0.14%	-27,726	-0.23%
Δ Particulate Matter (below 2.5 micrometers)	-2,856	-0.08%	-5,431	-0.16%
Δ Oxides of Sulfur	-16,307	-0.18%	-31,965	-0.34%
Δ Volatile Organic Compounds	-73,739	-0.60%	-142,347	-1.17%

5.6 Model Year Lifetime Analyses

5.6.1 Methodology

EPA also conducted a separate analysis of the total benefits over the model year lifetime of 2012 through 2016 model year vehicles. In contrast to the calendar year analysis, the model year lifetime analysis shows the lifetime impacts of the program on each MY fleet over the course of its existence.

In this analysis, a simplified VMT schedule is used. Rather than using a MY specific VMT schedule for each MY, a single VMT schedule is used for all five model years. This VMT schedule is more fully described in the draft joint TSD. In brief, it was derived using the same methodology as the MY-specific VMT schedules and is the average of the VMT schedules from 2012-2030 (Table 5-30).

All other inputs, including sales, emission factors and achieved emission levels are the same between the two analyses.

Table 5-30 - Updated Survival Fraction and Mileage Accumulation by Age

AGE	PA SURVIVAL FRACTION	PA MILEAGE	NPA SURVIVAL FRACTION	NPA MILEAGE
0	0.9950	16,932	0.9950	18,847
1	0.9900	16,603	0.9741	18,408
2	0.9831	16,257	0.9603	18,050
3	0.9731	15,814	0.9420	17,575
4	0.9593	15,414	0.9190	17,142
5	0.9413	14,993	0.8913	16,593
6	0.9188	14,545	0.8590	16,095
7	0.8918	14,105	0.8226	15,493
8	0.8604	13,624	0.7827	14,891
9	0.8252	13,192	0.7401	14,336
10	0.7866	12,668	0.6956	13,689
11	0.7170	12,222	0.6501	13,160
12	0.6125	11,705	0.6042	12,554
13	0.5094	11,191	0.5517	11,945
14	0.4142	10,727	0.5009	11,342
15	0.3308	10,283	0.4522	10,822
16	0.2604	9,878	0.4062	10,383
17	0.2028	9,482	0.3633	9,900
18	0.1565	9,090	0.3236	9,433
19	0.1200	8,691	0.2873	9,033
20	0.0916	8,366	0.2542	8,692
21	0.0696	8,126	0.2244	8,499
22	0.0527	8,003	0.1975	8,246
23	0.0399	7,774	0.1735	8,261
24	0.0301	7,587	0.1522	8,066
25	0.0227	7,424	0.1332	8,066
26	0.0000	7,334	0.1165	8,101
27	0.0000	7,200	0.1017	8,098
28	0.0000	7,103	0.0887	8,096
29	0.0000	7,044	0.0773	8,095
30	0.0000	7,042	0.0673	8,093
31	0.0000	7,039	0.0586	8,092
32	0.0000	7,033	0.0509	8,086
33	0.0000	7,021	0.0443	8,080
34	0.0000	7,007	0.0385	8,064
35	0.0000	6,988	0.0334	8,050

5.6.2 Results

The GHG emission reductions are shown for each model year, as are the co-pollutant impacts (Table 5-31, Table 5-32).

Table 5-31 – Lifetime GHG Emissions vs. Reference Case (MMT CO2 EQ)

	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016	Program Total
Δ Downstream Tailpipe Emission	-53.19	-79.99	-110.75	-154.99	-213.28	-612.19
Δ Downstream Indirect A/C	-5.33	-9.04	-12.88	-17.87	-20.28	-65.39
Δ Downstream Direct A/C	-6.92	-11.73	-16.72	-23.20	-26.32	-84.89
Δ Downstream CH4	0.00	0.01	0.01	0.01	0.02	0.05
Δ Downstream N2O	0.02	0.03	0.05	0.06	0.10	0.26
Total Δ Downstream	-65.41	-100.71	-140.29	-195.99	-259.76	-762.17
Δ Upstream CO_2	-14.23	-21.65	-30.06	-42.03	-56.79	-164.75
Δ Upstream CH4	-1.69	-2.58	-3.58	-5.01	-6.76	-19.62
ΔUpstream N2O	-0.07	-0.11	-0.15	-0.21	-0.28	-0.82
Total Δ Upstream	-15.99	-24.33	-33.79	-47.25	-63.83	-185.19
Total Program Δ GHG Emissions	-81.41	-125.05	-174.08	-243.23	-323.59	-947.36
Total Program Fuel Savings (Billion Barrels)	0.16	0.24	0.33	0.46	0.63	1.82

Table 5-32 – Lifetime non-GHG Emissions vs. Reference Case (Short Tons)

	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016	Program Total
Downstream						
Δ VOC	1,495	2,373	3,336	4,751	6,763	18,717
Δ NO_X	3,991	6,602	9,469	13,485	20,082	53,629
Δ $PM_{2.5}$	152	241	338	482	686.074	1,899
Δ CO	63,783	102,779	145,598	207,338	295,494	814,992
Δ SO_2	-1,234	-1,877	-2,607	-3,645	-4,925	-14,288
Δ Benzene	65.1	103.4	145.4	207.1	294.2	815
Δ 1,3 Butdiene	10.8	17.1	24.1	34.3	48.8	135
Δ Formaldehyde	25.9	41.1	57.9	82.4	117.1	324
Δ Acetaldehyde	20.3	32.2	45.3	64.5	91.6	254
Δ Acrolein	1.0	1.7	2.3	3.3	4.7	13
Upstream						
Δ VOC	-37,188	-56,572	-78,562	-109,850	-148,418	-430,591
Δ NO_X	-10,888	-16,564	-23,002	-32,163	-43,455	-126,072
Δ $PM_{2.5}$	-1,510	-2,297	-3,190	-4,460	-6,026	-17,484
Δ CO	-3,549	-5,398	-7,496	-10,482	-14,162	-41,087
Δ SO_2	-6,807	-10,354	-14,379	-20,106	-27,165	-78,812
Δ Benzene	-80.4	-122.3	-169.9	-237.6	-321.0	-931
Δ 1,3 Butdiene	-0.9	-1.3	-1.8	-2.6	-3.5	-10
Δ Formaldehyde	-28.2	-42.9	-59.5	-83.2	-112.5	-326
Δ Acetaldehyde	-3.7	-5.7	-7.9	-11.0	-14.9	-43
Δ Acrolein	-0.5	-0.8	-1.1	-1.5	-2.1	-6
Total						
Δ VOC	-35,694	-54,199	-75,226	-105,099	-141,655	-411,874
Δ NO_X	-6,897	-9,962	-13,533	-18,678	-23,373	-72,443
Δ $PM_{2.5}$	-1,358	-2,056	-2,852	-3,978	-5,340	-15,585
Δ CO	60,234	97,381	138,101	196,856	281,332	773,905
Δ SO_2	-8,041	-12,232	-16,986	-23,751	-32,090	-93,099
Δ Benzene	-15	-19	-24	-30	-27	-116
Δ 1,3 Butdiene	10	16	22	32	45	125
Δ Formaldehyde	-2	-2	-2	-1	5	-2
Δ Acetaldehyde	17	27	37	53	77	211
Δ Acrolein	1	1	1	2	3	7

5.7 Alternative 4% and 6% Scenarios

For this proposal, two alternative control scenarios were evaluated characterized by 4% and 6% annual growth in the GHG standards from the MY 2011 standard. Other than the standards, these scenarios share all inputs with the proposed EPA program. Only GHG reductions and fuel savings are shown for these programs.

5.7.1 4% Scenario

5.7.1.1 Standards and Achieved Levels

The program standards are shown in Table 5-33 and the achieved levels are shown in Table 5-34.

Table 5-33: 4% Scenario Standards

MODEL YEAR	PA EMISSION LEVEL	NPA EMISSION LEVEL	ANTICIPATED MY EMISSION LEVEL
2012	276	366	310
2013	265	355	298
2014	255	342	286
2015	246	331	275
2016	237	318	264

Table 5-34: 4% Scenario Achieved Levels

MODEL YEAR	ANTICIPATED PA EMISSION LEVEL	ANTICIPATED NPA EMISSION LEVEL	ANTICIPATED MY EMISSION LEVEL
2012	275	378	314
2013	266	368	304
2014	258	352	292
2015	249	338	279
2016	237	319	264

5.7.1.2 Results

Results are shown relative to the same reference scenario as the proposed EPA program. Both calendar year and model year lifetime results are shown.

Table 5-35 – Downstream CY GHG Reductions and Fuel Savings vs. Reference Case

	CY 2020	CY 2030	CY 2040	CY 2050
Downstream				
Δ CO_2 excluding indirect A/C controls (MMT CO_2 EQ)	-97.7	-196.6	-255.5	-320.7
ΔIndirect A/C CO_2(MMT CO_2 EQ)	-11.0	-21.1	-27.2	-34.1
Δ Direct A/C HFC (MMT CO_2 EQ)	-13.5	-27.2	-32.1	-34.9
Δ CH_4 (MMT CO_2 EQ)	0	0	0	0
Δ N_2O (MMT CO_2 EQ)	0	0	0.1	0.1
Δ Total GHG (MMT CO_2 EQ)	-122.2	-244.8	-314.7	-389.6
Upstream				
Δ CO_2 (MMT CO_2 EQ)	-26.4	-52.9	-68.7	-86.2
Δ CH_4 (MMT CO_2 EQ)	-4.1	-8.0	-10.4	-13.0
Δ N_2O (MMT CO_2 EQ)	-0.1	-0.3	-0.3	-0.4
Δ Total GHG	-30.5	-61.2	-79.4	-99.6
Total				
Δ Total GHG	-152.7	-306.0	-394.4	-489.2
Δ Fuel Consumption (Annual, Billion gallons)	-12.2	-24.5	-31.8	-39.9

Table 5-36 – Total Model Year Lifetime GHG Reductions vs. Baseline

	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016	Program Total
Downstream						
Δ CO_2 excluding indirect A/C controls (MMT CO_2 EQ)	-22.1	-55.2	-100.3	-145.4	-198.8	-521.8
ΔIndirect A/C CO_2(MMT CO_2 EQ)	-5.3	-9.0	-12.9	-17.9	-20.3	-65.4
Δ Direct A/C HFC (MMT CO_2 EQ)	-6.9	-11.7	-16.7	-23.2	-26.3	-84.9
Δ CH_4 (MMT CO_2 EQ)	0.0	0.0	0.0	0.0	0.0	0.0
Δ N_2O (MMT CO_2 EQ)	0.0	0.0	0.0	0.1	0.1	0.2
Δ Total GHG (MMT CO_2 EQ)	-34.3	-75.9	-129.9	-186.4	-245.3	-671.8
Upstream						
Δ CO_2 (MMT CO_2 EQ)	-6.7	-15.6	-27.5	-39.7	-53.3	-142.8
Δ CH_4 (MMT CO_2 EQ)	-0.8	-1.9	-3.3	-4.7	-6.3	-17.0
Δ N_2O (MMT CO_2 EQ)	0.0	-0.1	-0.1	-0.2	-0.3	-0.7
Δ Total GHG	-7.5	-17.6	-30.9	-44.6	-59.9	-160.5
Total						
Δ Total GHG	-41.8	-93.5	-160.8	-231.0	-305.2	-832.3
Δ Fuel Consumption (Annual, Billion gallons)	-3.09	-7.3	-12.7	-18.4	-24.7	-66.1

5.7.2 6% Scenario

5.7.2.1 Standards and Achieved Levels

The program standards are shown in Table 5-33 and the achieved levels are shown in Table 5-34.

Table 5-37: 6% Scenario Standards

MODEL YEAR	ANTICIPATED PA EMISSION LEVEL	ANTICIPATED NPA EMISSION LEVEL	ANTICIPATED MY EMISSION LEVEL
2012	269	362	304
2013	255	342	287
2014	241	323	270
2015	228	306	255
2016	216	290	241

Table 5-38: 6% Scenario Achieved Levels

MODEL YEAR	ANTICIPATED PA EMISSION LEVEL	ANTICIPATED NPA EMISSION LEVEL	ANTICIPATED MY EMISSION LEVEL
2012	270	375	309
2013	258	352	292
2014	244	332	275
2015	230	313	259
2016	216	290	241

5.7.2.2 Results

Results are shown relative to the same reference scenario as the proposed EPA program. Both calendar year and model year lifetime results are shown.

Table 5-39 –CY GHG Emissions and Fuel Consumption vs. Reference Case

	CY 2020	CY 2030	CY 2040	CY 2050
Downstream				
Δ CO_2 excluding indirect A/C controls (MMT CO_2 EQ)	-146.8	-290.8	-377.2	-473.3
ΔIndirect A/C CO_2(MMT CO_2 EQ)	-11.0	-21.3	-27.5	-34.4
Δ Direct A/C HFC (MMT CO_2 EQ)	-13.5	-27.2	-32.1	-34.9
Δ CH_4 (MMT CO_2 EQ)	0.0	0.0	0.0	0.0
Δ N_2O (MMT CO_2 EQ)	0.0	0.0	0.1	0.1
Δ Total GHG (MMT CO_2 EQ)	-171.3	-339.2	-436.6	-542.4
Upstream				
Δ CO_2 (MMT CO_2 EQ)	-38.4	-75.9	-98.4	-123.4
Δ CH_4 (MMT CO_2 EQ)	-5.5	-10.7	-14.0	-17.4
Δ N_2O (MMT CO_2 EQ)	-0.1	-0.4	-0.4	-0.5
Δ Total GHG	-44.0	-87.0	-112.7	-141.4
Total				
Δ Total GHG	-215.2	-426.2	-549.3	-683.9
Δ Fuel Consumption (Annual, Billion gallons)	-17.8	-35.1	-45.5	-57.1

Table 5-40 –MY Lifetime GHG Emissions and Fuel Consumption vs. Reference Case

	MY 2012	**MY 2013**	**MY 2014**	**MY 2015**	**MY 2016**	**Program Total**
Downstream						
Δ CO_2 excluding indirect A/C controls (MMT CO_2 EQ)	-36.5	-96.8	-162.5	-225.7	-292.9	-814.4
ΔIndirect A/C CO_2(MMT CO_2 EQ)	-5.3	-9.0	-12.9	-17.9	-20.3	-65.4
Δ Direct A/C HFC (MMT CO_2 EQ)	-6.9	-11.7	-16.7	-23.2	-26.3	-84.9
Δ CH_4 (MMT CO_2 EQ)	0.0	0.0	0.0	0.0	0.0	0.1
Δ N_2O (MMT CO_2 EQ)	0.0	0.0	0.1	0.1	0.1	0.4
Δ Total GHG (MMT CO_2 EQ)	-48.7	-117.5	-192.0	-266.7	-339.3	-964.2
Upstream						
Δ CO_2 (MMT CO_2 EQ)	-10.2	-25.7	-42.6	-59.2	-76.1	-213.9
Δ CH_4 (MMT CO_2 EQ)	-1.2	-3.1	-5.1	-7.1	-9.1	-25.5
Δ N_2O (MMT CO_2 EQ)	-0.1	-0.1	-0.2	-0.3	-0.4	-1.1
Δ Total GHG	-11.4	-28.9	-47.9	-66.6	-85.6	-240.4
Total						
Δ Total GHG	-60.2	-146.4	-239.9	-333.3	-424.9	-1204.7
Δ Fuel Consumption (Annual, Billion gallons)	-4.7	-11.9	-19.7	-27.4	-35.2	-99.0

5.A Appendix to Chapter 5: Details of the TLAAS Impacts Analysis

5.A.1 Introduction and Summary

The TLAAS program allows manufacturers with total domestic sales of less than 400,000 vehicles during model year 2009 to place up to 100,000 vehicles from model years 2012-2015 into a separate fleet. This separate fleet is subject to a 25% less stringent standard than the manufacturer's primary fleet (subject to various further constraints described in section III of the preamble and in the proposed rule itself).

Several manufacturer decisions and marketplace events determine the impacts of the TLAAS program. This appendix presents a sensitivity analysis that brackets the impact of the program, and provides additional details on the assumptions made in the EPA emission analysis.

Although the bracketing analyses presented here range from 0 to 25 MMT of CO_2 emissions, in all cases the TLAAS program has a proportionally small impact (< 3%) on the total program benefits over the model years 2012-2016.

Under the estimation procedure used in the emission inventory analysis (as opposed to the bracketing analysis mentioned immediately above), the TLAAS is projected to result in an approximately 3.4 MMT decrease in greenhouse gas benefits from this rule over the lifetime of vehicles manufactured in model years 2012-2015 (assuming that it is technically feasible for all TLAAS-eligible producers to meet the otherwise-applicable GHG standards for those years, a dubious assumption given the very short lead times available).

5.A.2 Factors Determining the Impact of the TLAAS

The greatest challenge to accurately estimating the impacts of the TLAAS are uncertainties about manufacturer eligibility and manufacturer usage of the program. There is a third, albeit smaller uncertainty, concerning the size of the vehicles placed in the program.

Eligibility

Up to eleven major manufacturers are potentially eligible for TLAAS based on preliminary EPA analysis of projected domestic sales for model year 2009. These manufacturers are Porsche, Tata, Mazda, Mitsubishi, Suzuki, Daimler, Subaru, BMW, Volkswagen, Hyundai, and Kia.

Manufacturers such as Hyundai, Kia, Mazda, and Volkswagen are preliminarily estimated at 2009 domestic sales bordering 400,000. If none of these four manufacturers are eligible for the TLAAS program, the program covers up to 700,000 vehicles. If all four are included, the program increases in size by approximately 50% to 1.1 million vehicles.

The impacts of the program therefore partially depend on manufacturer eligibility.

Manufacturer Usage

By reducing the compliance burden, the TLAAS provides needed lead time flexibility to manufacturers in order to comply with the Light Duty Vehicle Greenhouse Gas Program in the short term, and provides needed lead time for these manufacturers to bring their entire fleet into compliance with the stringent 2016 MY standards. However, it is unclear whether manufacturers will participate in the TLAAS program to the fullest extent allowed, as there are two disincentives to fully utilizing the TLAAS.

Vehicles in the TLAAS fleet may consume more fuel than comparably sized vehicles in the primary fleet. Assuming consumers place some weight on fuel economy when purchasing a vehicle, manufacturers with TLAAS fleets may thus place their vehicles at a competitive disadvantage in the marketplace.

Further, at the cessation of the TLAAS program, manufacturers will need their fleet to meet the more stringent main program standards. If a manufacturer takes full advantage of the program by using the maximum 25% additional emission allotment, they may place themselves at a technological disadvantage when the program ends. Both in terms of engineering and manufacturing, a manufacturer is unlikely to want to fall behind its competitors. To avoid this scenario, a manufacturer may make gradual gains over the TLAAS program, and gradually use less of the 25% additional emission allotment.

Because of these disincentives, manufacturers may likewise choose to not fully utilize the TLAAS vehicle production volumes.

Size and Classification of the Vehicles Placed in the TLAAS Fleet

As the TLAAS program allows 25% additional emissions over the footprint-based main fleet standards, the size of the vehicles placed in the TLAAS fleet is significant. If a manufacturer places small but high emitting vehicles in the TLAAS fleet (ie, Porsche Carrera), the impact of the program is less than if large and high emitting vehicles are placed in the TLAAS fleet.

A manufacturer who utilized the TLAAS fleet for small vehicles would necessarily have a proportionally lower net impact. Similarly, due to the two distinct footprint curves, the choice whether to place cars or trucks in the TLAAS fleet will also determine impact.

5.A.3 Bounding Analysis of TLAAS Impact

This section provides upper and lower bounds for the potential impacts from the TLAAS, and then describes the inputs used in the emission analysis.

TLAAS is an optional program which can be used for a limited number of eligible vehicles to achieve compliance with the Light Duty Vehicle Greenhouse Gas Program.

Consequently, no manufacturer is obligated to use the program, and the lower bound of the program impact could theoretically be zero. This is considered a highly unlikely scenario, as several manufacturers are anticipated to use the TLAAS to meet their compliance targets given the lack of lead time for these manufacturers to make the major conversions necessary to meet the standards.

Conversely, as an upper bound, every manufacturer could use their full allocation on their largest vehicle, could potentially increase sales of those vehicles to 100,000 over the four year period, and could use the full 25% "cushion" for each of these vehicles. This is also an unlikely scenario, as it would require companies such as Porsche and BMW to sell specific vehicle models (such as the Porsche Boxster, or the Rolls Royce Phantom) in unprecedented numbers.

As a boundary analysis, EPA analyzed these upper and lower bound scenarios . The GHG savings from the lower bound program was estimated at 950 MMT GHG reduced over lifetime of model years 2012-2016 (i.e. impact of the TLAAS is zero), while the upper bound impact was 925 MMT GHG reduced over the same period. Thus, the maximum potential impact of the program, even under this most extreme scenario is approximately 25 MMT.

As noted, neither of these scenarios is remotely likely. However, the point of the bounding analysis is to show that the greatest possible impact of the proposed TLAAS is still relatively minimal.

5.A.4 Approach used for Estimating TLAAS Impact

Having bounded the analysis, a third approach was used for the emission modeling described in DRIA chapter 5. In this analysis, all eleven manufacturers were assumed to use the default vehicle allocation schedule from the TLAAS. This is a conservative estimate, as several of the manufacturers are unlikely to utilize their allocation due to either lack of need, or the disincentives discussed above.

Table 5-41:TLAAS Default Vehicle Production Volumes

MODEL YEAR	2012	2013	2014	2015
Sales Volume	**40,000**	**30,000**	**20,000**	**10,000**

The allocation was split evenly between cars and trucks for each manufacturer. The TLAAS fleet was assumed to emit as much CO_2 per mile as expected from the largest footprint car or truck in each manufacturer's fleet. This estimate combines the impact of the 25% additional emission allotment and the vehicle size factors discussed above. These vehicles were then proportionally averaged into the manufacturer's GHG score. This resulted in an emission impact of approximately 3.4 MMT CO_2 over the lifetime of the 2012-2015 MY vehicles.

The gram per mile impacts are listed here for each of these scenarios.

	TLAAS impact (Grams CO_2 Emissions Per Mile)		
Model Year	**Lower Bound Scenario**	**Upper Bound Scenario**	**Estimate Used In Emission Analysis**
2012	0	2.0	0.3
2013	0	1.5	0.2
2014	0	1.0	0.2
2015	0	0.5	0.1
2016	0	0	0.0

Refereneces

All references can be found in the EPA DOCKET: EPA-HQ-OAR-2009-0472.

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[51] 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/

[52] Mcculloch A.; Lindley A. A. From mine to refrigeration: a life cycle inventory analysis of the production of HFC-134a .. ; International journal of refrigeration 2003, vol. 26, no8, pp. 865-872

[53] 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

[54] EPA. Draft MOVES 2009. http://www.epa.gov/otaq/models/moves/index.htm

[55] U.S. EPA 2009. Updated OMEGA Post-Processor Spreadsheet. August 15, 2009.

[56] Updated Tables to MOVES in Docket. Samplevehiclepopulation and emissionbyage.

[57] John Koupal, Richard Rykowski, Todd Sherwood, Ed Nam. “Documentation of Updated Light-duty Vehicle GHG Scenarios.” Memo to Docket ID No. EPA-HQ-OAR-2008-0318

[58] MOVES documentation and technical documents can be seen at http://www.epa.gov/otaq/models/moves/index.htm.

[59] Reference OMEGA Peer Review

[60] U.S. EPA. Draft Regulatory Impact Analysis: Changes to Renewable Fuel Standard Program. Chapters 2 and 3.May 26, 2009.

[61] 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/

[62] U.S. EPA. 2008. RFS2 Modified version of GREET1.7 Upstream Emissions Spreadsheet, October 31, 2008.

[63] U.S. EPA, Achieved CO_2 standards worksheet. 2009.

[64] NHTSA. 2009. Average Fuel Economy Standards, Passenger Cars and Light Trucks, Model Year 2011. Docket ID: NHTSA-2009-0062-0001. http://www.nhtsa.dot.gov/portal/nhtsa_static_file_downloader.jsp?file=/staticfiles/DOT/NHTSA/Rulemaking/Rules/Associated Files/CAFE_Updated_Final_Rule_MY2011.pdf

[65] NHTSA. 2009. Average Fuel Economy Standards, Passenger Cars and Light Trucks, Model Year 2011. http://www.nhtsa.dot.gov/portal/nhtsa_static_file_downloader.jsp?file=/staticfiles/DOT/NHTSA/Rulemaking/Rules/Associated Files/CAFE_Updated_Final_Rule_MY2011.pdf

[66] U.S. EPA. Baseline and Reference Fleet File, as documented in TSD chapter 1. August 2009..

[67] Energy Information Administration. Annual Energy Outlook 2009. Supplemental Transportation Tables. April 2009. http://www.eia.doe.gov/oiaf/aeo/supplement/sup_tran.xls

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[68] NHTSA. 2009. Average Fuel Economy Standards, Passenger Cars and Light Trucks, Model Year 2011. Docket ID: NHTSA-2009-0062-0001. http://www.nhtsa.dot.gov/portal/nhtsa_static_file_downloader.jsp?file=/staticfiles/DOT/NHTSA/Rulemaking/Rules/Associated Files/CAFE_Updated_Final_Rule_MY2011.pdf

[69] NHTSA. 2009. Average Fuel Economy Standards, Passenger Cars and Light Trucks, Model Year 2011. Docket ID: NHTSA-2009-0062-0001. http://www.nhtsa.dot.gov/portal/nhtsa_static_file_downloader.jsp?file=/staticfiles/DOT/NHTSA/Rulemaking/Rules/Associated Files/CAFE_Updated_Final_Rule_MY2011.pdf

[70] U.S. EPA. Baseline and Reference Fleet File, as documented in TSD chapter 1. August 2009..

[71] EPA. Emission Facts: Average Carbon Dioxide Emissions Resulting from Gasoline and Diesel Fuel. EPA420-F-05-001 February 2005

[72] U.S. EPA. Baseline and Reference Fleet File, as documented in TSD chapter 1. August 2009..

[73] Office of Energy Efficiency and Renewable Energy, U.S. Department of Energy. Transportation Energy Data Book: Edition 27. Chapter 4. 2008.

[74] NHTSA. Vehicle Survivability and Travel Mileage Schedules. 2006.

[75] Draft TSD Chapter 4

[76] NHTSA. Vehicle Survivability and Travel Mileage Schedules. 2006.

[77] Draft TSD Chapter 4

[78] EPA. Final Technical Support Document.Fuel Economy Labeling of Motor Vehicle Revisions to Improve Calculation of Fuel Economy Estimates

[79] John Koupal, Richard Rykowski, Todd Sherwood, Ed Nam. “Documentation of Updated Light-duty Vehicle GHG Scenarios.” Memo to Docket ID No. EPA-HQ-OAR-2008-0318

[80] Draft RIA chapter 2.

[81] Office of Energy Efficiency and Renewable Energy, U.S. Department of Energy. Transportation Energy Data Book: Edition 27. 2008.

[82] EPA. Final Technical Support Document. Fuel Economy Labeling of Motor Vehicle Revisions to Improve Calculation of Fuel Economy Estimates

[83] Average Carbon Dioxide Emissions Resulting from Gasoline and Diesel Fuel. EPA420-F-05-001 February 2005. http://www.epa.gov/otaq/climate/420f05001.htm

[84] Craig Harvey, EPA, “Calculation of Upstream Emissions for the GHG Vehicle Rule.” 2009.

[85] Control of Emissions of Air Pollution From Locomotive Engines and Marine Compression-Ignition Engines Less Than 30 Liters per Cylinder, Republication, Final Rule (Federal Register Vol 73, No. 126, page 37096, June 30, 2008).

[86] Control of Emissions From Nonroad Spark-Ignition Engines and Equipment, Final Rule (Federal Register Vol 73, No. 196, page 59034, October 8, 2008).

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[87] Draft Regulatory Impact Analysis: Control of Emissions of Air Pollution from Category 3 Marine Diesel Engines, Chapter 3. This is available in Docket OAR-2007-0121at http://www.regulations.gov/

CHAPTER 6: Vehicle Program Costs Including Fuel Consumption Impacts

This chapter presents the costs of the proposed GHG vehicle program including the costs associated with addition of new technology and savings associated with improved fuel consumption. In section 6.1, vehicle compliance costs are presented on a per-car and per-truck basis for each manufacturer and the industry as a whole. Vehicle compliance costs are also presented on an annual basis for each manufacturer and the industry as a whole. Where appropriate, net present values are presented at both a 3 percent and a 7 percent discount rate for annual costs in the years 2012 through 2050. In section 6.2, the cost per ton of GHG reduced is presented as a result of the proposal. In section 6.3, fuel consumption impacts are presented on a per-year basis for cars and trucks in terms of gallons saved and in terms of dollars saved. In section 6.4, the vehicle program costs and fuel consumption impacts are summarized. This chapter does not present costs associated with noise, congestion, accidents and other economic impacts associated with increased driving that could result from the proposed program. Such impacts are presented in Chapter 8 of this draft RIA.

6.1 Vehicle Program Costs

Chapter 4 of this draft RIA presents the outputs of the OMEGA model for the model year 2016. Here, we build on those results and calculate estimated costs for each model year beginning with 2012 and going through 2050. We do this both on a per-vehicle basis and an annual basis. Costs here include costs associated with the proposed A/C credit program. For details on the individual technology costs please refer to Chapter 3 of the draft joint TSD. For details on the OMEGA model inputs (i.e., how the individual technology costs are combined into package costs) please refer to Chapter 1 of this draft RIA. For details on the A/C costs, please refer to Chapter 2 of this draft RIA.

6.1.1 Vehicle Compliance Costs on a Per-Vehicle Basis

As stated above, Chapter 4 of this draft RIA presents the cost per vehicle for each manufacturer in the 2016 model year. Those 2016 MY costs are reproduced in Table 6-1. To estimate the cost per vehicle for model years 2012 through 2015, we first looked at the projected CO2 levels for each manufacturer's fleet for each year 2011 though 2016. Those CO2 levels are presented in Table 6-2 for cars and Table 6-3 for trucks.[S] The achieved CO2 levels for 2012-2015 were derived using the same process described in chapter 5 of the DRIA. Starting with the calculated manufacturer, vehicle class, and model year specific achieved standards, we estimated the cost effective environmentally neutral credit trading based on the

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[S] Note that the 2012-2015 CO2 levels are estimates based upon assumptions of manufacturer fleetwide CO2 averages in 2011, which are extrapolated from a 2008 base fleet. Consequently, the average CO2 emission levels for some manufacturers are potentially too high for the 2011MY which makes the transition to the 2012MY appear as a more significant change. As a result, 2012MY costs represent a large percentage of the total costs. As an example, the 2012MY cost for Suzuki as shown in Table 6-5 is approximately 60% of the 2016MY cost. In reality, the transition between MY 2011 and MY 2016 may be significantly smoother, and is likely to be smoother due to multiyear planning.

2016 achieved levels predicted by OMEGA. Based on this process, we projected the most likely achieved levels for 2012-2015 for each manufacturer.

There are some differences between cost effective achieved levels and the achieved levels shown in DRIA chapter 5. As shown here, the cost effective achieved levels for the intermediate years were derived in the following manner. MY 2011 baseline CO2 was determined from the reference fleet file.[88] MY 2016 achieved CO_2 was determined from the OMEGA output described in DRIA chapter 4. To determine the intermediate years, an interpolation was performed between these two points. Two different forms of interpolation were used. For manufacturers that fully comply with the 2016 standards, the change between 2011 and 2016 was weighted by the percent change in their achieved target for each year (as determined in DRIA chapter 5). For the manufacturers that do not fully comply in 2016, these manufacturers improved by 20% of their total change each year.

Two manufacturers, Subaru and Mitsubishi, had their improvement front loaded in order to produce early year compliance. These companies are anticipated to comply with the intermediate year standards, but the 2008 base fleet may understate their expected performance.[T] The analysis behind the cost effective achieved levels is contained in the EPA docket.[89]

We then used these CO2 values to generate ratios that could be applied to the 2016 MY costs to arrive at cost estimates for each of the intervening years. This methodology is based, in part, on the credit carry-forward and carry-back provisions contained in the proposal. However, we must also remember that the technology costs and, subsequently, the package costs in the 2016 MY have undergone some learning effects as described in Chapter 3 of the draft joint TSD. We compared the 2016 MY package costs to each of the intervening years and the results, on a percentage basis, are shown in Table 6-4. We have also done this for the years following 2016 to reflect the effects of the near term and long term ICMs as described in Chapter 3 of the draft joint TSD. The process for estimating costs in the intervening years is best understood by way of an example: General Motors cars are estimated to incur a cost of $969 in the 2016 MY while achieving a CO2 average of 240 g/mi; for the 2011 and 2012 MYs, GM cars are projected to achieve a CO2 average of 306 and 276, respectively. We can apply the ratio (306-276)/(306-240)=0.45 to GM's 2016 cost of $969, and then apply the 2012 relative to 2016 cost factor of 117%, to arrive at an estimated 2012 cost of $507.[U] We then carry out this process for each manufacturer for each year to arrive at the results presented in Table 6-5 for cars, Table 6-6 for trucks, and Table 6-7 for cars and trucks combined. Table 6-8 shows the industry average cost per car, cost per truck, and cost per vehicle (car/truck combined) for the 2012 and later model years.[V]

[T] *Ibid.*

[U] Numbers in the text are rounded for clarity so results using numbers shown in the text may not match those in tables.

[V] Note that the costs per car, truck and vehicle presented here do not include possible maintenance savings associated with the new A/C systems. They also do not include maintenance costs associated with low friction lubes and low rolling resistenance tires. We include higher new vehicle costs for these latter items but

Table 6-1 Cost per Car and Truck, including A/C, for the 2016 MY (2007 dollars)

MANUFACTURER	$/CAR	$/TRUCK
BMW	$1,700	$1,664
Chrysler	$1,331	$1,505
Daimler	$1,630	$1,356
Ford	$1,434	$1,485
GeneralMotors	$969	$1,781
Honda	$606	$695
Hyundai	$739	$1,679
Kia	$741	$1,177
Mazda	$946	$1,029
Mitsubishi	$1,067	$1,263
Nissan	$1,012	$1,193
Porsche	$1,548	$666
Subaru	$902	$1,328
Suzuki	$1,093	$1,263
Tata	$1,269	$673
Toyota	$599	$435
Volkswagen	$1,626	$949
Overall	$968	$1,213

Table 6-2 Projected CO2 Levels for MYs 2011-2016, Cars Only (g/mi CO2)

MANUFACTURER	2011MY	2012MY	2013MY	2014MY	2015MY	2016MY
BMW	308.0	292.5	278.2	263.3	248.4	235.3
Chrysler	313.1	279.0	270.2	261.3	250.0	219.6
Daimler	308.6	293.1	278.8	263.9	249.0	236.0
Ford	311.0	276.5	268.3	259.5	246.2	226.4
GeneralMotors	305.8	276.4	267.7	259.1	246.0	239.8
Honda	263.2	251.2	240.3	228.9	217.4	207.7
Hyundai	282.2	260.0	251.8	243.5	232.3	226.8
Kia	280.5	263.0	254.6	245.8	234.4	223.1
Mazda	286.8	260.1	251.8	243.0	231.4	221.0
Mitsubishi	287.1	258.1	246.5	231.0	215.6	211.7
Nissan	278.4	262.7	255.1	246.9	235.8	217.4
Porsche	339.1	317.9	297.9	277.3	256.7	237.9
Subaru	304.0	272.9	258.6	249.9	241.3	231.3
Suzuki	284.5	247.0	238.4	229.7	217.9	203.3
Tata	347.3	328.9	311.8	294.1	276.4	260.4
Toyota	250.9	240.5	231.3	221.5	211.7	203.7
Volkswagen	291.5	278.3	266.4	253.8	241.2	230.4
Overall	285.1	264.0	254.5	244.4	232.4	220.9

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do not account for higher replacement costs during vehicle lifetimes even though oil is changed many times and tires are changed once or twice. We intend to include these maintenance costs and savings in our final rule analysis.

Table 6-3 Projected CO2 Levels for MYs 2011-2016, Trucks Only (g/mi CO2)

MANUFACTURER	2011MY	2012MY	2013MY	2014MY	2015MY	2016MY
BMW	357.3	341.2	326.5	311.2	295.8	282.4
Chrysler	386.7	365.7	354.6	344.0	326.5	314.1
Daimler	423.0	397.6	373.7	349.0	324.3	301.7
Ford	413.4	382.1	370.3	360.2	342.5	316.6
GeneralMotors	410.5	392.7	380.8	369.3	351.0	308.4
Honda	346.7	338.3	331.2	323.5	315.8	310.0
Hyundai	357.6	330.6	320.3	308.4	293.1	257.6
Kia	353.9	339.2	329.1	317.8	302.8	291.4
Mazda	332.7	326.0	314.9	302.7	287.4	267.9
Mitsubishi	337.2	327.2	322.4	317.9	311.5	307.0
Nissan	387.3	370.3	358.9	348.7	331.1	321.5
Porsche	369.6	361.0	353.7	345.8	337.9	332.0
Subaru	334.9	294.4	275.9	264.9	254.0	240.9
Suzuki	356.7	314.7	306.1	296.7	283.8	280.7
Tata	362.5	355.2	349.3	342.7	336.1	331.5
Toyota	353.4	345.8	339.6	332.8	325.9	321.0
Volkswagen	417.6	398.9	381.5	363.4	345.3	329.2
Overall	383.6	365.3	355.5	345.8	331.7	310.9

Table 6-4 Package Costs Measured Relative to the Package Costs for the 2016MY

YEAR	PACKAGE COSTS RELATIVE TO 2016
2012	117%
2013	115%
2014	108%
2015	102%
2016	100%
2017	100%
2018	100%
2019	100%
2020	100%
2021	100%
2022+	92%

Table 6-5 Cost per Car, including A/C, by Manufacturer (2007 dollars)

MANUFACTURER	2012MY	2013MY	2014MY	2015MY	2016MY
BMW	$426	$801	$1,130	$1,425	$1,700
Chrysler	$571	$703	$797	$918	$1,331
Daimler	$408	$768	$1,084	$1,367	$1,630
Ford	$686	$831	$945	$1,123	$1,434
GeneralMotors	$507	$643	$740	$897	$969
Honda	$155	$288	$406	$512	$606
Hyundai	$348	$466	$558	$680	$739
Kia	$265	$385	$484	$608	$741
Mazda	$451	$578	$681	$814	$946
Mitsubishi	$483	$661	$858	$1,035	$1,067
Nissan	$306	$446	$566	$724	$1,012
Porsche	$381	$725	$1,022	$1,289	$1,548
Subaru	$454	$648	$726	$796	$902
Suzuki	$593	$713	$798	$916	$1,093
Tata	$315	$596	$841	$1,060	$1,269
Toyota	$155	$286	$404	$509	$599
Volkswagen	$412	$770	$1,086	$1,369	$1,626
Overall	$374	$531	$663	$813	$968

Table 6-6 Cost per Truck, including A/C, by Manufacturer (2007 dollars)

MANUFACTURER	2012MY	2013MY	2014MY	2015MY	2016MY
BMW	$420	$786	$1,109	$1,398	$1,664
Chrysler	$510	$763	$956	$1,276	$1,505
Daimler	$333	$634	$895	$1,128	$1,356
Ford	$564	$760	$882	$1,112	$1,485
GeneralMotors	$364	$596	$777	$1,061	$1,781
Honda	$188	$337	$475	$599	$695
Hyundai	$532	$720	$893	$1,107	$1,679
Kia	$325	$536	$735	$984	$1,177
Mazda	$125	$326	$515	$736	$1,029
Mitsubishi	$488	$709	$874	$1,101	$1,263
Nissan	$363	$592	$758	$1,042	$1,193
Porsche	$179	$323	$455	$574	$666
Subaru	$673	$959	$1,069	$1,169	$1,328
Suzuki	$820	$967	$1,079	$1,238	$1,263
Tata	$186	$330	$465	$586	$673
Toyota	$120	$213	$300	$378	$435
Volkswagen	$237	$446	$629	$794	$949
Overall	$358	$539	$682	$886	$1,213

Table 6-7 Cost per Vehicle (car/truck combined), including A/C, by Manufacturer (2007 dollars)

MANUFACTURER	2012MY	2013MY	2014MY	2015MY	2016MY
BMW	$424	$797	$1,124	$1,418	$1,691
Chrysler	$534	$738	$887	$1,080	$1,408
Daimler	$376	$710	$998	$1,259	$1,509
Ford	$641	$806	$922	$1,119	$1,452
GeneralMotors	$443	$622	$756	$968	$1,311
Honda	$167	$305	$428	$538	$632
Hyundai	$384	$516	$623	$759	$907
Kia	$304	$473	$635	$813	$973
Mazda	$384	$529	$651	$801	$959
Mitsubishi	$484	$670	$861	$1,045	$1,095
Nissan	$328	$501	$639	$829	$1,070
Porsche	$354	$661	$944	$1,201	$1,444
Subaru	$527	$747	$831	$905	$1,023
Suzuki	$683	$806	$892	$1,019	$1,147
Tata	$281	$528	$738	$935	$1,117
Toyota	$142	$260	$368	$465	$545
Volkswagen	$376	$712	$1,003	$1,265	$1,508
Overall	$368	$534	$670	$838	$1,050

Table 6-8 Industry Average Cost per Car, Truck, and Combined by Year (2007 dollars)

YEAR	$/CAR	$/TRUCK	$/VEHICLE
2012	$374	$358	$368
2013	$531	$539	$534
2014	$663	$682	$670
2015	$813	$886	$838
2016	$968	$1,213	$1,050
2017	$968	$1,213	$1,047
2018	$968	$1,213	$1,044
2019	$968	$1,213	$1,042
2020	$968	$1,213	$1,040
2021	$968	$1,213	$1,039
2022	$890	$1,116	$955
2023	$890	$1,116	$955
2024	$890	$1,116	$955
2025	$890	$1,116	$955
2026	$890	$1,116	$954
2027	$890	$1,116	$954
2028	$890	$1,116	$954
2029	$890	$1,116	$953
2030	$890	$1,116	$953
2031	$890	$1,116	$953
2032	$890	$1,116	$953
2033	$890	$1,116	$953
2034	$890	$1,116	$953
2035	$890	$1,116	$953

2036	$890	$1,116	$953
2037	$890	$1,116	$953
2038	$890	$1,116	$953
2039	$890	$1,116	$953
2040	$890	$1,116	$953
2041	$890	$1,116	$953
2042	$890	$1,116	$953
2043	$890	$1,116	$953
2044	$890	$1,116	$953
2045	$890	$1,116	$953
2046	$890	$1,116	$953
2047	$890	$1,116	$953
2048	$890	$1,116	$953
2049	$890	$1,116	$953
2050	$890	$1,116	$953

6.1.2 Vehicle Compliance Costs on a Per-Year Basis

Given the cost per car and cost per truck estimates shown in Table 6-5 and Table 6-6, respectively, we can calculate annual costs by multiplying by estimated sales. Table 6-9 shows projected car sales by manufacturer for model years 2012-2016. Table 6-10 shows projected truck sales by manufacturer for model years 2012-2016. Table 6-11 shows combined sales by manufacturer for 2012-2016. Table 6-11 shows annual costs attributable to cars by manufacturer for MYs 2012-2016, Table 6-12 shows the same for trucks, and Table 6-13 shows the same for cars and trucks combined. Table 6-14 then shows the annual costs by the entire industry for cars, trucks, and total for the years 2012 through 2050 with net present values using both a 3 percent and a 7 percent discount rate.[W]

[W] Note that the vehicle compliance costs presented here do not include costs associated with upgrading testing facilities to accommodate N2O testing. While including those costs would likely have very little impact on the costs presented here for new vehicle technology, the costs should be included and we intend to do so in the final rule analysis.

Table 6-9 Estimated Annual Car Sales by Manufacturer (# of Units)

MANUFACTURER	2012MY	2013MY	2014MY	2015MY	2016MY
BMW	283,471	323,191	352,248	371,668	380,804
Chrysler	178,635	175,072	169,046	136,583	138,602
Daimler	1,348,260	1,424,345	1,446,097	1,503,175	1,511,354
Ford	149,192	135,946	135,141	130,588	131,022
General Motors	1,484,580	1,620,301	1,708,507	1,789,813	1,820,234
Honda	1,155,008	1,352,607	1,493,242	1,562,496	1,593,092
Hyundai	580,538	558,975	562,862	590,579	596,891
Kia	22,878	32,822	35,534	40,586	41,584
Mazda	304,524	309,667	331,198	347,533	351,081
Mitsubishi	313,489	318,669	338,487	340,069	345,489
Nissan	172,172	190,133	204,335	229,562	235,205
Porsche	64,843	61,169	56,478	52,368	53,459
Subaru	958,696	1,031,569	1,073,307	1,104,272	1,123,486
Suzuki	31,605	35,813	38,470	36,175	37,064
Tata	86,537	86,220	81,480	75,965	77,427
Toyota	1,697,762	1,862,201	1,985,033	2,114,273	2,154,115
Volkswagen	423,433	458,641	467,885	465,263	476,699
Industry	9,255,624	9,977,341	10,479,350	10,890,967	11,067,608

Table 6-10 Estimated Annual Truck Sales by Manufacturer (# of Units)

MANUFACTURER	2012MY	2013MY	2014MY	2015MY	2016MY
BMW	142,861	141,949	144,022	139,034	135,569
Chrysler	282,472	244,441	222,545	112,381	109,674
Daimler	1,025,575	1,107,535	1,202,141	1,230,889	1,202,442
Ford	88,877	77,593	76,913	73,425	74,135
General Motors	1,209,642	1,320,438	1,342,856	1,355,820	1,322,512
Honda	669,948	724,500	687,208	691,641	675,173
Hyundai	141,028	135,751	134,274	132,978	129,763
Kia	42,168	46,256	53,335	48,583	47,372
Mazda	78,789	74,596	72,192	69,894	68,310
Mitsubishi	71,930	71,136	66,919	59,361	57,998
Nissan	109,351	115,684	125,189	113,366	110,541
Porsche	10,098	11,440	9,124	7,349	7,171
Subaru	477,897	478,571	474,558	454,488	444,471
Suzuki	20,767	20,639	19,379	16,822	17,273
Tata	30,391	29,750	30,545	27,204	26,526
Toyota	1,019,375	1,019,048	1,045,671	1,081,323	1,057,837
Volkswagen	109,415	100,952	104,023	102,743	100,186
Industry	5,530,583	5,720,280	5,810,895	5,717,300	5,586,953

Table 6-11 Estimated Annual Costs by Manufacturer, including A/C, for Cars ($Millions of 2007 dollars)

MANUFACTURER	2012MY	2013MY	2014MY	2015MY	2016MY
BMW	$120	$260	$400	$530	$650
Chrysler	$100	$120	$130	$130	$180
Daimler	$70	$150	$220	$310	$380
Ford	$930	$1,180	$1,370	$1,690	$2,170
General Motors	$750	$1,040	$1,260	$1,600	$1,760
Honda	$180	$390	$610	$800	$960
Hyundai	$200	$260	$310	$400	$440
Kia	$80	$120	$160	$210	$260
Mazda	$140	$180	$230	$280	$330
Mitsubishi	$30	$40	$50	$50	$60
Nissan	$290	$460	$610	$800	$1,140
Porsche	$10	$30	$40	$50	$60
Subaru	$70	$90	$100	$100	$120
Suzuki	$50	$60	$60	$70	$80
Tata	$10	$20	$30	$40	$50
Toyota	$260	$530	$800	$1,080	$1,290
Volkswagen	$170	$350	$510	$640	$780
Industry	$3,460	$5,300	$6,950	$8,850	$10,710

Table 6-12 Estimated Annual Costs by Manufacturer, including A/C, for Trucks ($Millions of 2007 dollars)

MANUFACTURER	2012MY	2013MY	2014MY	2015MY	2016MY
BMW	$60	$110	$160	$190	$230
Chrysler	$140	$190	$210	$140	$170
Daimler	$40	$70	$110	$130	$150
Ford	$580	$840	$1,060	$1,370	$1,790
General Motors	$440	$790	$1,040	$1,440	$2,360
Honda	$130	$240	$330	$410	$470
Hyundai	$80	$100	$120	$150	$220
Kia	$30	$40	$50	$70	$80
Mazda	$10	$20	$30	$40	$60
Mitsubishi	$0	$10	$10	$10	$10
Nissan	$170	$280	$360	$470	$530
Porsche	$0	$10	$10	$10	$10
Subaru	$60	$70	$80	$90	$100
Suzuki	$20	$30	$30	$30	$30
Tata	$10	$20	$20	$30	$30
Toyota	$120	$220	$310	$410	$460
Volkswagen	$30	$50	$70	$80	$100
Industry	$1,980	$3,090	$3,960	$5,060	$6,780

Table 6-13 Estimated Annual Costs by Manufacturer, including A/C, for Cars and Trucks Combined ($Millions of 2007 dollars)

MANUFACTURER	2012MY	2013MY	2014MY	2015MY	2016MY
BMW	$180	$370	$560	$720	$880
Chrysler	$240	$310	$340	$270	$350
Daimler	$110	$220	$330	$440	$530
Ford	$1,510	$2,020	$2,430	$3,060	$3,960
General Motors	$1,190	$1,830	$2,300	$3,040	$4,120
Honda	$310	$630	$940	$1,210	$1,430
Hyundai	$280	$360	$430	$550	$660
Kia	$110	$160	$210	$280	$340
Mazda	$150	$200	$260	$320	$390
Mitsubishi	$30	$50	$60	$60	$70
Nissan	$460	$740	$970	$1,270	$1,670
Porsche	$10	$40	$50	$60	$70
Subaru	$130	$160	$180	$190	$220
Suzuki	$70	$90	$90	$100	$110
Tata	$20	$40	$50	$70	$80
Toyota	$380	$750	$1,110	$1,490	$1,750
Volkswagen	$200	$400	$580	$720	$880
Industry	$5,440	$8,390	$10,910	$13,910	$17,490

Table 6-14 Annual Sales & Costs for Cars & Trucks (Monetary Values in 2007 dollars)

YEAR	CAR SALES	TRUCK SALES	CAR COSTS ($MILLIONS)	TRUCK COSTS ($MILLIONS)	TOTAL COSTS ($MILLIONS)
2012	9,255,624	5,530,583	$3,460	$1,980	$5,440
2013	9,977,341	5,720,280	$5,300	$3,090	$8,390
2014	10,479,350	5,810,895	$6,950	$3,960	$10,910
2015	10,890,967	5,717,300	$8,850	$5,060	$13,910
2016	11,067,608	5,586,953	$10,710	$6,780	$17,490
2017	11,398,169	5,403,989	$11,030	$6,560	$17,590
2018	11,684,257	5,282,864	$11,310	$6,410	$17,720
2019	11,948,850	5,191,459	$11,570	$6,300	$17,870
2020	12,190,082	5,088,666	$11,800	$6,170	$17,970
2021	12,184,615	5,018,346	$11,790	$6,090	$17,880
2022	12,224,907	4,966,015	$10,880	$5,540	$16,420
2023	12,393,064	4,990,624	$11,030	$5,570	$16,600
2024	12,615,769	5,057,793	$11,230	$5,640	$16,870
2025	12,867,956	5,154,435	$11,450	$5,750	$17,200
2026	13,056,941	5,196,282	$11,620	$5,800	$17,420
2027	13,146,812	5,220,321	$11,700	$5,830	$17,530
2028	13,245,293	5,211,789	$11,790	$5,820	$17,610
2029	13,390,625	5,172,196	$11,920	$5,770	$17,690
2030	13,550,044	5,250,009	$12,060	$5,860	$17,920
2031	13,653,024	5,289,909	$12,150	$5,900	$18,050
2032	13,756,787	5,330,112	$12,250	$5,950	$18,200
2033	13,861,339	5,370,621	$12,340	$5,990	$18,330
2034	13,966,685	5,411,438	$12,430	$6,040	$18,470

2035	14,072,832	5,452,565	$12,530	$6,080	$18,610
2036	14,179,785	5,494,004	$12,620	$6,130	$18,750
2037	14,287,552	5,535,759	$12,720	$6,180	$18,900
2038	14,396,137	5,577,830	$12,820	$6,220	$19,040
2039	14,505,548	5,620,222	$12,910	$6,270	$19,180
2040	14,615,790	5,662,936	$13,010	$6,320	$19,330
2041	14,726,870	5,705,974	$13,110	$6,370	$19,480
2042	14,838,794	5,749,339	$13,210	$6,420	$19,630
2043	14,951,569	5,793,034	$13,310	$6,460	$19,770
2044	15,065,201	5,837,061	$13,410	$6,510	$19,920
2045	15,179,696	5,881,423	$13,510	$6,560	$20,070
2046	15,295,062	5,926,122	$13,620	$6,610	$20,230
2047	15,411,305	5,971,160	$13,720	$6,660	$20,380
2048	15,528,430	6,016,541	$13,820	$6,710	$20,530
2049	15,646,447	6,062,267	$13,930	$6,770	$20,700
2050	15,765,360	6,108,340	$14,030	$6,820	$20,850
NPV, 3%			$257,680	$132,320	$390,000
NPV, 7%			$141,860	$74,700	$216,550

6.2 Cost per Ton of Emissions Reduced

We have calculated the cost per ton of GHG (CO2 equivalent, or CO2e) reductions associated with this proposal using the costs shown in Table 6-14 and the emissions reductions described in Chapter 5. We have calculated the cost per metric ton of GHG emissions reductions 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. Note that we have not included the savings associated with reduced fuel consumption, nor any of the other benefits of this proposal in the cost per ton calculations. If we were to include fuel savings in the cost estimates, the cost per ton would be less than $0, since the fuel savings outweigh the costs (see Section 6.3 below). With regard to the proposed CH4 and N2O standards, since these standards would be emissions caps designed to ensure manufacturers do not backslide from current levels, we have not estimated costs associated with the standards (since the standards would not require any change from current practices nor do we estimate they would result in emissions reductions).

The results for CO2e costs per ton under the proposed vehicle program are shown in Table 6-15.

Table 6-15 Annual Cost Per Metric Ton of CO2e Reduced, in $2007 dollars

YEAR	COST ($MILLIONS) [*]	CO2-EQUIVLANET REDUCTION (MILLION METRIC TONS)	COST PER TON
2020	$18,000	170	$110
2030	$17,900	320	$60
2040	$19,300	420	$50
2050	$20,900	520	$40

[*] Costs here include vehicle compliance costs and do not include any fuel savings (discussed in section 6.3) or other benefits of this proposal (discussed in Chapter 8).

6.3 Fuel Consumption Impacts

In this section, we present the impact of the proposed program on fuel consumption and the consumer savings realized due to the lower fuel consumption. Chapter 5 provides more detail on the estimated reduction in the gallons of fuel expected to be consumed as a result of the proposal.

The proposed CO2 standards would result in significant improvements in the fuel efficiency of affected vehicles. Drivers of those vehicles would see corresponding savings associated with reduced fuel expenditures. We have estimated the impacts on fuel consumption for both the proposed tailpipe CO2 standards and the proposed A/C credit program. To do this, fuel consumption is calculated using both current CO2 emission levels and the proposed CO2 standards. The difference between these estimates represents the net savings from the proposed CO2 standards.

The expected impacts on fuel consumption are shown in Table 6-16. The gallons shown in the tables reflect impacts from the proposed CO2 standards, including the proposed A/C credit program, and include increased consumption resulting from the rebound effect. Using these fuel consumption estimates, we can calculate the monetized fuel savings associated with the proposed CO2 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 2009. AEO is the government consensus estimate used by NHTSA and many other government agencies to estimate the projected price of fuel. We have included all fuel taxes in these estimates since these are the prices paid by consumers. As such, the savings shown reflect savings to the consumer. These results are also shown in Table 6-16. Note that we present the monetized fuel savings using pre-tax fuel prices in Chapter 8 of this draft RIA. The fuel savings based on pre-tax fuel prices reflect the societal savings in contrast to the consumer savings presented in Table 6-16. Also in Chapter 8, we present the benefit-cost of the proposal and, for that reason, present the fuel impacts as negative costs of the program while here we present them as positive savings.

Table 6-16 Annual Fuel Consumption Impacts of the Proposed Vehicle Standards and A/C Credit Programs

(Monetary values in 2007 dollars)

YEAR	GALLONS (MILLIONS)	FUEL PRICE INCLUDING TAXES ($/GALLON)	SAVINGS ($MILLIONS)
2012	500	$2.70	$1,400
2013	1,300	$2.85	$3,800
2014	2,400	$3.00	$7,200
2015	3,900	$3.16	$12,400
2016	5,900	$3.27	$19,400
2017	7,900	$3.39	$26,700
2018	9,800	$3.48	$34,100
2019	11,600	$3.56	$41,300
2020	13,400	$3.62	$48,400
2021	15,000	$3.64	$54,600
2022	16,600	$3.67	$60,800
2023	18,100	$3.69	$66,700
2024	19,500	$3.69	$72,000
2025	20,900	$3.68	$76,800
2026	22,100	$3.72	$82,200
2027	23,300	$3.72	$86,500
2028	24,300	$3.76	$91,600
2029	25,300	$3.87	$97,800
2030	26,200	$3.82	$100,000
2031	27,000	$3.84	$103,800
2032	27,800	$3.86	$107,500
2033	28,600	$3.88	$111,100
2034	29,400	$3.90	$114,700
2035	30,100	$3.92	$118,300
2036	30,900	$3.95	$121,900
2037	31,600	$3.97	$125,500
2038	32,400	$3.99	$129,200
2039	33,200	$4.01	$133,000
2040	33,900	$4.03	$136,800
2041	34,700	$4.05	$140,700
2042	35,500	$4.07	$144,700
2043	36,300	$4.10	$148,800
2044	37,200	$4.12	$153,100
2045	38,000	$4.14	$157,400
2046	38,900	$4.16	$161,900
2047	39,800	$4.19	$166,500
2048	40,700	$4.21	$171,200
2049	41,600	$4.23	$176,100
2050	42,600	$4.25	$181,000
NPV, 3%			$1,850,200
NPV, 7%			$826,900

As shown in Table 6-16, we are projecting that consumers would realize very large fuel savings as a result of the standards contained in today's proposal. There are several ways to view this value. Some, as demonstrated below in Chapter 8 of this draft RIA, view these fuel savings as a reduction in the cost of owning a vehicle, whose full benefits consumers realize. This approach assumes that, regardless how consumers in fact make their decisions on how much fuel economy to purchase, they will gain these fuel savings. Another view says that consumers do not necessarily value fuel savings as equal to the results of this calculation. Instead, consumers may either undervalue or overvalue fuel economy relative to these savings, based on their personal preferences. This issue is discussed further in Section 8.1.2 of this draft RIA.

If we limit the analysis to the five model years 2012-2016—in other words, the fuel consumption savings during the lifetimes of those five model years, the results would be as shown in Table 6-17.

Table 6-17 Annual Fuel Savings for 2012-2016 MY Vehicles Using Pre-tax Fuel Prices ($Millions of 2007 dollars)

YEAR	2012MY	2013MY	2014MY	2015MY	2016MY	SUM
2012	$1,300					$1,300
2013	$1,300	$2,100				$3,500
2014	$1,400	$2,200	$3,100			$6,700
2015	$1,400	$2,200	$3,200	$4,600		$11,500
2016	$1,400	$2,200	$3,200	$4,700	$6,500	$18,100
2017	$1,400	$2,200	$3,200	$4,700	$6,600	$18,100
2018	$1,400	$2,200	$3,200	$4,700	$6,600	$18,000
2019	$1,300	$2,100	$3,100	$4,600	$6,500	$17,600
2020	$1,200	$2,000	$3,000	$4,400	$6,300	$17,000
2021	$1,100	$1,900	$2,800	$4,200	$6,000	$16,100
2022	$1,100	$1,700	$2,600	$4,000	$5,700	$15,100
2023	$900	$1,600	$2,400	$3,700	$5,400	$14,100
2024	$800	$1,400	$2,200	$3,400	$5,000	$12,800
2025	$600	$1,200	$2,000	$3,100	$4,600	$11,500
2026	$500	$1,000	$1,700	$2,800	$4,200	$10,200
2027	$400	$800	$1,400	$2,300	$3,700	$8,700
2028	$300	$700	$1,100	$2,000	$3,200	$7,300
2029	$300	$600	$1,000	$1,700	$2,700	$6,200
2030	$200	$400	$800	$1,300	$2,200	$5,000
2031	$200	$300	$600	$1,100	$1,800	$4,000
2032	$100	$300	$500	$900	$1,500	$3,300
2033	$100	$200	$400	$700	$1,200	$2,600
2034	$100	$200	$300	$600	$1,000	$2,100
2035	$100	$200	$300	$500	$800	$1,700
2036	$100	$100	$200	$400	$600	$1,400
2037	$100	$100	$200	$300	$500	$1,200
2038	$0	$100	$200	$300	$400	$1,000
2039	$0	$100	$100	$200	$400	$800
2040	$0	$100	$100	$200	$300	$700
2041	$0	$0	$100	$100	$300	$600
2042	$0	$0	$100	$100	$200	$500
2043	$0	$0	$100	$100	$200	$400

2044	$0	$0	$100	$100	$100	$300
2045	$0	$0	$100	$100	$100	$300
2046	$0	$0	$0	$100	$100	$300
2047	$0	$0	$0	$100	$100	$200
2048	$0	$0	$0	$100	$100	$200
2049	$0	$0	$0	$0	$100	$200
2050	$0	$0	$0	$0	$100	$100
NPV, 3%	$15,600	$24,400	$34,800	$49,800	$68,500	$193,100
NPV, 7%	$12,100	$19,000	$27,200	$38,900	$53,700	$150,900

6.4 Vehicle Program Cost Summary

The vehicle program costs consist of the vehicle compliance costs and the fuel savings (fuel savings are expressed here as negative fuel costs) that would result from the reduction in fuel consumption. These costs are summarized in Table 6-18.

Table 6-18 Annual Vehicle Program Costs Including Fuel Costs Using Post-Tax Fuel Prices ($Millions of 2007 dollars)

YEAR	VEHICLE COMPLIANCE COSTS	FUEL COSTS (NEGATIVE COSTS ARE SAVINGS)	TOTAL COSTS (NEGATIVE COSTS ARE SAVINGS)
2012	$5,400	-$1,400	$4,000
2013	$8,400	-$3,800	$4,600
2014	$10,900	-$7,200	$3,700
2015	$13,900	-$12,400	$1,500
2016	$17,500	-$19,400	-$1,900
2017	$17,600	-$26,700	-$9,100
2018	$17,700	-$34,100	-$16,400
2019	$17,900	-$41,300	-$23,400
2020	$18,000	-$48,400	-$30,400
2021	$17,900	-$54,600	-$36,700
2022	$16,400	-$60,800	-$44,400
2023	$16,600	-$66,700	-$50,100
2024	$16,900	-$72,000	-$55,100
2025	$17,200	-$76,800	-$59,600
2026	$17,400	-$82,200	-$64,800
2027	$17,500	-$86,500	-$69,000
2028	$17,600	-$91,600	-$74,000
2029	$17,700	-$97,800	-$80,100
2030	$17,900	-$100,000	-$82,100
2031	$18,100	-$103,800	-$85,700
2032	$18,200	-$107,500	-$89,300
2033	$18,300	-$111,100	-$92,800
2034	$18,500	-$114,700	-$96,200
2035	$18,600	-$118,300	-$99,700
2036	$18,800	-$121,900	-$103,100
2037	$18,900	-$125,500	-$106,600
2038	$19,000	-$129,200	-$110,200
2039	$19,200	-$133,000	-$113,800

2040	$19,300	-$136,800	-$117,500
2041	$19,500	-$140,700	-$121,200
2042	$19,600	-$144,700	-$125,100
2043	$19,800	-$148,800	-$129,000
2044	$19,900	-$153,100	-$133,200
2045	$20,100	-$157,400	-$137,300
2046	$20,200	-$161,900	-$141,700
2047	$20,400	-$166,500	-$146,100
2048	$20,500	-$171,200	-$150,700
2049	$20,700	-$176,100	-$155,400
2050	$20,900	-$181,000	-$160,100
NPV, 3%	$390,000	-$1,850,200	-$1,460,200
NPV, 7%	$216,600	-$826,900	-$610,300

References

All references can be found in the EPA DOCKET: EPA-HQ-OAR-2009-0472.

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[88] U.S. EPA. Baseline and Reference Fleet File, as documented in TSD chapter 1. August 2009.

[89] US EPA 2009. Cost effective achieved levels spreadsheet.

CHAPTER 7: Environmental and Health Impacts

7.1 Health and Environmental Effects of Non-GHG Pollutants

7.1.1 Health Effects Associated with Exposure to 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 would not be directly regulated by the proposed standards, but the proposed standards would affect emissions of these pollutants and precursors. Reductions in these pollutants would be co-benefits of this proposal (that is, benefits in addition to the benefits of reduced GHGs).

7.1.1.1 Particulate Matter

7.1.1.1.1 Background

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). Current national ambient air quality standards (NAAQS) use $PM_{2.5}$ as the indicator for fine particles (with $PM_{2.5}$ referring to particles with a nominal mean aerodynamic diameter less than or equal to 2.5 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 are a subset of fine particles, generally less than 100 nanometers (0.1 μm) in aerodynamic diameter.

Particles span many sizes and shapes and consist of hundreds of different chemicals. 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 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 pollutants 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.[90]

7.1.1.1.2 Health Effects of PM

This section provides a summary of the health effects associated with exposure to ambient concentrations of PM.[X] The information in this section is based on the data and conclusions in the PM Air Quality Criteria Document (PM AQCD) and PM Staff Paper prepared by the U.S. Environmental Protection Agency (EPA).[Y,91,92] We also present additional recent studies published after the cut-off date for the PM AQCD.[93,Z] Taken together this information supports the conclusion that exposure to ambient concentrations of PM are associated with adverse health effects.

7.1.1.1.2.1 Short-term Exposure Mortality and Morbidity Studies

As discussed in the PM AQCD, short-term exposure to $PM_{2.5}$ is associated with premature mortality from cardiopulmonary diseases,[94] hospitalization and emergency department visits for cardiopulmonary diseases,[95] increased respiratory symptoms,[96] decreased lung function[97] and physiological changes or biomarkers for cardiac changes.[98,99] In addition, the PM AQCD described a limited body of new evidence from epidemiologic studies for potential relationships between short term exposure to PM and health endpoints such as low birth weight, preterm birth, and neonatal and infant mortality.[100]

Among the studies of effects associated with short-term exposure to $PM_{2.5}$, several specifically address the contribution of mobile sources to short-term $PM_{2.5}$-related effects on premature mortality. The results from these studies generally indicated that several combustion-related fine particle source-types are likely associated with mortality, including

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[XX] 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 both components may contribute to adverse health effects.

[Y] The PM NAAQS is currently under review and the EPA is considering all available science on PM health effects, including information which has been published since 2004, in the development of the upcoming PM Integrated Science Assessment Document (ISA). A second draft of the PM ISA was completed in July 2009 and was submitted for review by the Clean Air Scientific Advisory Committee (CASAC) of EPA's Science Advisory Board. Comments from the general public have also been requested. For more information, see http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=210586.

[Z] These additional studies are included in the 2006 Provisional Assessment of Recent Studies on Health Effects of Particulate Matter Exposure. The provisional assessment did not and could not (given a very short timeframe) undergo the extensive critical review by CASAC and the public, as did the PM AQCD. The provisional assessment found that the "new" studies expand the scientific information and provide important insights on the relationship between PM exposure and health effects of PM. The provisional assessment also found that "new" studies generally strengthen the evidence that acute and chronic exposure to fine particles and acute exposure to thoracic coarse particles are associated with health effects. Further, the provisional science assessment found that the results reported in the studies did not dramatically diverge from previous findings, and taken in context with the findings of the AQCD, the new information and findings did not materially change any of the broad scientific conclusions regarding the health effects of PM exposure made in the AQCD. However, it is important to note that this assessment was limited to screening, surveying, and preparing a provisional assessment of these studies. For reasons outlined in Section I.C of the preamble for the final PM NAAQS rulemaking in 2006 (see 71 FR 61148-49, October 17, 2006), EPA based its NAAQS decision on the science presented in the 2004 AQCD.

motor vehicle emissions as well as other sources.[101] The analyses incorporate source apportionment tools into short-term exposure studies and are briefly mentioned here. Analyses incorporating source apportionment by factor analysis with daily time-series studies of daily death rates indicated a relationship between mobile source $PM_{2.5}$ and mortality.[102,103,104,105] Another recent study in 14 U.S. cities examined the effect of PM_{10} exposures on daily hospital admissions for cardiovascular disease. This study found that the effect of PM_{10} was significantly greater in areas with a larger proportion of PM_{10} coming from motor vehicles, indicating that PM_{10} from these sources may have a greater effect on the toxicity of ambient PM_{10} when compared with other sources.[106] These studies provide evidence that PM-related emissions, specifically from mobile sources, are associated with adverse health effects.

7.1.1.1.2.2 Long-term Exposure Mortality and Morbidity Studies

Long-term exposure to ambient $PM_{2.5}$ is associated with premature mortality from cardiopulmonary diseases and lung cancer,[107] and effects on the respiratory system such as decreased lung function or the development of chronic respiratory disease.[108] Of specific importance, the PM AQCD also noted that the PM components of gasoline and diesel engine exhaust represent one class of hypothesized likely important contributors to the observed ambient PM-related increases in lung cancer incidence and mortality.[109]

The PM AQCD and PM Staff Paper emphasized the results of two long-term epidemiologic studies, the Six Cities and American Cancer Society (ACS) prospective cohort studies, based on several factors – the large air quality data set for PM in the Six Cities Study, the fact that the study populations were similar to the general population, and the fact that these studies have undergone extensive reanalysis.[110,111,112,113114,115] These studies indicate that there are positive associations for all-cause, cardiopulmonary, and lung cancer mortality with long-term exposure to $PM_{2.5}$. One analysis of a subset of the ACS cohort data, which was published after the PM AQCD was finalized but in time for the 2006 Provisional Assessment, found a larger association than had previously been reported between long-term $PM_{2.5}$ exposure and mortality in the Los Angeles area using a new exposure estimation method that accounted for variations in concentration within the city.[116]

As discussed in the PM AQCD, the morbidity studies that combine the features of cross-sectional and cohort studies provide the best evidence for chronic exposure effects. Long-term studies evaluating the effect of ambient PM on children's development have shown some evidence indicating effects of $PM_{2.5}$ and/or PM_{10} on reduced lung function growth.[117] In another recent publication included in the 2006 Provisional Assessment, investigators in southern California reported the results of a cross-sectional study of outdoor $PM_{2.5}$ and a measure of atherosclerosis development in the Los Angeles basin.[118] The study found significant associations between ambient residential $PM_{2.5}$ and carotid intima-media thickness (CIMT), an indicator of subclinical atherosclerosis, an underlying factor in cardiovascular disease.

7.1.1.2 Ozone

7.1.1.2.1 Background

Ground-level ozone pollution is typically formed by the reaction of VOCs and NO_X in the lower atmosphere in the presence of heat and 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.

7.1.1.2.2 Health Effects of Ozone

Exposure to ambient ozone contributes to a wide range of adverse health effects.[AA] These health effects are well documented and are critically assessed in the EPA ozone air quality criteria document (ozone AQCD) and EPA staff paper.[119,120] We are relying on the

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[AA] 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.

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 recent 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.[121] People who are more susceptible to effects associated with exposure to ozone can include children, asthmatics and the elderly. Those with greater exposures to ozone, for instance due to time spent outdoors (e.g., children and outdoor workers), are also of concern.

Based on a large number of scientific studies, EPA has identified several key health effects associated with exposure to levels of ozone found today in many areas of the country. Short-term (1 to 3 hours) and prolonged exposures (6 to 8 hours) to ambient ozone concentrations have been linked to lung function decrements, respiratory symptoms, increased hospital admissions and emergency room visits for respiratory problems.[122, 123, 124, 125, 126, 127] Repeated exposure to ozone can increase susceptibility to respiratory infection and lung inflammation and can aggravate preexisting respiratory diseases, such as asthma.[128, 129, 130, 131, 132] 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.[133, 134, 135, 136]

Children and adults who are outdoors and active during the summer months, such as construction workers, are among those most at risk of elevated ozone exposures.[137] 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.[138] For example, summer camp studies in the Eastern United States and Southeastern Canada have reported statistically significant reductions in lung function in children who are active outdoors.[139, 140, 141, 142, 143, 144, 145, 146] 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.[147, 148, 149, 150]

7.1.1.3 Nitrogen Oxides and Sulfur Oxides

7.1.1.3.1 Background

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 derived), 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 vapor 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 7.1.1.1.2. NO_X along with non-methane hydrocarbons (NMHC) are the two major precursors of ozone. The health effects of ozone are covered in Section 7.1.1.2.2.

7.1.1.3.2 Health Effects of Sulfur Oxides

Information on the health effects of SO_2 can be found in the U.S. Environmental Protection Agency Integrated Science Assessment for Sulfur Oxides.[151] SO_2 has long been known to cause adverse respiratory health effects, particularly among individuals with asthma. Other potentially sensitive groups include children and the elderly. During periods of elevated ventilation, asthmatics may experience symptomatic bronchoconstriction within minutes of exposure. Following an extensive evaluation of health evidence from epidemiologic and laboratory studies, the EPA has concluded that there is a causal relationship between respiratory health effects and short-term exposure to SO_2. Separately, based on an evaluation of the epidemiologic evidence of associations between short-term exposure to SO_2 and mortality, the EPA has concluded that the overall evidence is suggestive of a causal relationship between short-term exposure to SO_2 and mortality.

7.1.1.3.3 Health Effects of Nitrogen Oxides

Information on the health effects of NO_2 can be found in the U.S. Environmental Protection Agency Integrated Science Assessment (ISA) for Nitrogen Oxides.[152] The U.S. 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 at exposures as low as 0.26 ppm NO_2 for 30 minutes. 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. 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 (nonaccidental) mortality, hospital admissions or emergency department visits for cardiovascular disease, and decrements in lung function growth associated with chronic exposure.

7.1.1.4 Carbon Monoxide

We are relying on the data and conclusions in the EPA Air Quality Criteria Document for CO (CO Criteria Document), which was published in 2000, regarding the health effects associated with CO exposure.[BB,153] Carbon monoxide enters the bloodstream through the lungs and forms carboxyhemoglobin (COHb), a compound that inhibits the blood's capacity to carry oxygen to organs and tissues.[154,155] Carbon monoxide has long been known to have substantial adverse effects on human health, including toxic effects on blood and tissues, and effects on organ functions. Although there are effective compensatory increases in blood flow to the brain, at some concentrations of COHb somewhere above 20 percent, these compensations fail to maintain sufficient oxygen delivery, and metabolism declines.[156] The subsequent hypoxia in brain tissue then produces behavioral effects, including decrements in continuous performance and reaction time.[157]

Carbon monoxide has been linked to increased risk for people with heart disease, reduced visual perception, cognitive functions and aerobic capacity, and possible fetal effects.[158] Persons with heart disease are especially sensitive to CO poisoning and may experience chest pain if they breathe the gas while exercising.[159] Infants, elderly persons, and individuals with respiratory diseases are also particularly sensitive. Carbon monoxide can affect healthy individuals, impairing exercise capacity, visual perception, manual dexterity, learning functions, and ability to perform complex tasks.[160]

Several epidemiological studies have shown a link between CO and premature morbidity (including angina, congestive heart failure, and other cardiovascular diseases). Several studies in the United States and Canada have also reported an association between ambient CO exposures and frequency of cardiovascular hospital admissions, especially for congestive heart failure (CHF). An association between ambient CO exposure and mortality has also been reported in epidemiological studies, though not as consistently or specifically as with CHF admissions. EPA reviewed these studies as part of the CO Criteria Document

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[BB] The CO NAAQS is currently under review and the EPA is considering all available science on CO health effects, including information which has been published since 2000, in the development of the upcoming CO Integrated Science Assessment Document (ISA). A first draft of the CO ISA was completed in March 2009 and was submitted for review by the Clean Air Scientific Advisory Committee (CASAC) of EPA's Science Advisory Board. For more information, see http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=203935.

review process and noted the possibility that the average ambient CO levels used as exposure indices in the epidemiology studies may be surrogates for ambient air mixes impacted by combustion sources and/or other constituent toxic components of such mixes. More research will be needed to better clarify CO's role.[161]

7.1.1.5 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.[162] These compounds include, but are not limited to, benzene, 1,3-butadiene, formaldehyde, acetaldehyde, acrolein, polycyclic organic matter (POM), and naphthalene. These compounds, except acetaldehyde, were identified as national or regional risk drivers in the 2002 National-scale Air Toxics Assessment (NATA) and have significant inventory contributions from mobile sources.

Table 7-1 Mobile Source Inventory Contribution to 2002 Emissions of NATA Risk Drivers[a]

2002 NATA Risk Driver	Percent of National Emissions Attributable to All Mobile Sources	Percent of National Emissions Attributable to Light-Duty Vehicles
Benzene	59%	41%
1,3-Butadiene	58%	37%
Formaldehyde	43%	19%
Acrolein	18%	9%
Polycyclic organic matter (POM)[b]	6%	3%
Naphthalene	35%	22%
Diesel PM and Diesel exhaust organic gases	100%	1%

[a] This table is generated from data contained in the pollutant specific Microsoft Access database files found in the State-Specific Emission by County section of the 2002 NATA webpage (http://www.epa.gov/ttn/atw/nata2002/tables.html) and data from the 2002 National Emissions Inventory (NEI; http://www.epa.gov/ttn/chief/net/2002inventory.html), which is the underlying basis for the emissions used in the 2002 NATA (http://www.epa.gov/ttn/atw/nata2002/methods.html).

[b] This POM inventory includes the 15 POM compounds: benzo[b]fluoranthene, benz[a]anthracene, indeno(1,2,3-c,d)pyrene, benzo[k]fluoranthene, chrysene, benzo[a]pyrene, dibenz(a,h)anthracene, anthracene, pyrene, benzo(g,h,i)perylene, fluoranthene, acenaphthylene, phenanthrene, fluorine, and acenaphthene.

According to NATA for 2002, mobile sources were responsible for 47 percent of outdoor toxic emissions, over 50 percent of the cancer risk, and over 80 percent of the noncancer hazard. Benzene is the largest contributor to cancer risk of all 124 pollutants quantitatively assessed in the 2002 NATA and mobile sources were responsible for 59 percent of benzene emissions in 2002. In 2007, EPA finalized vehicle and fuel controls that address this public health risk; it will reduce total emissions of mobile source air toxics by 330,000 tons in 2030, including 61,000 tons of benzene.[163]

Noncancer health effects can result from chronic,[CC] subchronic,[DD] or acute[EE] 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 2002 NATA, nearly the entire U.S. population was exposed to an average 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. Mobile sources were responsible for over 80 percent of the noncancer (respiratory) risk from outdoor air toxics in 2002. The majority of this risk was from exposure to acrolein. The confidence in the RfC for acrolein is medium and confidence in NATA estimates of population noncancer hazard from ambient exposure to this pollutant is low.[164,165]

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 2002 NATA website.[166] 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.

7.1.1.5.1 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.[167,168,169] 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.[170,171]

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.[172,173] The most sensitive noncancer effect observed in humans, based on current data, is the depression of the absolute lymphocyte count in blood.[174,175] In addition, recent 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.[176,177,178,179] EPA's IRIS program has not yet evaluated these new data.

7.1.1.5.2 1,3-Butadiene

[CC] 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).

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

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

EPA has characterized 1,3-butadiene as carcinogenic to humans by inhalation.[180,181] 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.[182,183] 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.[184]

7.1.1.5.3 Formaldehyde

Since 1987, EPA has classified formaldehyde as a probable human carcinogen based on evidence in humans and in rats, mice, hamsters, and monkeys.[185] EPA is currently reviewing recently published epidemiological data. For instance, research conducted by the National Cancer Institute (NCI) found an increased risk of nasopharyngeal cancer and lymphohematopoietic malignancies such as leukemia among workers exposed to formaldehyde.[186,187] 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 exposures.[188] A recent National Institute of Occupational Safety and Health (NIOSH) study of garment workers also found increased risk of death due to leukemia among workers exposed to formaldehyde.[189] 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.[190]

In the past 15 years there has been substantial research on the inhalation dosimetry for formaldehyde in rodents and primates by the CIIT Centers for Health Research (formerly the Chemical Industry Institute of Toxicology), with a focus on use of rodent data for refinement of the quantitative cancer dose-response assessment.[191,192,193] CIIT's risk assessment of formaldehyde incorporated mechanistic and dosimetric information on formaldehyde. 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.[194,195,196,197] These findings are not supportive of interpreting the CIIT model results as providing a conservative (health protective) estimate of human risk. 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.

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."[198] EPA is reviewing the recent work cited above from the NCI and NIOSH, as well as the analysis by the CIIT Centers for Health Research and other studies, as part of a reassessment of the human hazard and dose-response associated with formaldehyde.

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.[199,200]

7.1.1.5.4 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.[201] 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.[202,203] 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.[204] In short-term (4 week) rat studies, degeneration of olfactory epithelium was observed at various concentration levels of acetaldehyde exposure.[205,206] 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.[207] The agency is currently conducting a reassessment of the health hazards from inhalation exposure to acetaldehyde.

7.1.1.5.5 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.[208] The IARC determined in 1995 that acrolein was not classifiable as to its carcinogenicity in humans.[209]

Acrolein is extremely acrid and irritating to humans when inhaled, with acute exposure resulting in upper respiratory tract irritation, mucus hypersecretion and congestion. Levels considerably lower than 1 ppm (2.3 mg/m^3) elicit subjective complaints of eye and nasal irritation and a decrease in the respiratory rate.[210,211] Lesions to the lungs and upper respiratory tract of rats, rabbits, and hamsters have been observed after subchronic exposure to acrolein. Based on animal data, 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. This was demonstrated in mice with allergic airway-disease by comparison to non-diseased mice in a study of the acute respiratory irritant effects of acrolein.[212]

EPA is currently in the process of conducting an assessment of acute exposure effects for acrolein. 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.[213]

7.1.1.5.6 Polycyclic Organic Matter (POM)

POM is generally defined as a large class of organic compounds which have multiple benzene rings and a boiling point greater than 100 degrees Celsius. Many of the compounds included in the class of compounds known as POM are classified by EPA as probable human carcinogens based on animal data. One of these compounds, naphthalene, is discussed separately below. Polycyclic aromatic hydrocarbons (PAHs) are a subset of POM that contain only hydrogen and carbon atoms. A number of PAHs are known or suspected carcinogens. Recent studies have found that maternal exposures to PAHs (a subclass of POM) 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 at age three.[214,215] EPA has not yet evaluated these recent studies.

7.1.1.5.7 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.[216] The draft reassessment completed external peer review.[217] 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. Once EPA evaluates public and peer reviewer comments, the document will be revised. 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.[218] 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.[219] Naphthalene also causes a number of chronic non-cancer effects in animals, including abnormal cell changes and growth in respiratory and nasal tissues.[220]

7.1.1.5.8 Other Air Toxics

In addition to the compounds described above, other compounds in gaseous hydrocarbon and PM emissions from vehicles would be affected by today's proposed action.

Mobile source air toxic compounds that would potentially be impacted include ethylbenzene, polycyclic organic matter, propionaldehyde, toluene, and xylene. Information regarding the health effects of these compounds can be found in EPA's IRIS database.[221]

7.1.2 Environmental Effects Associated with Exposure to Pollutants

In this section we will discuss the environmental effects associated with non-GHG co-pollutants, specifically: particulate matter, ozone, NO_X, SO_X, carbon monoxide and air toxics.

7.1.2.1 Visibility Degradation

Emissions from LD vehicles contribute to poor visibility in the U.S. through their primary $PM_{2.5}$ and NO_X emissions (which contribute to the formation of secondary $PM_{2.5}$). These 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.

The U.S. government places special emphasis on protecting visibility in national parks and wilderness areas. Section 169 of the Clean Air Act requires the U.S. government to address existing visibility impairment and future visibility impairment in the 156 national parks (see Figure 7-1) exceeding 6,000 acres, and wilderness areas exceeding 5,000 acres, which are categorized as mandatory class I federal areas (62 FR 38680, July 18, 1997).

7.1.2.1.1 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 7-1). 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. Optical measurements are used to directly measure light extinction or its components. Such measurements are taken principally with either a transmissometer, which measures total light extinction, or a nephelometer, which measures particle scattering (the largest human-caused component of total extinction). Scene characteristics are typically recorded three times daily with 35 millimeter 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 proposed 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. The rural East generally has higher levels of impairment than remote sites in the West, with the exception of urban-influenced sites such as San Gorgonio Wilderness (CA) and Point Reyes National Seashore (CA), which have annual average levels comparable to certain sites in the Northeast. Regional differences are illustrated by Figures 4-39a and 4-39b in the Air Quality Criteria Document for Particulate Matter, which show that, for Class I areas, visibility levels on the 20% haziest days in the West are about equal to levels on the 20% best days in the East.[222]

Higher visibility impairment levels in the East are due to generally higher concentrations of anthropogenic fine particles, particularly sulfates, and higher average relative humidity levels. In fact, sulfates account for 60-86% of the haziness in eastern sites.[223] Aerosol light extinction due to sulfate on the 20% haziest days is significantly larger in eastern Class I areas as compared to western areas (Figures 4-40a and 4-40b in the Air Quality Criteria Document for Particulate Matter).[224] With the exception of remote sites in the northwestern U.S., visibility is typically worse in the summer months. This is particularly true in the Appalachian region, where average light extinction in the summer exceeds the annual average by 40%.[225]

7.1.2.1.2 Addressing Visibility in the U.S.

The U.S. EPA is pursuing a two-part strategy to address visibility. First, to address the welfare effects of PM on visibility, EPA set secondary $PM_{2.5}$ standards which act in conjunction with the establishment of a regional haze program. In setting this secondary standard, EPA has concluded that $PM_{2.5}$ causes adverse effects on visibility in various locations, depending on PM concentrations and factors such as chemical composition and average relative humidity. Second, section 169 of the Clean Air Act provides additional authority to address existing visibility impairment and prevent future visibility impairment in the 156 national parks, forests and wilderness areas categorized as mandatory Class I federal areas (62 FR 38680-81, July 18, 1997).[FF] Figure 7-1 below identifies where each of these parks are located in the U.S. In July 1999, the regional haze rule (64 FR 35714) was put in place to protect the visibility in mandatory Class I federal areas. Visibility can be said to be impaired in both $PM_{2.5}$ nonattainment areas and mandatory Class I federal areas.[GG]

[FF] These areas are defined in section 162 of the Act 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.

[GG] As mentioned above, the EPA recently amended the PM NAAQS, making the secondary NAAQS equal, in all respects, to the primary standards for both $PM_{2.5}$ and PM_{10}, (71 FR 61144, Oct. 17, 2006). In February 2009, the D.C. Circuit Court remanded the secondary standards for fine particles, based on EPA's failure to adequately

Figure 7-1 Mandatory Class I Areas in the U.S.

7.1.2.2 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.[226] 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".[227] Like carbon dioxide (CO_2) and other gaseous substances, ozone enters plant tissues primarily through apertures (stomata) in leaves in a process called "uptake".[228] 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.[229,230] 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

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explain why setting the secondary PM2.5 NAAQS equivalent to the primary standards provided the required protection for public welfare including protection from visibility impairment.

reduced,[231] 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.[232,233]

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)[234,235,236] 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.[237]

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.

Ozone also has been conclusively shown to cause discernible injury to forest trees.[238,239] 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.[240,241]

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.[242] 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.[243,244,245] 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.

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."[246] In addition, economic studies have shown reduced economic benefits as a result of predicted reductions in crop yields associated with observed ozone levels.[247,248,249]

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.[250] 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.

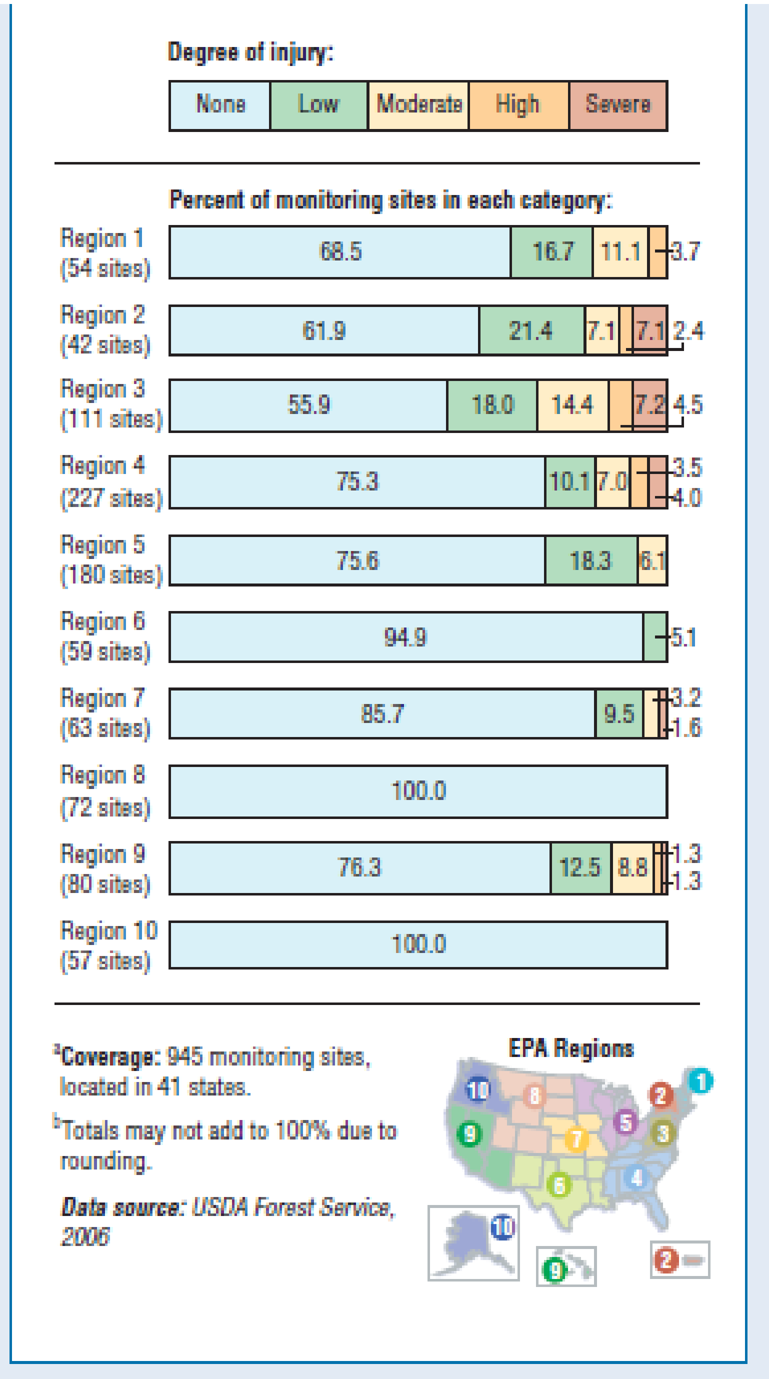
Air pollution can have noteworthy cumulative impacts on forested ecosystems by affecting regeneration, productivity, and species composition.[251] In the U.S., ozone in the lower atmosphere is one of the pollutants of primary concern. Ozone injury to forest plants can be diagnosed by examination of plant leaves. Foliar injury is usually the first visible sign of injury to plants from ozone exposure and indicates impaired physiological processes in the leaves.[252]

In the U.S. this 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.[253,254] 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. Monitoring of ozone injury to plants by the USDA Forest Service has expanded over the last 10 years from monitoring sites in 10 states in 1994 to nearly 1,000 monitoring sites in 41 states in 2002.

7.1.2.2.1 Recent Ozone Data for the U.S.

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 U.S. Department of Agriculture (USDA) Forest Service Forest Inventory and Analysis (FIA) program which examines ozone injury to ozone-sensitive plant species at ground monitoring sites in forest land across the country (This indicator does not include woodlots and urban trees). Sites are selected using a systematic sampling grid, based on a global sampling design.[255, 256] 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. The data underlying the indictor in Figure 7-2 are 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 are 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.[257, 258]

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 7-2 Ozone Injury to Forest Plants in U.S. by EPA Regions, 2002[ab]

7.1.2.2.1.1 Indicator Limitations

Field and laboratory studies were reviewed to identify the forest plant species in each region that are highly sensitive to ozone air pollution. Other forest plant species, or even genetic variants of the same species, may not be harmed 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 is considerably reduced under conditions of low soil moisture, but most of the variability in the index (70%) was explained by ozone concentration.[259] Ozone may have other adverse impacts on plants (e.g., reduced productivity) that do not show signs of visible foliar injury.[260]

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.

7.1.2.3 Ozone Impacts on Forest Health

Air pollution can impact the environment and affect ecological systems, leading to changes in the biological community (both in the diversity of species and the health and vigor of individual species). As an example, many studies have shown that ground-level ozone reduces the health of plants including many commercial and ecologically important forest tree species throughout the United States.[261]

When ozone is present in the air, it can enter the leaves of plants, where it can cause significant cellular damage. Since photosynthesis occurs in cells within leaves, the ability of the plant to produce energy by photosynthesis can be compromised if enough damage occurs to these cells. If enough tissue becomes damaged it can reduce carbon fixation and increase plant respiration, leading to reduced growth and/or reproduction in young and mature trees. Ozone stress also increases the susceptibility of plants to disease, insects, fungus, and other environmental stressors (e.g., harsh weather). Because ozone damage can consist of visible injury to leaves, it also reduces the aesthetic value of ornamental vegetation and trees in urban landscapes, and negatively affects scenic vistas in protected natural areas.

Assessing the impact of ground-level ozone on forests in the eastern 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.[262]

Some of the common tree species in the United States that are sensitive to ozone are black cherry (*Prunus serotina*), tulip-poplar (*Liriodendron tulipifera)*, 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.

7.1.2.4 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). Reflecting this fact, the PM AQCD concludes that regardless of size fractions, particles containing nitrates and sulfates have the greatest potential for widespread environmental significance, while effects are also related to other chemical constituents found in ambient PM, such as trace metals and organics. The following characterizations of the nature of these welfare effects are based on the information contained in the PM AQCD and PM Staff Paper.[263,264]

7.1.2.4.1 Deposition of Nitrogen and Sulfur

Nitrogen and sulfur interactions in the environment are highly complex. Both are essential, and sometimes limiting, nutrients needed for growth and productivity. Excesses of nitrogen or sulfur can lead to soil and water acidification, nutrient enrichment, and eutrophication.[265]

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.[266] 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.[267] 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 syndrome known as nitrogen saturation. These effects 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.[268]

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 alga, 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.[269]

7.1.2.4.2 Deposition of Heavy Metals

Heavy metals, including cadmium, copper, lead, chromium, mercury, nickel and zinc, have the greatest potential for influencing forest growth (PM AQCD, p. 4-87).[270] 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 (PM AQCD, p. 4-75). 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, 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 (PM AQCD, p. 4-76). 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 (PM AQCD 4-76,77).[271] 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 (PM AQCD, p. 4-75). As the fallen leaves decompose, the heavy metals are transferred into the soil.[272,273]

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.[274,275] Over fifty percent of the mercury in the Chesapeake Bay has been attributed to atmospheric deposition.[276] Overall, the National Science and Technology Council identifies atmospheric deposition as the primary source of mercury to aquatic systems.[277] 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.[278,279] 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.[280] Plant uptake of platinum has been observed at these locations.

7.1.2.4.3 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.[281] 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.[282]

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.[283,284] Analyses of PAH deposition in Chesapeake and Galveston Bay indicate that dry deposition and gas exchange from the atmosphere to the surface water predominate.[285,286] 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.[287] 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.[288] 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.[289] 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.[290]

Cousins et al. estimate that more than ninety percent of semi-volatile organic compound (SVOC) emissions in the United Kingdom deposit on soil.[291] An analysis of PAH concentrations near a Czechoslovakian roadway indicated that concentrations were thirty times greater than background.[292]

7.1.2.4.4 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.

7.1.2.5 Environmental Effects of Air Toxics

Fuel combustion emissions 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.[293] In laboratory experiments, a wide range of tolerance to VOCs has been observed.[294] 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.[295]

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.[296,297,298] 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.

7.2 Non-GHG Air Quality Impacts

7.2.1 Introduction

Chapter 5 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 hazardous air pollutants. Section 7.2.2 describes current ambient levels of PM, ozone, CO 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. Air quality modeling will be done for the final rule, however, and those plans are discussed in Section 7.2.3.

7.2.2 Current Levels of Pollutants

7.2.2.1 Particulate Matter

As described in Section 7.1.1.1, PM 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).[HH] As of June 5, 2009 there are 39 1997 $PM_{2.5}$ nonattainment areas comprised of 208 full or partial counties with a total population exceeding 88 million. Area designations for the 2006 24-hour $PM_{2.5}$ NAAQS are expected to be promulgated in 2009 and become effective 90 days after publication in the Federal Register.

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.[299] 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.[300]

7.2.2.2 Ozone

As described in Section 7.1.1.2, ozone causes adverse health effects, and the U.S. government has set national standards to protect against those health effects. The NAAQS for ozone is an 8-hour standard set at 0.075 ppm. The most recent revision to this standard was in

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[HH] 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.

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).[II] As of June 5, 2009 there are 55 1997 8-hour ozone nonattainment areas comprised of 290 full or partial counties with a total population of approximately 132 million.[301] 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.[JJ] The attainment dates associated with the potential nonattainment areas based on the 2008 8-hour ozone NAAQS will likely be in the 2013 to 2021 timeframe, depending on the severity of the problem in each area. Table 7-2 provides an estimate, based on 2004-06 air quality data, of the counties with design values greater than the 2008 ozone NAAQS.

Table 7-2 Counties with Design Values Greater Than the 2008 Ozone NAAQS Based on 2005-2007 Air Quality Data

	NUMBER OF COUNTIES	POPULATION[A]
1997 Ozone Standard: counties within the 57 areas currently designated as nonattainment	293	131,977,890
2008 Ozone Standard: additional counties that would not meet the 2008 NAAQS[b]	227	41,285,262
Total	520	173,263,152

Notes:
[a] Population numbers are from 2000 census data.
[b] Attainment designations for the 2008 ozone NAAQS have not yet been made. Nonattainment for the 2008 Ozone NAAQS will be based on three years of air quality data from later years. Also, the county numbers in the table include only the counties with monitors violating the 2008 Ozone NAAQS. The numbers in this table may be an underestimate of the number of counties and populations that will eventually be included in areas with multiple counties designated nonattainment.

7.2.2.3 Carbon Monoxide

As described in Section 7.1.1.4, CO causes adverse health effects, and the U.S. government has set national standards to protect against those health effects. There are two CO NAAQS. The 8-hour average CO NAAQS is 9 ppm, not to be exceeded more than once per year, and the 1-hour average CO NAAQS is 35 ppm, not to be exceeded more than once

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[II] 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.

[JJ] 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.

per year. The two standards are the identical standards that were promulgated in 1971. Reviews of the CO NAAQS in both 1985 and 1994 kept the standards at the same levels. As of June 5, 2009 there are approximately 479,000 people living in a portion of Clark Co., NV which is currently the only area in the country that is designated as nonattainment for CO, see Table 7-3.[302] The CO NAAQS is currently under review and a final rule is expected to be final in May 2011.

Table 7-3 Classified Carbon Monoxide Nonattainment Areas as of June 2009

AREA	CLASSIFICATION	POPULATION
Clark County (p), NV	Nonattainment	478,766
Total		478,766

7.2.2.4 Air Toxics

According to the National Air Toxics Assessment (NATA) for 2002, mobile sources were responsible for 47 percent of outdoor toxic emissions and over 50 percent of the cancer risk.[303] Nearly the entire U.S. population was exposed to an average concentration of air toxics that has the potential for adverse noncancer respiratory health effects. EPA recently finalized vehicle and fuel controls to reduce mobile source air toxics.[304] 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 recent 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.[305]

7.2.3 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 7.2.3.1 provides more detail on the photochemical model, the Community Multi-scale Air Quality (CMAQ) model, which will be utilized for the final rule analysis.

7.2.3.1 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, CO 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.

Section II.G.1 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 5 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 2005-based 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.).[306,307,308] The CMAQ model is a well-known and well-established tool and is commonly used by EPA for regulatory analyses, for instance the recent ozone NAAQS proposal, and by States in developing attainment demonstrations for their State Implementation Plans.[309] The CMAQ model (version 4.6) was peer-reviewed in February of 2007 for EPA as reported in “Third Peer Review of CMAQ Model,” and the EPA Office of Research and Development (ORD) peer review report which includes version 4.7 is currently being finalized.[310]

CMAQ includes many science modules that simulate the emission, production, decay, deposition and transport of organic and inorganic gas-phase and particle-phase pollutants in the atmosphere. We intend to use the most recent CMAQ version (version 4.7), which was officially released by EPA’s Office of Research and Development (ORD) in December 2008 and reflects updates to earlier versions in a number of areas to improve the underlying science. These include (1) enhanced secondary organic aerosol (SOA) mechanism to include chemistry of isoprene, sesquiterpene, and aged in-cloud biogenic SOA in addition to terpene; (2) improved vertical convective mixing; (3) improved heterogeneous reaction involving nitrate formation; and (4) an updated gas-phase chemistry mechanism, Carbon Bond 05 (CB05), with extensions to model explicit concentrations of air toxic species as well as chlorine and mercury. This mechanism, CB05-toxics, also computes concentrations of species that are involved in aqueous chemistry and that are precursors to aerosols.

The CMAQ modeling domain will encompass all of the lower 48 States and portions of Canada and Mexico. The modeling domain will include a large continental U.S. 36 km grid and two 12 km grids (an Eastern US and a Western US domain), as shown in Figure 7-3. The modeling domain will contain 14 vertical layers with the top of the modeling domain at about 16,200 meters, or 100 millibars (mb).

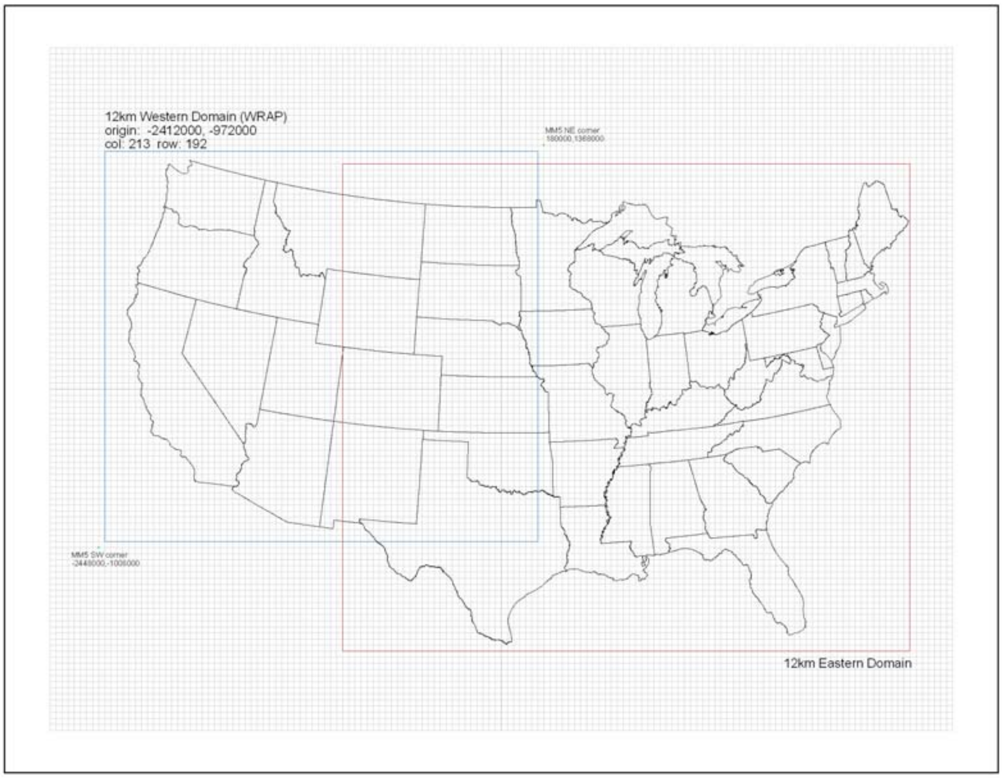

Figure 7-3 CMAQ 12-km Eastern and Western US modeling domains

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 will be derived from simulations of the Pennsylvania State University / National Center for Atmospheric Research Mesoscale Model[311] for the entire year of 2005. 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.[312] The meteorology for the national 36 km grid and the 12 km Eastern and Western U.S. grids will be developed by EPA and described in more detail within the final RIA and the technical support document for the final rule air quality modeling.

The lateral boundary and initial species concentrations will be provided by a three-dimensional global atmospheric chemistry model, the GEOS-CHEM model.[313] 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 for 2005 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 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.

7.3 Quantified and Monetized Co-Pollutant Health and Environmental Impacts

This section presents EPA's analysis of the 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. 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 any 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 in its regulatory impact analyses (RIAs), when possible. However, we were unable to do so in time for this proposal. 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-related benefits-per-ton values as an interim approach to estimating the PM-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-related benefits-per-ton values used to monetize the PM-related co-benefits associated with the proposal; the second explains what PM- 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 Ozone National Ambient Air Quality Standard (NAAQS) and the final PM NAAQS analysis, as well as the recent Portland Cement National Emissions Standards for Hazardous Air Pollutants (NESHAP) RIA (U.S. EPA, 2009a), and NO_2 NAAQS (U.S. EPA, 2009b).[314,315, 316,317]

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 5.5 for more information about the air toxics emissions impacts associated with the proposed standards.

7.3.1 Economic Value of Reductions in Criteria Pollutants

As described in Chapter 5.5, 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.

The dollar-per-ton estimates used in this analysis are provided in Table 7-4. In the summary of costs and benefits, Chapter 8.3 of this RIA, we present the monetized value of PM-related improvements associated with the proposal.

Table 7-4: Benefits-per-ton Values (2007$) Derived Using the ACS 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		Mobile Sources	
	SOx	VOC	NOx	Direct PM2.5	NOx	Direct PM2.5
2015	$28,000	$1,200	$4,700	$220,000	$4,900	$270,000
2020	$31,000	$1,300	$5,100	$240,000	$5,300	$290,000
2030	$36,000	$1,500	$6,100	$280,000	$6,400	$350,000
2040	$43,000	$1,800	$7,200	$330,000	$7,600	$420,000

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 145% (nearly two-and-a-half times) larger.

b The benefit-per-ton estimates 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.

c Benefit-per-ton values were estimated for the years 2015, 2020, and 2030. For 2040, EPA extrapolated exponentially based on the growth between 2020 and 2030.
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.

The benefit per-ton technique has been used in previous analyses, including EPA's recent Ozone National Ambient Air Quality Standards (NAAQS) RIA (U.S. EPA, 2008a),[318] proposed Portland Cement National Emissions Standards for Hazardous Air Pollutants (NESHAP) RIA (U.S. EPA, 2009a),[319] and proposed NO_2 primary NAAQS (U.S. EPA, 2009b).[320] Table 7-5 shows the quantified and unquantified $PM_{2.5}$-related co-benefits captured in those benefit-per-ton estimates.

Table 7-5: 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 proposed NO_2 NAAQS,[KK] the benefits estimates utilize the concentration-response functions as reported in the epidemiology literature. Readers interested in reviewing the complete methodology for creating the benefit-per-ton estimates used in this analysis can consult the Technical Support Document (TSD)[321] accompanying the recent final ozone NAAQS RIA (U.S. EPA, 2008a). Readers can also refer to Fann et al. (2009)[322] for a detailed description of the benefit-per-ton methodology.[LL] A more detailed description of the benefit-per-ton estimates is also provided in the TSD that accompanies this rulemaking.

As described in the documentation for the benefit per-ton estimates cited above, national per-ton estimates were developed for selected pollutant/source category

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[KK] Although we summarize the main issues in this chapter, we encourage interested readers to see benefits chapter of the proposed primary NO2 NAAQS RIA for a more detailed description of recent changes to the PM benefits presentation and preference for the no-threshold model.

[LL] 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 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-related precursor emissions controlled by sector and multiplied by each per-ton value.

The benefit-per-ton coefficients in this analysis were derived using modified versions of the health impact functions used in the PM NAAQS Regulatory Impact Analysis. Specifically, this analysis uses the benefit-per-ton estimates first applied in the Portland Cement NESHAP RIA (U.S. EPA, 2009a), which incorporated functions directly from the epidemiology studies without an adjustment for an assumed threshold. Removing the threshold assumption is a key difference between the method used in this analysis to estimate PM co-benefits and the methods used in analyses prior to EPA's proposed Portland Cement NESHAP. The benefit-per-ton estimates now include incremental benefits down to the lowest modeled $PM_{2.5}$ air quality levels.

PM-related mortality provides the majority (85-95%) of the monetized value in each benefit-per-ton estimate. As such, EPA deems it important to characterize the uncertainty underlying the concentration-response (C-R) functions used in its benefits analyses of regulations affecting PM levels. 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). However, due to the limitations of the benefit-per-ton methodology employed here, the quantitative uncertainty analysis related to the C-R relationship between $PM_{2.5}$ and premature mortality that EPA usually conducts in association with its benefits analysis was not conducted for this proposal.

Typically, the premature mortality-related effect coefficients that underlie the benefits-per-ton estimates are drawn from epidemiology studies that examine two large population cohorts: the American Cancer Society cohort (Pope et al., 2002)[323] and the Harvard Six Cities cohort (Laden et al., 2006).[324] The concentration-response (C-R) function developed from the extended analysis of American Cancer Society (ACS) cohort, as reported in Pope et al. (2002), has previously been used by EPA to generate its primary benefits estimate. The extended analysis of the Harvard Six Cities cohort, as reported by Laden et al (2006), was published after the completion of the Staff Paper for the 2006 $PM_{2.5}$ NAAQS and has been used as an alternative estimate in the $PM_{2.5}$ NAAQS RIA and $PM_{2.5}$ co-benefits estimates in analyses completed since the $PM_{2.5}$ NAAQS. These are logical choices for anchor points when presenting PM-related benefits because, although both studies are well designed and peer reviewed, there are strengths and weaknesses inherent in each, which argues for using both studies to generate benefits estimates. Using the alternate relationships between $PM_{2.5}$ and premature mortality supplied by experts as part of EPA's 206 Expert Elicitation Study, higher and lower benefits estimates are plausible, but most of the expert-based estimates fall between the two epidemiology-based estimates (Roman et al., 2008; IEc, 2006).[325,326] However, due to the analytical limitations associated with this analysis, we have chosen to use the benefit-per-ton value derived from the ACS study and note that benefits would be approximately 145% (or nearly two-and-a-half times) larger if the Harvard Six Cities values were used.

As a note to those who might be comparing the benefits estimates in this rule to those in previous EPA analyses, it is the nature of benefits analyses for assumptions and methods to evolve over time to reflect the most current interpretation of the scientific and economic literature. For a period of time (2004-2008), EPA's Office of Air and Radiation (OAR) valued mortality risk reductions using a value of statistical life (VSL) estimate derived from a limited analysis of some of the available studies. OAR arrived at a VSL using a range of $1 million to $10 million (2000$) consistent with two meta-analyses of the wage-risk literature. The $1 million value represented the lower end of the interquartile range from the Mrozek and Taylor (2002)[327] meta-analysis of 33 studies. The $10 million value represented the upper end of the interquartile range from the Viscusi and Aldy (2003)[328] meta-analysis of 43 studies. The mean estimate of $5.5 million (2000$) was also consistent with the mean VSL of $5.4 million estimated in the Kochi et al. (2006)[329] meta-analysis. However, the Agency neither changed its official guidance on the use of VSL in rule-makings nor subjected the interim estimate to a scientific peer-review process through the Science Advisory Board (SAB) or other peer-review group.

Until updated guidance is available, EPA determined that a single, peer-reviewed estimate applied consistently best reflects the SAB-EEAC advice it has received. Therefore, EPA has decided to apply the VSL that was vetted and endorsed by the SAB in the Guidelines for Preparing Economic Analyses (U.S. EPA, 2000)[330] while they continue efforts to update their guidance on this issue.[MM] This approach calculates a mean value across VSL estimates derived from 26 labor market and contingent valuation studies published between 1974 and 1991. The mean VSL across these studies is $6.3 million (2000$). The dollar-per-ton estimates used in this analysis are based on this VSL.

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. Please refer to Section VII.E for a description of EPA's modeling plans and to Section VIII.G.2 for the description of the quantification and monetization of health impacts for the FRM.
- This analysis assumes that all fine particles, regardless of their chemical composition, are equally potent in causing premature mortality. This is an

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[MM] In the (draft) update of the Economic Guidelines (U.S. EPA, 2008c), EPA retained the VSL endorsed by the SAB with the understanding that further updates to the mortality risk valuation guidance would be forthcoming in the near future. Therefore, this report does not represent final agency policy. The draft update of the Economic Guidelines is available on the Internet at <http://yosemite.epa.gov/ee/epa/eermfile.nsf/vwAN/EE-0516-01.pdf/$File/EE-0516-01.pdf>.

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 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 benefits categories that we were 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, 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 VIII.G.2 for a description of the quantification and monetization of health impact 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 C-R 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 C-R 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).
- 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.

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.

7.3.2 Human Health and Environmental Benefits for the Final Rule

7.3.2.1 Human Health and Environmental Impacts

To model the ozone and PM air quality benefits of the final rule, EPA will use the Community Multiscale Air Quality (CMAQ) model (see Section 7.2.3.1 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).[331] 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 7-6 lists the co-pollutant health effect exposure-response functions we will use to quantify the co-pollutant incidence impacts associated with the final light-duty vehicles standard.

Table 7-6: Health Impact Functions Used in BenMAP to Estimate Impacts of $PM_{2.5}$ and Ozone Reductions

ENDPOINT	*POLLUTANT*	*STUDY*	*STUDY POPULATION*
Premature Mortality			
Premature mortality – daily time series	O_3	Multi-city Bell et al (2004) (NMMAPS study)[332] – Non-accidental Huang et al (2005)[333] - Cardiopulmonary Schwartz (2005)[334] – Non-accidental Meta-analyses: Bell et al (2005)[335] – All cause Ito et al (2005)[336] – Non-accidental Levy et al (2005)[337] – All cause	All ages
Premature mortality —cohort study, all-cause	$PM_{2.5}$	Pope et al. (2002)[338] Laden et al. (2006)[339]	>29 years >25 years
Premature mortality, total exposures	$PM_{2.5}$	Expert Elicitation (IEc, 2006)[340]	>24 years
Premature mortality — all-cause	$PM_{2.5}$	Woodruff et al. (1997)[341]	Infant (<1 year)
Chronic Illness			
Chronic bronchitis	$PM_{2.5}$	Abbey et al. (1995)[342]	>26 years
Nonfatal heart attacks	$PM_{2.5}$	Peters et al. (2001)[343]	Adults (>18 years)
Hospital Admissions			
RespirFSatory	O_3	Pooled estimate: Schwartz (1995) - ICD 460-519 (all resp)[344] Schwartz (1994a; 1994b) - ICD 480-486 (pneumonia)[345,346] Moolgavkar et al. (1997) - ICD 480-487 (pneumonia)[347] Schwartz (1994b) - ICD 491-492, 494-496 (COPD) Moolgavkar et al. (1997) – ICD 490-496 (COPD)	>64 years
		Burnett et al. (2001)[348]	<2 years
	$PM_{2.5}$	Pooled estimate: Moolgavkar (2003)—ICD 490-496 (COPD)[349] Ito (2003)—ICD 490-496 (COPD)[350]	>64 years
	$PM_{2.5}$	Moolgavkar (2000)—ICD 490-496 (COPD)[351]	20–64 years
	$PM_{2.5}$	Ito (2003)—ICD 480-486 (pneumonia)	>64 years
	$PM_{2.5}$	Sheppard (2003)—ICD 493 (asthma)[352]	<65 years
Cardiovascular	$PM_{2.5}$	Pooled estimate: Moolgavkar (2003)—ICD 390-429 (all cardiovascular) Ito (2003)—ICD 410-414, 427-428 (ischemic heart disease, dysrhythmia, heart failure)	>64 years
	$PM_{2.5}$	Moolgavkar (2000)—ICD 390-429 (all cardiovascular)	20–64 years

Asthma-related ER visits	O_3	Pooled estimate: Jaffe et al (2003)[353] Peel et al (2005)[354] Wilson et al (2005)[355]	 5–34 years All ages All ages
Asthma-related ER visits (con't)	$PM_{2.5}$	Norris et al. (1999)[356]	0–18 years
Other Health Endpoints			
Acute bronchitis	$PM_{2.5}$	Dockery et al. (1996)[357]	8–12 years
Upper respiratory symptoms	$PM_{2.5}$	Pope et al. (1991)[358]	Asthmatics, 9–11 years
Lower respiratory symptoms	$PM_{2.5}$	Schwartz and Neas (2000)[359]	7–14 years
Asthma exacerbations	$PM_{2.5}$	Pooled estimate: Ostro et al. (2001)[360] (cough, wheeze and shortness of breath) Vedal et al. (1998)[361] (cough)	6–18 years[a]
Work loss days	$PM_{2.5}$	Ostro (1987)[362]	18–65 years
School absence days	O_3	Pooled estimate: Gilliland et al. (2001)[363] Chen et al. (2000)[364]	5–17 years[b]
Minor Restricted Activity Days (MRADs)	O_3	Ostro and Rothschild (1989)[365]	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.

7.3.2.2 Monetized Estimates of Impacts of Reductions in Co-Pollutants

Table 7-7 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 7-7: Valuation Metrics Used in BenMAP to Estimate Monetary Co-Benefits

Endpoint	Valuation Method	Valuation (2000$)
Premature mortality	Assumed Mean VSL	$6,300,000
Chronic Illness		
Chronic Bronchitis	WTP: Average Severity	$340,482
Myocardial Infarctions, Nonfatal	Medical Costs Over 5 Years. Varies by age and discount rate. Russell (1998)[366]	---
	Medical Costs Over 5 Years. Varies by age and discount rate. Wittels (1990)[367]	---
Hospital Admissions		
Respiratory, Age 65+	COI: Medical Costs + Wage Lost	$18,353
Respiratory, Ages 0-2	COI: Medical Costs	$7,741
Chronic Lung Disease (less Asthma)	COI: Medical Costs + Wage Lost	$12,378
Pneumonia	COI: Medical Costs + Wage Lost	$14,693
Asthma	COI: Medical Costs + Wage Lost	$6,634
Cardiovascular	COI: Medical Costs + Wage Lost (20-64)	$22,778
	COI: Medical Costs + Wage Lost (65-99)	$21,191
ER Visits, Asthma	COI: Smith et al. (1997)[368]	$312
	COI: Standford et al. (1999)[369]	$261
Other Health Endpoints		
Acute Bronchitis	WTP: 6 Day Illness, CV Studies	$356
Upper Respiratory Symptoms	WTP: 1 Day, CV Studies	$25
Lower Respiratory Symptoms	WTP: 1 Day, CV Studies	$16
Asthma Exacerbation	WTP: Bad Asthma Day, Rowe and Chestnut (1986) [370]	$43
Work Loss Days	Median Daily Wage, County-Specific	---
Minor Restricted Activity Days	WTP: 1 Day, CV Studies	$51
School Absence Days	Median Daily Wage, Women 25+	$75
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 version 3.0.

7.3.2.3 Other Unquantified Health and Environmental Impacts

In addition to the co-pollutant health and environmental impacts we will 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. For air toxics, the available tools and methods to assess risk from mobile sources at the national scale are not adequate for extrapolation to benefits assessment. In addition to inherent limitations in the tools for national-scale modeling of air toxics and exposure, there is a lack of epidemiology data for air toxics in the general population. Table 7-8 lists these unquantified health and environmental impacts.

Table 7-8: 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 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 8.4 for additional information on the health effects of air toxics.

[f] Please refer to Chapter 8.4 for additional information on the welfare effects of air toxics.

In addition to the co-pollutant health and environmental impacts we will quantify for the analysis of the final standard, there are a number of other health and human welfare endpoints that we will not be able to quantify or monetize 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. Chapter 7.3 of the RIA lists these unquantified health and environmental impacts.

While there will be impacts associated with air toxic pollutant emission changes that result from the final standard, we will 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.[371] While EPA has since improved the tools, there remain critical limitations for estimating incidence and assessing benefits of reducing mobile source air toxics. EPA continues to work to address these limitations; however, we do not anticipate having methods and tools available for national-scale application in time for the analysis of the final rules.[NN]

7.4 Changes in Global Mean Temperature and Sea-Level Rise Associated with the Proposal's GHG Emissions Reductions

7.4.1 Introduction

Based on modeling analysis performed by the EPA, reductions in CO2 and other GHGs associated with the Proposal will affect climate change projections. Because GHGs mix well 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 centuries. Two common indicators of climate change are global mean surface temperature and sea-level rise. This section estimates the response in global mean surface temperature and sea-level rise projections to the estimated net global GHG emissions reductions associated with the Proposal (see Chapter 5 for the estimated net reductions in global emissions over time by GHG).

7.4.2 Estimated Projected Reductions in Global Mean Surface Temperature and Sea-Level Rise

We estimated changes in projected atmospheric CO_2 concentrations, global mean surface temperature and sea-level rise to 2100 using the MiniCAM (Mini Climate Assessment Model) integrated assessment model[372] coupled with the MAGICC (Model for the Assessment of Greenhouse-gas Induced Climate Change) simple climate model.[373] MiniCAM was used to create the globally and temporally consistent set of climate relevant variables required for running MAGICC. MAGICC was then used to estimate the change in the atmospheric CO_2 concentrations, global mean surface temperature and sea-level rise over time. Given the magnitude of the estimated emissions reductions associated with the rule, a simple climate model such as MAGICC is reasonable for estimating the atmospheric and climate response.

An emissions scenario for the proposal was developed by applying the proposal's estimated emissions reductions to the MiniCAM reference (no climate policy or baseline) scenario (used as the basis for the Representative Concentration Pathway RCP4.5[374]). Specifically, the CO_2, N_2O, CH_4, and HFC-134a emissions reductions from Chapter 5 were

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[NN] 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.

applied as net reductions to the MiniCAM global baseline net emissions for each GHG. All emissions reductions were assumed to begin in 2012, with zero emissions change in 2011 and linearly increasing to equal the value supplied (in Chapter 5) for 2020. The emissions reductions past 2050 were scaled with total U.S. road transportation fuel consumption from the MiniCAM reference scenario. Using MAGICC, the atmospheric CO_2 concentration, the global mean temperature, and sea-level change were projected at five-year time steps to 2100 for both the reference (no climate policy) scenario and the emissions scenario specific to the Proposal. To capture some of the uncertainty in the climate system, the changes in projected temperatures 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.[375]

To compute the reductions in atmospheric CO_2 concentration, temperature, and sea-level rise specifically attributable to the Proposal, the output from the Proposal's emissions scenario was subtracted from the reference (no policy or baseline) emissions case scenario. As a result of the Proposal's emissions reductions, the atmospheric CO_2 concentration is projected to be reduced by approximately 2.9 to 3.2 parts per million (ppm), the global mean temperature is projected to be reduced by approximately 0.007-0.016°C by 2100 and global mean sea-level rise is projected to be reduced by approximately 0.06-0.15 cm by 2100.

Figure 7-4 provides the estimated reductions in projected global mean surface temperatures associated with the Proposal. Figure 7-5 provides the estimated reductions in global mean sea-level rise associated with the Proposal.

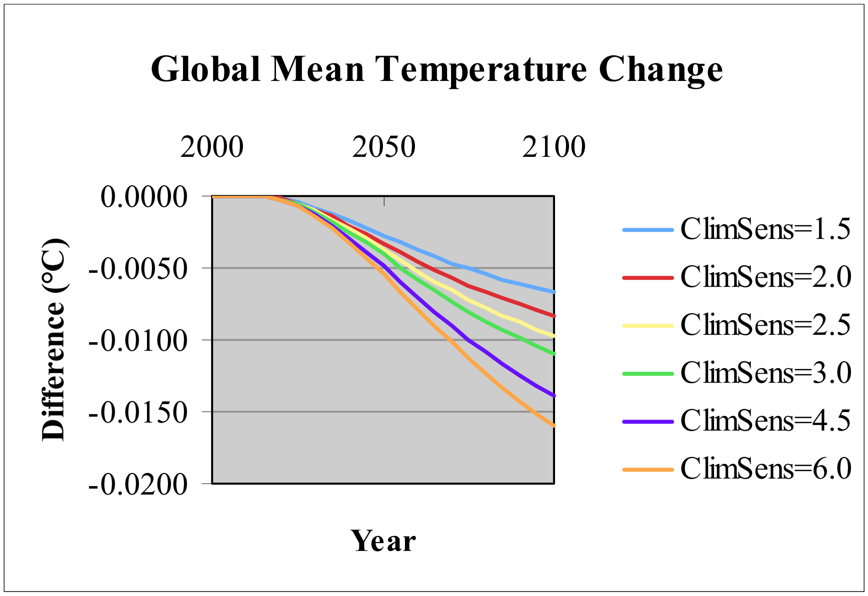

Figure 7-4 Estimated Projected Reductions in Global Mean Surface Temperatures from Baseline for the Proposed Vehicles Rulemaking (for climate sensitivities ranging from 1.5-6°C)

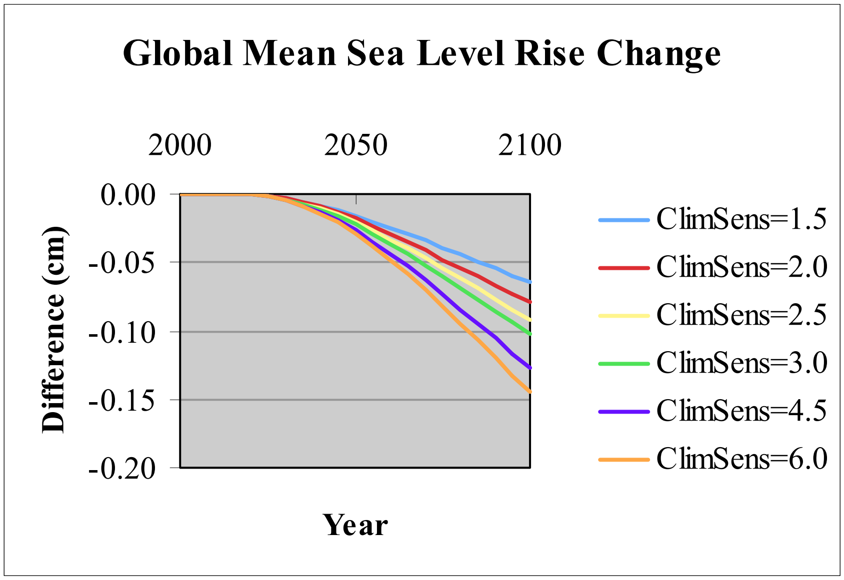

Figure 7-5 Estimated Projected Reductions in Global Mean Sea-Level Rise from Baseline for the Proposed Vehicles Rulemaking (for climate sensitivities ranging from 1.5-6°C)

The results in both Figure 7-4 and Figure 7-5 show a relatively small reduction in the projected global mean surface temperature and sea level respectively, across all climate sensitivities. The projected reductions are small relative to the IPCC's 2100 "best estimates" for global mean temperature increases (1.8 – 4.0ºC) and sea-level rise (0.20-0.59m) for all global GHG emissions sources for a range of emissions scenarios.[376] These projected reductions are proportionally representative of changes to U.S. GHG emissions in the transportation sector. While not formally estimated for the proposed rulemaking, a reduction in projected global mean temperature and sea-level rise implies a reduction in the risks associated with of climate change. Both figures illustrate that the distribution for projected global mean temperature and sea-level rise increases has shifted down. The benefits of GHG emissions reductions can be characterized both qualitatively and quantitatively, some of which can be monetized (seeChapter 7.5). There are substantial uncertainties in modeling the global risks of climate change, which complicates quantification and benefit-cost assessments. Changes in climate variables are a meaningful proxy for changes in the risk of all 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., respectively forest disturbance and catastrophic events such as collapse of large ice sheets and subsequent sea-level rise).

7.5 SCC and GHG Benefits

We assigned a monetary value to reductions in CO_2 emissions using the marginal dollar value (i.e., cost) of climate-related damages resulting from carbon emissions, also referred to as "social cost of carbon" (SCC). The SCC is intended to measure the monetary value society places on impacts resulting from increased GHGs, such as property damage from sea level rise, forced migration due to dry land loss, and mortality changes associated with vector-borne diseases. Published estimates of the SCC vary widely, however, as a result of uncertainties about future economic growth, climate sensitivity to GHG emissions, procedures used to model the economic impacts of climate change, and the choice of discount rates. Furthermore, some of the likely and potential damages from climate change—for example, the loss of endangered species—are generally not included in current SCC estimates. These omissions may turn out to be significant, in the sense that they may mean that the best current estimates are too low. As noted by the IPCC Fourth Assessment Report, "It is very likely that globally aggregated figures underestimate the damage costs because they cannot include many non-quantifiable impacts."[377]

Today's joint proposals present a set of interim SCC values reflecting a federal interagency group's interpretation of the relevant climate economics literature. The interim SCC values, which reflect an interim interpretation of the current literature, are derived using several discount rates. The interim SCC values include:

- $5 (based on a 5% discount rate);
- $10(5% using Newell-Pizer adjustment);,
- $20(average SCC value from the average SCC estimates based on 5% and 3%);
- $34 (3%);
- $56 (3% using Newell-Pizer adjustment).

These interim SCC values are in 2007 dollars, and are based on a CO_2 emissions change of 1 metric ton in 2007. Section III.H.6 of the Preamble provides a complete discussion about SCC and the interim set of values.

The tables below summarize the total GHG benefits for the lifetime of the rule, which are calculated by using the five interim SCC values. Specifically, total monetized benefits in each year are calculated by multiplying the marginal benefits estimates per metric ton of CO_2 (the SCC) by the reductions in CO_2 for that year. We have also approximated the total monetized benefits for non-CO_2 GHGs by multiplying the SCC value by the reductions in non-CO_2 GHGs for that year. Marginal benefit estimates per metric ton of non-CO_2 GHGs are currently unavailable, but work is on-going to monetize benefits related to the mitigation of other non-CO_2 GHGs.

Table 7-9: Upstream and Downstream CO2 Benefits for the Given SCC Value, Calendar Year Analysis (Millions of 2007 dollars)

YEAR	5%	5% NEWELL-PIZER	FROM 3% AND 5%	3%	3% NEWELL-PIZER
2012	$35	$70	$132	$230	$383
2013	$89	$179	$340	$590	$984
2014	$168	$336	$639	$1,109	$1,849
2015	$281	$562	$1,068	$1,855	$3,092
2016	$439	$878	$1,668	$2,898	$4,829
2017	$601	$1,203	$2,285	$3,968	$6,614
2018	$768	$1,536	$2,919	$5,069	$8,449
2019	$939	$1,878	$3,568	$6,197	$10,328
2020	$1,112	$2,225	$4,227	$7,342	$12,237
2021	$1,288	$2,577	$4,896	$8,503	$14,172
2022	$1,465	$2,929	$5,566	$9,666	$16,111
2023	$1,645	$3,290	$6,250	$10,855	$18,092
2024	$1,827	$3,654	$6,942	$12,057	$20,095
2025	$2,014	$4,027	$7,652	$13,290	$22,151
2026	$2,200	$4,400	$8,359	$14,519	$24,198
2027	$2,386	$4,772	$9,067	$15,748	$26,247
2028	$2,568	$5,136	$9,759	$16,949	$28,249
2029	$2,749	$5,497	$10,445	$18,141	$30,235
2030	$2,931	$5,861	$11,137	$19,342	$32,237
2031	$3,117	$6,234	$11,844	$20,571	$34,285
2032	$3,306	$6,611	$12,562	$21,818	$36,363
2033	$3,501	$7,002	$13,305	$23,108	$38,513
2034	$3,702	$7,404	$14,068	$24,434	$40,723
2035	$3,912	$7,824	$14,865	$25,819	$43,031
2036	$4,129	$8,258	$15,691	$27,253	$45,421
2037	$4,357	$8,715	$16,558	$28,758	$47,930
2038	$4,594	$9,188	$17,458	$30,322	$50,536
2039	$4,844	$9,687	$18,406	$31,969	$53,281
2040	$5,104	$10,209	$19,396	$33,688	$56,147
2041	$5,379	$10,758	$20,441	$35,502	$59,170
2042	$5,668	$11,336	$21,539	$37,409	$62,349
2043	$5,973	$11,945	$22,696	$39,420	$65,700
2044	$6,294	$12,587	$23,916	$41,538	$69,229
2045	$6,632	$13,263	$25,200	$43,768	$72,947
2046	$6,987	$13,975	$26,552	$46,117	$76,861
2047	$7,362	$14,724	$27,976	$48,590	$80,983
2048	$7,756	$15,512	$29,473	$51,191	$85,318
2049	$8,171	$16,342	$31,049	$53,927	$89,878
2050	$8,607	$17,214	$32,706	$56,805	$94,675
NPV, 3%	$62,100	$124,200	$236,000	$409,800	$683,100
NPV, 7%	$25,600	$51,200	$97,200	$168,800	$281,300

Table 7-10: Upstream and Downstream non-CO2 GHG Benefits for the Given SCC Value, Calendar Year Analysis (Millions of 2007 dollars)

YEAR	5%	5% NEWELL-PIZER	FROM 3% AND 5%	3%	3% NEWELL-PIZER
2012	$5	$11	$21	$36	$60
2013	$13	$27	$51	$88	$147
2014	$24	$48	$91	$158	$263
2015	$38	$76	$145	$252	$419
2016	$55	$109	$208	$361	$601
2017	$72	$144	$274	$476	$793
2018	$91	$181	$344	$597	$996
2019	$110	$220	$417	$725	$1,208
2020	$133	$266	$506	$879	$1,465
2021	$154	$308	$585	$1,016	$1,694
2022	$175	$351	$667	$1,158	$1,929
2023	$198	$395	$751	$1,304	$2,173
2024	$220	$440	$837	$1,453	$2,422
2025	$243	$487	$925	$1,606	$2,677
2026	$267	$533	$1,013	$1,760	$2,934
2027	$290	$580	$1,102	$1,913	$3,189
2028	$313	$626	$1,189	$2,064	$3,441
2029	$334	$668	$1,269	$2,204	$3,674
2030	$358	$716	$1,361	$2,364	$3,940
2031	$379	$758	$1,441	$2,503	$4,172
2032	$400	$801	$1,521	$2,642	$4,403
2033	$422	$843	$1,602	$2,782	$4,637
2034	$443	$886	$1,683	$2,924	$4,873
2035	$465	$930	$1,766	$3,067	$5,112
2036	$487	$974	$1,851	$3,214	$5,357
2037	$510	$1,019	$1,937	$3,364	$5,607
2038	$533	$1,066	$2,025	$3,517	$5,862
2039	$557	$1,114	$2,116	$3,675	$6,124
2040	$581	$1,163	$2,209	$3,836	$6,394
2041	$607	$1,214	$2,306	$4,005	$6,676
2042	$633	$1,267	$2,407	$4,180	$6,967
2043	$661	$1,321	$2,511	$4,361	$7,268
2044	$689	$1,378	$2,619	$4,548	$7,580
2045	$719	$1,437	$2,730	$4,742	$7,904
2046	$749	$1,498	$2,846	$4,944	$8,240
2047	$781	$1,561	$2,967	$5,153	$8,588
2048	$814	$1,627	$3,091	$5,369	$8,949
2049	$847	$1,695	$3,220	$5,593	$9,322
2050	$883	$1,765	$3,354	$5,826	$9,710
NPV, 3%	$7,100	$14,200	$27,100	$47,000	$78,400
NPV, 7%	$3,000	$6,000	$11,400	$19,700	$32,900

Table 7-11: Upstream and Downstream CO2-Equivalent Benefits for the Given SCC Value, Calendar Year Analysis (Millions of 2007 dollars)

YEAR	5%	5% NEWELL-PIZER	FROM 3% AND 5%	3%	3% NEWELL-PIZER
2012	$40	$81	$153	$266	$443
2013	$103	$206	$391	$678	$1,131
2014	$192	$384	$729	$1,267	$2,112
2015	$319	$638	$1,213	$2,107	$3,511
2016	$494	$987	$1,876	$3,258	$5,430
2017	$673	$1,347	$2,559	$4,444	$7,407
2018	$859	$1,717	$3,263	$5,667	$9,444
2019	$1,049	$2,098	$3,985	$6,922	$11,537
2020	$1,246	$2,491	$4,734	$8,222	$13,703
2021	$1,442	$2,885	$5,481	$9,520	$15,866
2022	$1,640	$3,280	$6,232	$10,824	$18,040
2023	$1,842	$3,685	$7,001	$12,159	$20,265
2024	$2,047	$4,094	$7,779	$13,510	$22,517
2025	$2,257	$4,514	$8,577	$14,897	$24,828
2026	$2,466	$4,933	$9,373	$16,279	$27,131
2027	$2,676	$5,352	$10,169	$17,661	$29,435
2028	$2,881	$5,762	$10,947	$19,014	$31,690
2029	$3,083	$6,165	$11,714	$20,345	$33,909
2030	$3,289	$6,578	$12,498	$21,707	$36,178
2031	$3,496	$6,992	$13,285	$23,074	$38,457
2032	$3,706	$7,412	$14,083	$24,460	$40,766
2033	$3,923	$7,845	$14,906	$25,890	$43,150
2034	$4,145	$8,290	$15,751	$27,357	$45,595
2035	$4,377	$8,753	$16,631	$28,886	$48,143
2036	$4,616	$9,232	$17,541	$30,467	$50,778
2037	$4,867	$9,734	$18,494	$32,122	$53,537
2038	$5,127	$10,254	$19,483	$33,839	$56,398
2039	$5,400	$10,801	$20,522	$35,643	$59,405
2040	$5,686	$11,371	$21,605	$37,525	$62,541
2041	$5,986	$11,972	$22,747	$39,507	$65,846
2042	$6,301	$12,603	$23,945	$41,589	$69,315
2043	$6,633	$13,267	$25,207	$43,781	$72,968
2044	$6,983	$13,965	$26,534	$46,086	$76,809
2045	$7,350	$14,700	$27,930	$48,510	$80,851
2046	$7,736	$15,473	$29,398	$51,060	$85,101
2047	$8,143	$16,286	$30,943	$53,743	$89,571
2048	$8,570	$17,139	$32,565	$56,560	$94,267
2049	$9,018	$18,036	$34,269	$59,520	$99,201
2050	$9,490	$18,979	$36,060	$62,631	$104,385
NPV, 3%	$69,200	$138,400	$263,000	$456,900	$761,400
NPV, 7%	$28,600	$57,100	$108,500	$188,500	$314,200

EPA also conducted a separate analysis of the GHG benefits over the model year lifetimes of the 2012 through 2016 model year vehicles. In contrast to the calendar year analysis, the model year lifetime analysis shows the lifetime impacts of the program on each of these MY fleets over the course of its lifetime. Full details of the inputs to this analysis can be found in DRIA chapter 5. The GHG benefits of the full life of each of the five model years from 2012 through 2016 are shown in Table 7-12 through Table 7-16 for each of the five different social cost of carbon values. The GHG benefits are shown for each year in the model year life and in net present value using both a 3 percent and a 7 percent discount rate.

Table 7-12: Upstream and Downstream CO2-Equivalent Benefits for the 5% SCC Value, Model Year Analysis (Millions of 2007 dollars)

YEAR	2012	2013	2014	2015	2016	SUM
2012	$42	$0	$0	$0	$0	$42
2013	$42	$67	$0	$0	$0	$109
2014	$42	$66	$95	$0	$0	$204
2015	$42	$66	$95	$137	$0	$340
2016	$41	$66	$95	$137	$188	$526
2017	$40	$65	$94	$136	$187	$522
2018	$39	$63	$92	$135	$187	$516
2019	$37	$61	$90	$133	$185	$507
2020	$36	$59	$88	$130	$182	$494
2021	$34	$56	$84	$126	$178	$478
2022	$32	$53	$80	$121	$172	$459
2023	$29	$50	$76	$115	$166	$436
2024	$25	$46	$71	$109	$158	$409
2025	$21	$40	$65	$102	$150	$378
2026	$18	$34	$57	$94	$140	$341
2027	$15	$28	$48	$81	$128	$300
2028	$12	$23	$40	$69	$112	$257
2029	$10	$19	$34	$58	$95	$216
2030	$8	$16	$28	$49	$80	$181
2031	$7	$13	$23	$40	$67	$150
2032	$5	$11	$19	$33	$56	$124
2033	$5	$9	$16	$28	$46	$103
2034	$4	$8	$13	$23	$38	$85
2035	$3	$6	$11	$19	$31	$71
2036	$3	$5	$9	$16	$26	$60
2037	$2	$5	$8	$14	$22	$51
2038	$2	$4	$7	$12	$19	$43
2039	$1	$3	$6	$10	$16	$37
2040	$1	$3	$4	$9	$14	$31
2041	$1	$2	$4	$6	$12	$26
2042	$1	$2	$4	$6	$9	$21
2043	$1	$2	$3	$5	$8	$19
2044	$1	$2	$3	$5	$7	$17
2045	$1	$2	$3	$4	$6	$15
2046	$1	$1	$2	$4	$6	$14
2047	$1	$1	$2	$3	$5	$12
2048	$0	$1	$2	$3	$5	$11
2049	$0	$0	$2	$3	$4	$8
2050	$0	$0	$0	$2	$4	$6
NPV, 3%	$477	$733	$1,021	$1,426	$1,897	$5,555
NPV, 7%	$368	$543	$727	$978	$1,251	$3,866

Table 7-13: Upstream and Downstream CO2-Equivalent Benefits for the 5% Newell-Pizer SCC Value, Model Year Analysis (Millions of 2007 dollars)

YEAR	2012	2013	2014	2015	2016	SUM
2012	$84	$0	$0	$0	$0	$84
2013	$84	$133	$0	$0	$0	$217
2014	$84	$133	$191	$0	$0	$407
2015	$83	$133	$190	$274	$0	$680
2016	$82	$131	$190	$273	$376	$1,052
2017	$80	$129	$187	$273	$374	$1,044
2018	$78	$126	$185	$270	$374	$1,033
2019	$75	$122	$180	$266	$370	$1,013
2020	$71	$118	$175	$260	$364	$988
2021	$68	$112	$168	$252	$356	$956
2022	$64	$107	$160	$242	$345	$918
2023	$58	$100	$152	$231	$332	$872
2024	$50	$91	$142	$219	$316	$818
2025	$42	$79	$130	$205	$300	$756
2026	$35	$67	$113	$187	$280	$683
2027	$29	$56	$96	$163	$256	$601
2028	$24	$47	$81	$139	$223	$513
2029	$20	$39	$68	$116	$190	$432
2030	$16	$32	$56	$97	$160	$361
2031	$13	$26	$47	$81	$133	$300
2032	$11	$22	$38	$67	$111	$249
2033	$9	$18	$32	$55	$92	$206
2034	$8	$15	$26	$46	$76	$171
2035	$7	$13	$22	$38	$63	$142
2036	$5	$11	$19	$32	$52	$120
2037	$5	$9	$16	$27	$44	$102
2038	$3	$8	$14	$23	$37	$86
2039	$3	$6	$12	$20	$32	$73
2040	$3	$5	$9	$17	$28	$62
2041	$2	$5	$8	$13	$24	$52
2042	$2	$4	$7	$12	$18	$43
2043	$2	$4	$6	$10	$16	$38
2044	$2	$3	$6	$9	$14	$35
2045	$2	$3	$5	$8	$13	$31
2046	$1	$3	$5	$7	$12	$28
2047	$1	$2	$4	$7	$10	$25
2048	$0	$2	$4	$6	$9	$21
2049	$0	$0	$3	$5	$8	$17
2050	$0	$0	$0	$5	$7	$12
NPV, 3%	$955	$1,467	$2,042	$2,853	$3,794	$11,109
NPV, 7%	$736	$1,086	$1,453	$1,955	$2,503	$7,733

Table 7-14: Upstream and Downstream CO2-Equivalent Benefits for the from 3% and 5% SCC Value, Model Year Analysis (Millions of 2007 dollars)

YEAR	2012	2013	2014	2015	2016	SUM
2012	$160	$0	$0	$0	$0	$160
2013	$160	$253	$0	$0	$0	$413
2014	$160	$252	$362	$0	$0	$774
2015	$158	$252	$361	$521	$0	$1,292
2016	$156	$249	$360	$519	$714	$1,998
2017	$152	$245	$356	$519	$711	$1,984
2018	$148	$240	$351	$513	$711	$1,962
2019	$142	$233	$343	$505	$702	$1,925
2020	$136	$224	$333	$493	$692	$1,878
2021	$129	$213	$320	$479	$676	$1,816
2022	$121	$203	$304	$460	$655	$1,743
2023	$110	$190	$289	$438	$630	$1,657
2024	$95	$173	$270	$416	$600	$1,555
2025	$81	$150	$247	$389	$569	$1,436
2026	$67	$128	$215	$355	$532	$1,298
2027	$56	$107	$183	$309	$487	$1,141
2028	$46	$89	$154	$263	$424	$976
2029	$38	$74	$128	$221	$361	$821
2030	$31	$61	$107	$185	$303	$686
2031	$25	$50	$88	$154	$253	$570
2032	$21	$41	$73	$127	$211	$473
2033	$17	$34	$60	$105	$175	$391
2034	$14	$29	$50	$87	$144	$324
2035	$12	$24	$42	$72	$119	$270
2036	$10	$21	$36	$61	$99	$227
2037	$9	$18	$31	$52	$84	$193
2038	$6	$15	$26	$45	$71	$164
2039	$6	$11	$23	$38	$62	$139
2040	$5	$10	$17	$33	$53	$118
2041	$4	$9	$15	$24	$46	$99
2042	$4	$8	$14	$22	$34	$81
2043	$4	$7	$12	$20	$30	$73
2044	$3	$6	$11	$18	$27	$66
2045	$3	$6	$10	$16	$25	$59
2046	$3	$5	$9	$14	$22	$53
2047	$2	$5	$8	$13	$20	$47
2048	$0	$4	$7	$11	$18	$40
2049	$0	$0	$6	$10	$16	$32
2050	$0	$0	$0	$9	$14	$23
NPV, 3%	$1,814	$2,786	$3,879	$5,420	$7,208	$21,108
NPV, 7%	$1,398	$2,063	$2,762	$3,715	$4,756	$14,693

Table 7-15: Upstream and Downstream CO2-Equivalent Benefits for the 3% SCC Value, Model Year Analysis (Millions of 2007 dollars)

YEAR	2012	2013	2014	2015	2016	SUM
2012	$278	$0	$0	$0	$0	$278
2013	$277	$439	$0	$0	$0	$717
2014	$277	$438	$629	$0	$0	$1,344
2015	$274	$437	$627	$905	$0	$2,243
2016	$270	$432	$626	$902	$1,240	$3,471
2017	$264	$426	$619	$901	$1,235	$3,445
2018	$257	$416	$610	$890	$1,234	$3,407
2019	$247	$404	$595	$878	$1,220	$3,344
2020	$236	$389	$578	$857	$1,202	$3,261
2021	$224	$371	$555	$831	$1,174	$3,154
2022	$210	$352	$529	$799	$1,138	$3,028
2023	$191	$329	$502	$761	$1,094	$2,878
2024	$166	$301	$469	$722	$1,042	$2,700
2025	$140	$261	$429	$676	$989	$2,494
2026	$117	$222	$373	$617	$925	$2,254
2027	$97	$186	$318	$537	$845	$1,982
2028	$80	$154	$267	$457	$736	$1,694
2029	$65	$128	$223	$384	$627	$1,427
2030	$53	$105	$186	$321	$527	$1,192
2031	$43	$87	$153	$267	$440	$990
2032	$36	$71	$127	$221	$367	$821
2033	$30	$59	$105	$182	$303	$679
2034	$25	$50	$87	$151	$250	$563
2035	$21	$42	$74	$125	$207	$469
2036	$18	$36	$62	$106	$173	$395
2037	$16	$31	$54	$90	$146	$336
2038	$11	$27	$46	$78	$124	$284
2039	$10	$19	$40	$66	$107	$242
2040	$9	$17	$29	$58	$91	$204
2041	$8	$15	$26	$42	$80	$172
2042	$7	$14	$24	$38	$59	$141
2043	$6	$12	$21	$34	$53	$127
2044	$6	$11	$19	$31	$47	$114
2045	$5	$10	$17	$27	$43	$102
2046	$4	$9	$15	$25	$38	$91
2047	$4	$8	$14	$22	$34	$82
2048	$0	$7	$12	$20	$31	$70
2049	$0	$0	$11	$18	$27	$56
2050	$0	$0	$0	$16	$24	$40
NPV, 3%	$3,151	$4,840	$6,738	$9,414	$12,519	$36,661
NPV, 7%	$2,428	$3,584	$4,796	$6,452	$8,260	$25,519

Table 7-16: Upstream and Downstream CO2-Equivalent Benefits for the 3% Newell-Pizer SCC Value, Model Year Analysis (Millions of 2007 dollars)

YEAR	2012	2013	2014	2015	2016	SUM
2012	$463	$0	$0	$0	$0	$463
2013	$462	$732	$0	$0	$0	$1,194
2014	$462	$730	$1,048	$0	$0	$2,240
2015	$457	$729	$1,044	$1,508	$0	$3,739
2016	$451	$721	$1,043	$1,503	$2,067	$5,784
2017	$441	$711	$1,031	$1,501	$2,059	$5,742
2018	$428	$694	$1,016	$1,484	$2,057	$5,679
2019	$412	$674	$992	$1,463	$2,033	$5,573
2020	$393	$648	$963	$1,428	$2,003	$5,435
2021	$373	$618	$925	$1,385	$1,956	$5,257
2022	$350	$586	$881	$1,332	$1,897	$5,046
2023	$319	$549	$836	$1,269	$1,824	$4,796
2024	$276	$501	$782	$1,204	$1,737	$4,500
2025	$233	$435	$715	$1,126	$1,648	$4,157
2026	$195	$369	$622	$1,029	$1,541	$3,756
2027	$161	$309	$530	$896	$1,408	$3,304
2028	$133	$257	$445	$762	$1,227	$2,824
2029	$109	$213	$371	$640	$1,044	$2,378
2030	$89	$176	$309	$534	$878	$1,986
2031	$72	$144	$256	$445	$733	$1,651
2032	$60	$119	$211	$368	$611	$1,368
2033	$50	$98	$174	$303	$506	$1,132
2034	$42	$83	$145	$251	$417	$938
2035	$36	$70	$123	$209	$345	$782
2036	$30	$60	$104	$177	$288	$658
2037	$26	$51	$90	$149	$243	$560
2038	$18	$44	$77	$129	$206	$474
2039	$16	$32	$67	$110	$178	$403
2040	$14	$29	$49	$96	$152	$340
2041	$13	$26	$44	$70	$133	$286
2042	$12	$23	$40	$63	$98	$236
2043	$10	$21	$36	$57	$88	$212
2044	$9	$18	$32	$51	$79	$190
2045	$8	$17	$29	$46	$71	$170
2046	$7	$15	$26	$41	$64	$152
2047	$7	$13	$23	$37	$57	$137
2048	$0	$12	$20	$33	$51	$116
2049	$0	$0	$18	$29	$46	$93
2050	$0	$0	$0	$26	$41	$67
NPV, 3%	$5,251	$8,066	$11,229	$15,690	$20,865	$61,102
NPV, 7%	$4,046	$5,973	$7,994	$10,753	$13,766	$42,531

7.6 Weight Reduction and Vehicle Safety

Over the past 20 years there has been a generally increasing trend in the weight of vehicles (see figure III.X-1 below from EPA's Fuel Economy Trends Report).[378] There have been a number of factors contributing to this including: greater penetration of heavier trucks, introduction of SUVs, and an increasing amount of content in vehicles (including features for safety, noise reduction, added comfort, luxury, etc). This increased weight has been partially enabled by the increased efficiency of vehicles, especially in engines and transmissions. The impressive improvements in efficiency during this period have not only allowed for greater weight carrying capacity (and towing), but it has also allowed for greater acceleration performance in the fleet. Unfortunately, as the figure also shows, none of this efficiency improvement has been realized in fuel economy gains or GHG emissions reductions.

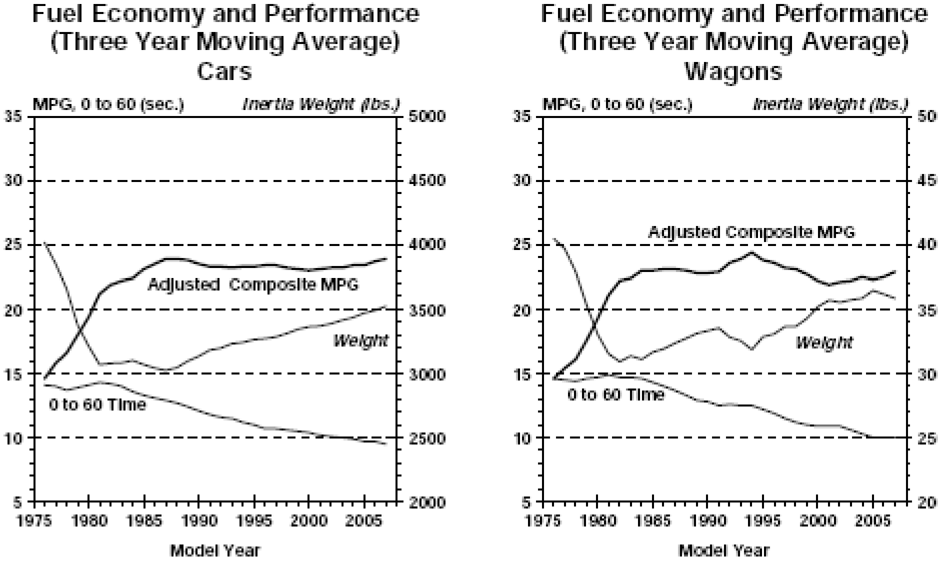

Figure 7-6: Weight, 0-to-60 MPH acceleration time and adjusted fuel economy for light-duty vehicles

During this same period, the safety of vehicles has also undergone tremendous improvement. Vehicles are designed to better withstand both frontal and side impacts, occupants are protected better with increased seat belt usage and air bags, and drivers are able to avoid accidents with anti-lock brakes (ABS), electronic stability control (ESC), and improved tires and suspension. NHTSA anticipates a 12.6 percent reduction in fatality levels between 2007 and 2020 with safety improvements due to pending NHTSA FMVSS and other factors. Assuming that safety improvements will be made evenly throughout that period, EPA estimates the reduction in fatalities between 2007 and 2016 to be 8.7%.

The interplay between vehicle weight and potential impact on safety is complex. While certainly an effective option for reducing CO_2 emissions, the reduction of vehicle weight is a controversial and complicated topic. In a joint technical analysis, EPA and NHTSA agree that automakers could reduce weight as one part of the industries' strategy for meeting the proposed standards. As shown in table III.D.6-3 of the Preamble, EPA is expecting that vehicle manufacturers will reduce the weight of their vehicles by approximately 4% on average between 2011 and 2016 although individual vehicles may have greater or smaller weight reduction (NHTSA's results are similar using the Volpe model.) The penetration and magnitude of these changes are consistent with the public announcements made by many of the manufacturers since early 2008 and are consistent with the meetings that EPA has had with senior engineers and technical leadership at many of the automotive companies during 2008 and 2009.

Between September 2008 and May 2009, EPA met with 11 major auto companies: GM, Chrysler, Ford, Nissan, Honda, Toyota, Mitsubishi, Hyundai/Kia, BMW, Mercedes and Volkswagen. Each company announced plans to reduce vehicle weight broadly across the passenger car vehicle and light truck categories within the 2012 to 2016 timeframe. Their plans for vehicle weight reduction are not limited to a single weight class but instead are expected to be implemented widely across the their products. The following statements summarize a number of automotive manufacturers' future plans to reduce vehicle weight announced in the public domain within the past two year:

- Ford: 250 to 750 pound weight reductions 2012 to 2020 across all vehicle platforms

- Toyota: 30% weight reduction on 2015 Corolla and a 10% weight reduction on mid-size vehicles by 2015

- Nissan: 15% average weight reduction by 2015

- Mazda: 100 kg (220 pound) weight reduction by 2011 and an additional 100 kg weight reduction by 2016

- Mercedes: 5% average weight reduction by 2015

Reducing vehicle mass without reducing the size, footprint or the structural integrity of the vehicle is technically feasible. Many of the technical options for doing so are outlined in Chapter 3 of the joint TSD and in this DRIA. Weight reduction can be accomplished by the proven methods described below. Every manufacturer can employ these methodologies to some degree, the magnitude to which each will be used will depend on opportunities within individual vehicle design.

- Material Substitution: Substitution of lower density and/or higher strength materials in a manner that preserves or improves the function of the component. This includes substitution of high-strength steels, aluminum, magnesium or composite materials for components currently fabricated from mild steel, e.g., the magnesium-alloy front structure used on the 2009 Ford F150 pickups (we note that since these MY 2009 F150s have only begun to enter the fleet, there is little real-world crash data available to evaluate the safety impacts of this new design). Light-weight materials with acceptable energy absorption properties can maintain structural integrity and absorption of crash energy relative to previous designs while providing a net decrease in component weight.

- Smart Design: Computer aided engineering (CAE) tools can be used to better optimize load paths within structures by reducing stresses and bending moments without adversely affecting structural integrity. This allows better optimization of the sectional thicknesses of structural components to reduce mass while maintaining or improving the function of the component. Smart designs also integrate separate parts in a manner that reduces mass by combining functions or the reduced use of separate fasteners. In addition, some "body on frame" vehicles are redesigned with a lighter "unibody" construction with little compromise in vehicle functionality.

- Reduced Powertrain Requirements: Reducing vehicle weight sufficiently allows for the use of a smaller, lighter and more efficient engine while maintaining or increasing performance. Approximately half of the reduction is due to these reduced powertrain output requirements from reduced engine power output and/or displacement, lighter weight transmission and final drive gear ratios. The subsequent reduced rotating mass (e.g. transmission, driveshafts/halfshafts, wheels and tires) via weight and/or size reduction of components are made possible by reduced torque output requirements.

- Mass Decompounding: Following from the point above, the compounded weight reductions of the body, engine and drivetrain can reduce stresses on the suspension components, steering components, brakes, and thus allow further reductions in the weight of these subsystems. The reductions in weight for unsprung masses such as brakes, control arms, wheels and tires can further reduce stresses in the suspension mounting points which can allow still further reductions in weight. For example, lightweighting can allow for the reduction in the size of the vehicle brake system, while maintaining the same stopping distance. It is estimated that 1.25 kilograms of secondary weight savings can be achieved for every kilogram of weight saved on a vehicle when all subsystems are redesigned to take into account the initial primary weight savings.[379]

Weight reduction is broadly applicable across all vehicle subsystems including the engine, exhaust system, transmission, chassis, suspension, brakes, body, closure panels, glazing, seats and other interior components, engine cooling systems and HVAC systems. EPA believes it is both technically feasible to reduce weight without reducing vehicle size, footprint or structural strength and manufacturers have indicated to the agencies that they will use these approaches to accomplish these tasks. We request written comment on this assessment and this projection, including up-to-date plans regarding the extent of use by each manufacturer of each of the methodologies described above.

EPA also projects that automakers will not reduce footprint in order to meet the proposed CO_2 standards in our modeling analysis. NHTSA and EPA have taken two measures to help ensure that the proposed rules provide no incentive for mass reduction to be accompanied by a corresponding decrease in the footprint of the vehicle (with its concomitant decrease in crush and crumple zones). The first design feature of the proposed rule is that the CO_2 or fuel economy targets are based on the attribute of footprint (which is a surrogate for vehicle size).[OO] The second design feature is that the shape of the footprint curve (or function) has been carefully chosen such that it neither encourages manufacturers to increase, nor decrease the footprint of their fleet. Thus, the standard curves are designed to be approximately "footprint neutral" within the sloped portion of the function.[PP] For further discussion on this, refer to Section II.C of the preamble, or Chapter 2 of the joint TSD. Thus the agencies are assuming in their modeling analysis that the manufacturers could reduce vehicle mass without reducing vehicle footprint as one way to respond to the proposed rule.[QQ]

In Section IV of the preamble, NHTSA presents a safety analysis of the proposed CAFE standards based on the 2003 Kahane analysis. NHTSA's Dr. Charles Kahane performed a thorough review on historical data regarding the relationship between mass reduction, wheel base, track width and fatality risk.[380,381] The results from 1991-1999 vehicle data indicate that a heavier vehicle is safer than a lighter one based on the assumption that historical vehicle mass reductions are accompanied with vehicle size and footprint reductions.

As discussed in Section IV of the Preamble, NHTSA has developed a worse case estimate of the impact of weight reductions on fatalities. The underlying data used for that analysis does not allow NHTSA to analyze the specific impact of weight reduction at constant footprint because historically there have not been a large number of vehicles produced that relied substantially on material substitution. Rather, the data set includes vehicles that were either smaller and lighter or larger and heavier. The numbers in the NHTSA analysis predict the safety-related fatality consequences that would occur in the unlikely event that weight reduction for model years 2012-2016 is accomplished by reducing mass and reducing footprint. EPA concurs with NHTSA that the safety analysis conducted by NHTSA and presented in Section IV is a worst case analysis for fatalities and we expect the actual impacts on vehicle safety could be much less. EPA and NHTSA are not able to quantify the lower-bound or the best-case potential impacts at this time.

The 2005 Dynamic Research, Incorporated (DRI) studies assessed the independent effects of vehicle weight and size on safety in order to determine if there are tradeoffs between improving vehicle safety and fuel consumption. In their 2005 studies,[382,383] one of which was published as a Society of Automotive Engineers Technical Paper and received peer review through that body, DRI presented results that indicate that vehicle weight reduction tends to decrease fatalities, but vehicle wheelbase and track reduction tends to increase fatalities. The DRI work focused on four major points, with #1 and #4 being discussed with additional detail below:

[OO] As the footprint attribute is defined as wheelbase times track width, the footprint target curves do not discourage manufacturers from reducing vehicle size by reducing front, rear, or side overhang, which can impact safety by resulting in less crush space.

[PP] This neutrality with respect to footprint does not extend to the smallest and largest vehicles, because the function is limited, or flattened, in these footprint ranges

[QQ] See Chapter 1 of the joint TSD for a description of potential footprint changes in the 2016 reference fleet

1. 2-Door vehicles represented a significant portion of the light duty fleet and should not be ignored.

2. Directional control and therefore crash avoidance improves with a reduction in curb weight.

3. The occupants of the impacted vehicle, or "collision partner" benefit from being impacted by a lighter vehicle.

4. Rollover fatalities are reduced by a reduction in curb weight due to lower centers of gravity and lower loads on the roof structures.

The data used for the DRI analysis was similar to NHTSA's 2003 Kahane study, using Fatality Analysis Reporting System (FARS) data for vehicle model years 1985 through 1998 for cars, and 1985 through 1997 trucks. This data overlaps Kahane's FARS data on model year 1991 to 1999 vehicles. DRI also used a logistical regression method similar to the approach taken by the 2003 Kahane study. However, DRI included 2-door passenger cars, whereas the Kahane study excluded all 2-door vehicles. The 2003 Kahane study excluded 2-door passenger cars because it found that for MY 1991-1999 vehicles, sports and muscle cars constituted a significant proportion of those vehicles. These vehicles have relatively high weight relative to their wheelbase, and are also disproportionately involved in crashes. Thus, Kahane concluded that including these vehicles in the analysis excessively skewed the regression results. As of July 1, 1999, 2-door passenger cars represented 29% of the registered cars in the United States. The majority of 2-door vehicles excluded in the 2003 Kahane study and included in DRI's analysis were high-sales volume light-duty vehicles and vehicles shared common vehicle platforms and architectures with 4-door vehicles that were included in the 2003 Kahane study. Specific examples include the Chevrolet Cavalier and Monte Carlo, Oldsmobile Achieva and Supreme, Buick Riviera, Ford Escort and Probe, Mercury Tracer, Honda Civic, Hyundai Accent, and VW Golf which do not necessarily represent high-weight, short-wheelbase sports and high-performance vehicle types. DRI's position was that this is a significant portion of the light duty fleet, too large to be ignored, and conclusions regarding the effects of weight and safety should be based on data for all cars, not just 4-doors.

DRI did, however, state in their conclusions that the results are sensitive to removing data for 2-doors and wagons, and that the results for 4-door cars with respect to the effects of wheelbase and track width were no longer statistically significant when 2-door cars were removed. EPA and NHTSA recognize the technical challenges of properly accounting for 2-door cars in a regression analysis evaluating the impacts of vehicle weight on safety, due to the concerns discussed for the Kahane study above. Thus, the agencies seek comment on how to ensure that any analysis supporting the final rule accounts as fully as possible for the range of safety impacts due to weight reduction on the variety of vehicles regulated under these proposed standards.

The DRI and Kahane studies also differ with respect to the impact of vehicle weight on rollover fatalities. The Kahane study treated curb weight as a surrogate for size and weight and analyzed them as a single variable. Using this method, the 2003 Kahane analysis indicates that curb weight reductions would increase fatalities due to rollovers. The DRI study differed by analyzing curb weight, wheelbase, and track as multiple variables and concluded that curb weight reduction would decrease rollover fatalities, and wheelbase and track reduction would increase rollover fatalities. DRI offers two potential root causes for higher curb weight resulting in higher rollover fatalities. The first is that a taller vehicle tends to be heavier than a shorter vehicle; therefore heavier vehicles may be more likely to rollover because the vehicle height and weight are correlated with vehicle center of gravity height. The second is that FMVSS 216 for roof crush strength requirements for passenger cars of model years 1995 through 1999 were proportional to the unloaded vehicle weight if the weight is less than 3,333 lbs, however they were a constant if the weight is greater than 3,333 lbs. Therefore heavier vehicles may have had relatively less rollover crashworthiness.

NHTSA has rejected the DRI analysis, and has not relied on it for its evaluation of safety impact changes in CAFE standards. See Section IV.G.6 of this Notice, as well as NHTSAs March 2009 Final Rulemaking for MY2011 CAFE standards (see 74 FR at 14402-05).

The DRI and Kahane analysis of the FARS data appear to be quite similar in one respect because the results are reproducible between the two studies when using aggregated vehicle attributes for 4-door cars.[382,383,384] The two analyses differ when individual vehicle attributes of mass, wheelbase and track width are separately analyzed. NHTSA has raised this as a concern with the DRI study. When 2-door vehicles are removed from the data set EPA is concerned that the results may no longer be statistically significant with respect to independent vehicle attributes due to the small size of the remaining data set, as DRI stated in the 2005 study.

The DRI analysis concluded that there would be small additional reductions in fatalities for cars and trucks if the weight reduction occurs without accompanying vehicle footprint or size changes. EPA notes that if DRI's results were to be applied using the curb weight reductions predicted by the OMEGA model, an overall reduction in fatalities would be predicted. EPA invites comment on all aspects of the issue of the impact of this kind of weight reduction on safety, including the usefulness of the DRI study in evaluating this issue.

The agencies are committed to continuing to analyze vehicle safety issues so a more informed evaluation can be made. We request comment on this issue. These comments should include not only further discussion and analysis of the relevant studies but data and analysis which can allow the agencies to more accurately quantify any potential safety issues with the proposed standards.

References

References can be found in the EPA DOCKET: EPA-HQ-OAR-2009-0472 or are publically available.

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[90] U.S. EPA. (2005). *Review of the National Ambient Air Quality Standard for Particulate Matter: Policy Assessment of Scientific and Technical Information, OAQPS Staff Paper.* EPA-452/R-05-005a. Retrieved March 19, 2009 from http://www.epa.gov/ttn/naaqs/standards/pm/data/pmstaffpaper_20051221.pdf. Section 2.2.

[91] U.S. EPA (2004). *Air Quality Criteria for Particulate Matter*. Volume I EPA600/P-99/002aF and Volume II EPA600/P-99/002bF. Retrieved on March 19, 2009 from Docket EPA-HQ-OAR-2003-0190 at http://www.regulations.gov/.

[92] U.S. EPA. (2005). *Review of the National Ambient Air Quality Standard for Particulate Matter: Policy Assessment of Scientific and Technical Information, OAQPS Staff Paper.* EPA-452/R-05-005a. Retrieved March 19, 2009 from http://www.epa.gov/ttn/naaqs/standards/pm/data/pmstaffpaper_20051221.pdf.

[93] U.S. EPA. (2006). *Provisional Assessment of Recent Studies on Health Effects of Particulate Matter Exposure.* EPA/600/R-06/063. Retrieved on March 19, 2009 from http://www.epa.gov/air/particlepollution/pdfs/ord_report_20060720.pdf.

[94] U.S. EPA (2004). *Air Quality Criteria for Particulate Matter.* Volume I EPA600/P-99/002aF and Volume II EPA600/P-99/002bF. Retrieved on March 19, 2009 from Docket EPA-HQ-OAR-2003-0190 at http://www.regulations.gov/. p. 8-305.

[95] U.S. EPA (2004). *Air Quality Criteria for Particulate Matter.* Volume I EPA600/P-99/002aF and Volume II EPA600/P-99/002bF. Retrieved on March 19, 2009 from Docket EPA-HQ-OAR-2003-0190 at http://www.regulations.gov/. p. 9-93.

[96] U.S. EPA (2004). *Air Quality Criteria for Particulate Matter*. Volume I EPA600/P-99/002aF and Volume II EPA600/P-99/002bF. Retrieved on March 19, 2009 from Docket EPA-HQ-OAR-2003-0190 at http://www.regulations.gov/. Section 8.3.3.1.

[97] U.S. EPA (2004). *Air Quality Criteria for Particulate Matter.* Volume I EPA600/P-99/002aF and Volume II EPA600/P-99/002bF. Retrieved on March 19, 2009 from Docket EPA-HQ-OAR-2003-0190 at http://www.regulations.gov/. Table 8-34.

[98] U.S. EPA (2004). *Air Quality Criteria for Particulate Matter.* Volume I EPA600/P-99/002aF and Volume II EPA600/P-99/002bF. Retrieved on March 19, 2009 from Docket EPA-HQ-OAR-2003-0190 at http://www.regulations.gov/. Section 8.3.1.3.4.

[99] U.S. EPA. (2006). *National Ambient Air Quality Standards for Particulate Matter*; Proposed Rule. 71 FR 2620, January 17, 2006.

[100] U.S. EPA (2004). *Air Quality Criteria for Particulate Matter.* Volume I EPA600/P-99/002aF and Volume II EPA600/P-99/002bF. Retrieved on March 19, 2009 from Docket EPA-HQ-OAR-2003-0190 at http://www.regulations.gov/. Section 8.3.4.

[101] U.S. EPA (2004). *Air Quality Criteria for Particulate Matter*. Volume I EPA600/P-99/002aF and Volume II EPA600/P-99/002bF. Retrieved on March 19, 2009 from Docket EPA-HQ-OAR-2003-0190 at http://www.regulations.gov/. p. 8-85.

[102] Laden, F., Neas, L.M., Dockery D.W., et al. (2000). Association of fine particulate matter from different sources with daily mortality in six U.S. cities. *Environ Health Perspectives, 108(10),* 941-947.

---

[103] Schwartz, J., Laden, F. Zanobetti, A. (2002). The concentration-response relation between PM(2.5) and daily deaths. *Environ Health Perspect, 110(10),* 1025-1029.

[104] Mar, T.F., Ito, K., Koenig, J.Q., Larson, T.V., Eatough, D.J., Henry, R.C., Kim, E., Laden, F., Lall, R., Neas, L., Stölzel, M., Paatero, P., Hopke, P.K., Thurston, G.D. (2006). PM source apportionment and health effects. 3. Investigation of inter-method variations in associations between estimated source contributions of PM2.5 and daily mortality in Phoenix, AZ. *J. Exposure Anal. Environ. Epidemiol, 16,* 311-320.

[105] Ito, K., Christensen, W.F., Eatough, D.J., Henry, R.C., Kim, E., Laden, F., Lall, R., Larson, T.V., Neas, L., Hopke, P.K., Thurston, G.D. (2006). PM source apportionment and health effects: 2. An investigation of intermethod variability in associations between source-apportioned fine particle mass and daily mortality in Washington, DC. *J. Exposure Anal. Environ. Epidemiol., 16,* 300-310.

[106] Janssen N.A., Schwartz J., Zanobetti A., et al. (2002). Air conditioning and source-specific particles as modifiers of the effect of PM10 on hospital admissions for heart and lung disease. *Environ Health Perspect, 110(1),* 43-49.

[107] U.S. EPA (2004). *Air Quality Criteria for Particulate Matter.* Volume I EPA600/P-99/002aF and Volume II EPA600/P-99/002bF. Retrieved on March 19, 2009 from Docket EPA-HQ-OAR-2003-0190 at http://www.regulations.gov/. p. 8-307.

[108] U.S. EPA (2004). *Air Quality Criteria for Particulate Matter*. Volume I EPA600/P-99/002aF and Volume II EPA600/P-99/002bF. Retrieved on March 19, 2009 from Docket EPA-HQ-OAR-2003-0190 at http://www.regulations.gov/. p. 8-313, 8-314.

[109] U.S. EPA (2004). *Air Quality Criteria for Particulate Matter*. Volume I EPA600/P-99/002aF and Volume II EPA600/P-99/002bF. Retrieved on March 19, 2009 from Docket EPA-HQ-OAR-2003-0190 at http://www.regulations.gov/. p.8-318.

[110] U.S. EPA (2004). *Air Quality Criteria for Particulate Matter*. Volume I EPA600/P-99/002aF and Volume II EPA600/P-99/002bF. Retrieved on March 19, 2009 from Docket EPA-HQ-OAR-2003-0190 at http://www.regulations.gov/. p. 8-306.

[111] U.S. EPA. (2005). *Review of the National Ambient Air Quality Standard for Particulate Matter: Policy Assessment of Scientific and Technical Information, OAQPS Staff Paper.* EPA-452/R-05-005a. Retrieved March 19, 2009 from http://www.epa.gov/ttn/naaqs/standards/pm/data/pmstaffpaper_20051221.pdf. p.3-18.

[112] Dockery, D.W., Pope, C.A. III, Xu, X, et al. (1993). An association between air pollution and mortality in six U.S. cities. *N Engl J Med, 329,*1753-1759. Retrieved on March 19, 2009 from http://content.nejm.org/cgi/content/full/329/24/1753.

[113] Pope, C.A., III, Thun, M.J., Namboodiri, M.M., Dockery, D.W., Evans, J.S., Speizer, F.E., and Heath, C.W., Jr. (1995). Particulate air pollution as a predictor of mortality in a prospective study of U.S. adults. *Am. J. Respir. Crit. Care Med, 151*, 669-674.

[114] Pope, C. A., III, Burnett, R.T., Thun, M. J., Calle, E.E., Krewski, D., Ito, K., Thurston, G.D., (2002). Lung cancer, cardiopulmonary mortality, and long-term exposure to fine particulate air pollution. *J. Am. Med. Assoc, 287*,1132-1141.

[115] Krewski, D., Burnett, R.T., Goldberg, M.S., et al. (2000). *Reanalysis of the Harvard Six Cities study and the American Cancer Society study of particulate air pollution and mortality.* A special report of the Institute's Particle Epidemiology Reanalysis Project. Cambridge, MA: Health Effects Institute. Retrieved on March 19, 2009 from http://es.epa.gov/ncer/science/pm/hei/Rean-ExecSumm.pdf

[116] Jerrett, M., Burnett, R.T., Ma, R., et al. (2005). Spatial Analysis of Air Pollution and Mortality in Los Angeles. *Epidemiology, 16(6),*727-736.

[117] U.S. EPA (2004). *Air Quality Criteria for Particulate Matter. Volume I* EPA600/P-99/002aF and Volume II EPA600/P-99/002bF. Retrieved on March 19, 2009 from Docket EPA-HQ-OAR-2003-0190 at http://www.regulations.gov/. Section 9.2.2.1.2.

---

[118] Künzli, N., Jerrett, M., Mack, W.J., et al. (2004). Ambient air pollution and atherosclerosis in Los Angeles. *Environ Health Perspect.,113*,201-206

[119] U.S. EPA. (2006*). Air Quality Criteria for Ozone and Related Photochemical Oxidants* (Final). EPA/600/R-05/004aF-cF. Washington, DC: U.S. EPA. Retrieved on March 19, 2009 from Docket EPA-HQ-OAR-2003-0190 at http://www.regulations.gov/.

[120] U.S. EPA. (2007*). Review of the National Ambient Air Quality Standards for Ozone: Policy Assessment of Scientific and Technical Information, OAQPS Staff Paper*. EPA-452/R-07-003. Washington, DC, U.S. EPA. Retrieved on March 19, 2009 from Docket EPA-HQ-OAR-2003-0190 at http://www.regulations.gov/.

[121] National Research Council (NRC), 2008. *Estimating Mortality Risk Reduction and Economic Benefits from Controlling Ozone Air Pollution.* The National Academies Press: Washington, D.C.

[122] Bates, D.V., Baker-Anderson, M., Sizto, R. (1990). Asthma attack periodicity: a study of hospital emergency visits in Vancouver. *Environ. Res., 51*,51-70.

[123] Thurston, G.D., Ito, K., Kinney, P.L., Lippmann, M. (1992). A multi-year study of air pollution and respiratory hospital admissions in three New York State metropolitan areas: results for 1988 and 1989 summers. *J. Exposure Anal. Environ. Epidemiol, 2*,429-450.

[124] Thurston, G.D., Ito, K., Hayes, C.G., Bates, D.V., Lippmann, M. (1994) Respiratory hospital admissions and summertime haze air pollution in Toronto, Ontario: consideration of the role of acid aerosols. *Environ. Res., 65,* 271-290.

[125] Lipfert, F.W., Hammerstrom, T. (1992). Temporal patterns in air pollution and hospital admissions. *Environ. Res., 59*,374-399.

[126] Burnett, R.T., Dales, R.E., Raizenne, M.E., Krewski, D., Summers, P.W., Roberts, G.R., Raad-Young, M., Dann,T., Brook, J. (1994). Effects of low ambient levels of ozone and sulfates on the frequency of respiratory admissions to Ontario hospitals. *Environ. Res., 65*, 172-194.

[127] U.S. EPA. (2006*). Air Quality Criteria for Ozone and Related Photochemical Oxidants* (Final). EPA/600/R-05/004aF-cF. Washington, DC: U.S. EPA. Retrieved on March 19, 2009 from Docket EPA-HQ-OAR-2003-0190 at http://www.regulations.gov/.

[128] U.S. EPA. (2006). *Air Quality Criteria for Ozone and Related Photochemical Oxidants* (Final). EPA/600/R-05/004aF-cF. Washington, DC: U.S. EPA. Retrieved on March 19, 2009 from Docket EPA-HQ-OAR-2003-0190 at http://www.regulations.gov/.

[129] Devlin, R. B., McDonnell, W. F., Mann, R., Becker, S., House, D. E., Schreinemachers, D., Koren, H. S. (1991). Exposure of humans to ambient levels of ozone for 6.6 hours causes cellullar and biochemical changes in the lung. *Am. J. Respir. Cell Mol. Biol., 4,* 72-81.

[130] Koren, H. S., Devlin, R. B., Becker, S., Perez, R., McDonnell, W. F. (1991). Time-dependent changes of markers associated with inflammation in the lungs of humans exposed to ambient levels of ozone. *Toxicol. Pathol., 19*, 406-411.

[131] Koren, H. S., Devlin, R. B., Graham, D. E., Mann, R., McGee, M. P., Horstman, D. H., Kozumbo, W. J., Becker, S., House, D. E., McDonnell, W. F., Bromberg, P. A. (1989). Ozone-induced inflammation in the lower airways of human subjects. *Am. Rev. Respir. Dis., 39,* 407-415.

[132] Schelegle, E.S., Siefkin, A.D., McDonald, R.J. (1991). Time course of ozone-induced neutrophilia in normal humans. *Am. Rev. Respir. Dis., 143*,1353-1358.

[133] U.S. EPA. (1996). *Air Quality Criteria for Ozone and Related Photochemical Oxidants*. EPA600-P-93-004aF. Washington. D.C.: U.S. EPA. Retrieved on March 19, 2009 from EPA-HQ-OAR-2005-0161. p. 7-171.

[134] Hodgkin, J.E., Abbey, D.E., Euler, G.L., Magie, A.R. (1984). COPD prevalence in nonsmokers in high and low photochemical air pollution areas. *Chest, 86*, 830-838.

---

[135] Euler, G.L., Abbey, D.E., Hodgkin, J.E., Magie, A.R. (1988). Chronic obstructive pulmonary disease symptom effects of long-term cumulative exposure to ambient levels of total oxidants and nitrogen dioxide in California Seventh-day Adventist residents. *Arch. Environ. Health, 43*, 279-285.

[136] Abbey, D.E., Petersen, F., Mills, P.K., Beeson, W.L. (1993). Long-term ambient concentrations of total suspended particulates, ozone, and sulfur dioxide and respiratory symptoms in a nonsmoking population. *Arch. Environ. Health, 48*, 33-46.

[137] U.S. EPA. (2007). *Review of the National Ambient Air Quality Standards for Ozone: Policy Assessment of Scientific and Technical Information, OAQPS Staff Paper.* EPA-452/R-07-003. Washington, DC, U.S. EPA. Retrieved on March 19, 2009 from Docket EPA-HQ-OAR-2003-0190 at http://www.regulations.gov/.

[138] U.S. EPA. (2006). *Air Quality Criteria for Ozone and Related Photochemical Oxidants* (Final). EPA/600/R-05/004aF-cF. Washington, DC: U.S. EPA. Retrieved on March 19, 2009 from Docket EPA-HQ-OAR-2003-0190 at http://www.regulations.gov/.

[139] U.S. EPA. (2006). *Air Quality Criteria for Ozone and Related Photochemical Oxidants* (Final). EPA/600/R-05/004aF-cF. Washington, DC: U.S. EPA. Retrieved on March 19, 2009 from Docket EPA-HQ-OAR-2003-0190 at http://www.regulations.gov/.

[140] Avol, E.L., Trim, S. C., Little, D.E., Spier, C.E., Smith, M. N., Peng, R.-C., Linn, W.S., Hackney, J.D., Gross, K.B., D'Arcy, J.B., Gibbons, D., Higgins, I.T.T. (1990 June). *Ozone exposure and lung function in children attending a southern California summer camp.* Paper no. 90-150.3. Paper presented at the 83rd annual meeting and exhibition of the Air & Waste Management Association, Pittsburgh, PA.

[141] Higgins, I. T.T., D'Arcy, J. B., Gibbons, D. I., Avol, E. L., Gross, K.B. (1990). Effect of exposures to ambient ozone on ventilatory lung function in children. *Am. Rev. Respir. Dis., 141*, 1136-1146.

[142] Raizenne, M.E., Burnett, R.T., Stern, B., Franklin, C.A., Spengler, J.D. (1989) Acute lung function responses to ambient acid aerosol exposures in children. *Environ. Health Perspect., 79,*179-185.

[143] Raizenne, M.; Stern, B.; Burnett, R.; Spengler, J. (1987 June) *Acute respiratory function and transported air pollutants: observational studies.* Paper no. 87-32.6. Paper presented at the 80th annual meeting of the Air Pollution Control Association, New York, NY.

[144] Spektor, D. M., Lippmann, M. (1991). Health effects of ambient ozone on healthy children at a summer camp. In: Berglund, R. L.; Lawson, D. R.; McKee, D. J., eds. *Tropospheric ozone and the environment: papers from an international conference*; March 1990; Los Angeles, CA. Pittsburgh, PA: Air & Waste Management Association; pp. 83-89. (A&WMA transaction series no. TR-19).

[145] Spektor, D. M., Thurston, G.D., Mao, J., He, D., Hayes, C., Lippmann, M. (1991). Effects of single- and multiday ozone exposures on respiratory function in active normal children. *Environ. Res, 55,*107-122.

[146] Spektor, D. M., Lippman, M., Lioy, P. J., Thurston, G. D., Citak, K., James, D. J., Bock, N., Speizer, F. E., Hayes, C. (1988). Effects of ambient ozone on respiratory function in active, normal children. *Am. Rev. Respir. Dis., 137*, 313-320.

[147] U.S. EPA. (2006). *Air Quality Criteria for Ozone and Related Photochemical Oxidants* (Final). EPA/600/R-05/004aF-cF. Washington, DC: U.S. EPA. Retrieved on March 19, 2009 from Docket EPA-HQ-OAR-2003-0190 at http://www.regulations.gov/.

[148] Hazucha, M. J., Folinsbee, L. J., Seal, E., Jr. (1992). Effects of steady-state and variable ozone concentration profiles on pulmonary function. *Am. Rev. Respir. Dis., 146,* 1487-1493.

[149] Horstman, D.H., Ball, B.A., Folinsbee, L.J., Brown, J., Gerrity, T. (1995) Comparison of pulmonary responses of asthmatic and nonasthmatic subjects performing light exercise while exposed to a low level of ozone. *Toxicol. Ind. Health., 11(4),* 369-85.

[150] Horstman, D.H.,; Folinsbee, L.J., Ives, P.J., Abdul-Salaam, S., McDonnell, W.F. (1990). Ozone concentration and pulmonary response relationships for 6.6-hour exposures with five hours of moderate exercise to 0.08, 0.10, and 0.12 ppm. *Am. Rev. Respir. Dis., 142*, 1158-1163.

---

[151] U.S. EPA. (2008). *Integrated Science Assessment (ISA) for Sulfur Oxides – Health Criteria (Final Report).* EPA/600/R-08/047F. Washington, DC: U.S. Environmental Protection Agency. Retrieved on March 18, 2009 from http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=198843

[152] U.S. EPA (2008). *Integrated Science Assessment for Oxides of Nitrogen – Health Criteria (Final Report).* EPA/600/R-08/071. Washington, DC,: U.S.EPA. Retrieved on March 19, 2009 from http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=194645.

[153] U.S. EPA (2000). Air Quality Criteria for Carbon Monoxide. EPA600-P-99-001F. June 1, 2000. U.S. Environmental Protection Agency, Office of Research and Development, National Center for Environmental Assessment, Washington, D.C. This document is available online at http://www.epa.gov/ncea/pdfs/coaqcd.pdf. A copy of this document is available in Docket EPA-HQ-OAR-2005-0161.

[154] U.S. EPA (2000). Air Quality Criteria for Carbon Monoxide. EPA600-P-99-001F. June 1, 2000. U.S. Environmental Protection Agency, Office of Research and Development, National Center for Environmental Assessment, Washington, D.C. This document is available online at http://www.epa.gov/ncea/pdfs/coaqcd.pdf. A copy of this document is available in Docket EPA-HQ-OAR-2005-0161.

[155] Coburn, R.F. (1979) Mechanisms of carbon monoxide toxicity. Prev. Med. 8:310-322.

[156] Helfaer, M.A., and Traystman, R.J. (1996) Cerebrovascular effects of carbon monoxide. In: Carbon Monoxide (Penney, D.G., ed). Boca Raton, CRC Press, 69-86.

[157] Benignus, V.A. (1994) Behavioral effects of carbon monoxide: meta analyses and extrapolations. J. Appl. Physiol. 76:1310-1316.

[158] U.S. EPA (2000). Air Quality Criteria for Carbon Monoxide. EPA600-P-99-001F. June 1, 2000. U.S. Environmental Protection Agency, Office of Research and Development, National Center for Environmental Assessment, Washington, D.C. This document is available online at http://www.epa.gov/ncea/pdfs/coaqcd.pdf. A copy of this document is available in Docket EPA-HQ-OAR-2005-0161.

[159] U.S. EPA (2000). Air Quality Criteria for Carbon Monoxide. EPA600-P-99-001F. June 1, 2000. U.S. Environmental Protection Agency, Office of Research and Development, National Center for Environmental Assessment, Washington, D.C. This document is available online at http://www.epa.gov/ncea/pdfs/coaqcd.pdf. A copy of this document is available in Docket EPA-HQ-OAR-2005-0161.

[160] U.S. EPA (2000). Air Quality Criteria for Carbon Monoxide. EPA600-P-99-001F. June 1, 2000. U.S. Environmental Protection Agency, Office of Research and Development, National Center for Environmental Assessment, Washington, D.C. This document is available online at http://www.epa.gov/ncea/pdfs/coaqcd.pdf. A copy of this document is available in Docket EPA-HQ-OAR-2005-0161.

[161] U.S. EPA (2000). Air Quality Criteria for Carbon Monoxide. EPA600-P-99-001F. June 1, 2000. U.S. Environmental Protection Agency, Office of Research and Development, National Center for Environmental Assessment, Washington, D.C. This document is available online at http://www.epa.gov/ncea/pdfs/coaqcd.pdf. A copy of this document is available in Docket EPA-HQ-OAR-2005-0161.

[162] U. S. EPA. (2009) 2002 National-Scale Air Toxics Assessment. http://www.epa.gov/ttn/atw/nata2002/risksum.html

[163] U.S. EPA (2007) Control of Hazardous Air Pollutants from Mobile Sources. 72 FR 8428; February 26, 2007.

[164] U.S. EPA (2003) Integrated Risk Information System File of Acrolein. National Center for Environmental Assessment, Office of Research and Development, Washington, D.C. 2003. This material is available electronically at http://www.epa.gov/iris/subst/0364.htm.

[165] U.S. EPA (2009) National-Scale Air Toxics Assessment for 2002. This material is available electronically at http://www.epa.gov/ttn/atw/nata2002/risksum.html.

[166] U.S. EPA (2009) National-Scale Air Toxics Assessment for 2002. http://www.epa.gov/ttn/atw/nata2002.

[167] U.S. EPA. 2000. Integrated Risk Information System File for Benzene. This material is available electronically at: http://www.epa.gov/iris/subst/0276.htm.

[168] International Agency for Research on Cancer, IARC monographs on the evaluation of carcinogenic risk of chemicals to humans, Volume 29, Some industrial chemicals and dyestuffs, International Agency for Research on Cancer, World Health Organization, Lyon, France, p. 345-389, 1982.

[169] Irons, R.D.; Stillman, W.S.; Colagiovanni, D.B.; Henry, V.A. (1992) Synergistic action of the benzene metabolite hydroquinone on myelopoietic stimulating activity of granulocyte/macrophage colony-stimulating factor in vitro, Proc. Natl. Acad. Sci. 89:3691-3695.

[170] International Agency for Research on Cancer (IARC). 1987. Monographs on the evaluation of carcinogenic risk of chemicals to humans, Volume 29, Supplement 7, Some industrial chemicals and dyestuffs, World Health Organization, Lyon, France.

[171] U.S. Department of Health and Human Services National Toxicology Program 11th Report on Carcinogens available at: http://ntp.niehs.nih.gov/go/16183.

[172] Aksoy, M. (1989). Hematotoxicity and carcinogenicity of benzene. Environ. Health Perspect. 82: 193-197.

[173] Goldstein, B.D. (1988). Benzene toxicity. Occupational medicine. State of the Art Reviews. 3: 541-554.

[174] Rothman, N., G.L. Li, M. Dosemeci, W.E. Bechtold, G.E. Marti, Y.Z. Wang, M. Linet, L.Q. Xi, W. Lu, M.T. Smith, N. Titenko-Holland, L.P. Zhang, W. Blot, S.N. Yin, and R.B. Hayes (1996) Hematotoxicity among Chinese workers heavily exposed to benzene. Am. J. Ind. Med. 29: 236-246.

[175] U.S. EPA 2002 Toxicological Review of Benzene (Noncancer Effects). Environmental Protection Agency, Integrated Risk Information System (IRIS), Research and Development, National Center for Environmental Assessment, Washington DC. This material is available electronically at http://www.epa.gov/iris/subst/0276.htm.

[176] Qu, O.; Shore, R.; Li, G.; Jin, X.; Chen, C.L.; Cohen, B.; Melikian, A.; Eastmond, D.; Rappaport, S.; Li, H.; Rupa, D.; Suramaya, R.; Songnian, W.; Huifant, Y.; Meng, M.; Winnik, M.; Kwok, E.; Li, Y.; Mu, R.; Xu, B.; Zhang, X.; Li, K. (2003). HEI Report 115, Validation & Evaluation of Biomarkers in Workers Exposed to Benzene in China.

[177] Qu, Q., R. Shore, G. Li, X. Jin, L.C. Chen, B. Cohen, et al. (2002). Hematological changes among Chinese workers with a broad range of benzene exposures. Am. J. Industr. Med. 42: 275-285.

[178] Lan, Qing, Zhang, L., Li, G., Vermeulen, R., et al. (2004). Hematotoxically in Workers Exposed to Low Levels of Benzene. Science 306: 1774-1776.

[179] Turtletaub, K.W. and Mani, C. (2003). Benzene metabolism in rodents at doses relevant to human exposure from Urban Air. Research Reports Health Effect Inst. Report No.113.

[180] U.S. EPA. 2002. Health Assessment of 1,3-Butadiene. Office of Research and Development, National Center for Environmental Assessment, Washington Office, Washington, DC. Report No. EPA600-P-98-001F. This document is available electronically at http://www.epa.gov/iris/supdocs/buta-sup.pdf.

[181] U.S. EPA. 2002 "Full IRIS Summary for 1,3-butadiene (CASRN 106-99-0)" Environmental Protection Agency, Integrated Risk Information System (IRIS), Research and Development, National Center for Environmental Assessment, Washington, DC http://www.epa.gov/iris/subst/0139.htm.

[182] International Agency for Research on Cancer (IARC) (1999) Monographs on the evaluation of carcinogenic risk of chemicals to humans, Volume 71, Re-evaluation of some organic chemicals, hydrazine and hydrogen peroxide and Volume 97 (in preparation), World Health Organization, Lyon, France.

[183] U.S. Department of Health and Human Services National Toxicology Program 11th Report on Carcinogens available at: http://ntp.niehs.nih.gov/go/16183.

[184] Bevan, C.; Stadler, J.C.; Elliot, G.S.; et al. (1996) Subchronic toxicity of 4-vinylcyclohexene in rats and mice by inhalation. Fundam. Appl. Toxicol. 32:1-10.

[185] U.S. EPA. 1987. Assessment of Health Risks to Garment Workers and Certain Home Residents from

Exposure to Formaldehyde, Office of Pesticides and Toxic Substances, April 1987.

[186] Hauptmann, M..; Lubin, J. H.; Stewart, P. A.; Hayes, R. B.; Blair, A. 2003. Mortality from lymphohematopoetic malignancies among workers in formaldehyde industries. Journal of the National Cancer Institute 95: 1615-1623.

[187] Hauptmann, M..; Lubin, J. H.; Stewart, P. A.; Hayes, R. B.; Blair, A. 2004. Mortality from solid cancers among workers in formaldehyde industries. American Journal of Epidemiology 159: 1117-1130.

[188] Beane Freeman, L. E.; Blair, A.; Lubin, J. H.; Stewart, P. A.; Hayes, R. B.; Hoover, R. N.; Hauptmann, M. 2009. Mortality from lymphohematopoietic malignancies among workers in formaldehyde industries: The National Cancer Institute cohort. J. National Cancer Inst. 101: 751-761.

[189] Pinkerton, L. E. 2004. Mortality among a cohort of garment workers exposed to formaldehyde: an update. Occup. Environ. Med. 61: 193-200.

[190] Coggon, D, EC Harris, J Poole, KT Palmer. 2003. Extended follow-up of a cohort of British chemical workers exposed to formaldehyde. J National Cancer Inst. 95:1608-1615.

[191] Conolly, RB, JS Kimbell, D Janszen, PM Schlosser, D Kalisak, J Preston, and FJ Miller. 2003. Biologically motivated computational modeling of formaldehyde carcinogenicity in the F344 rat. Tox Sci 75: 432-447.

[192] Conolly, RB, JS Kimbell, D Janszen, PM Schlosser, D Kalisak, J Preston, and FJ Miller. 2004. Human respiratory tract cancer risks of inhaled formaldehyde: Dose-response predictions derived from biologically-motivated computational modeling of a combined rodent and human dataset. Tox Sci 82: 279-296.

[193] Chemical Industry Institute of Toxicology (CIIT).1999. Formaldehyde: Hazard characterization and dose-response assessment for carcinogenicity by the route of inhalation. CIIT, September 28, 1999. Research Triangle Park, NC.

[194] U.S. EPA. Analysis of the Sensitivity and Uncertainty in 2-Stage Clonal Growth Models for Formaldehyde with Relevance to Other Biologically-Based Dose Response (BBDR) Models. U.S. Environmental Protection Agency, Washington, D.C., EPA/600/R-08/103, 2008

[195] Subramaniam, R; Chen, C; Crump, K; .et .al. (2008) Uncertainties in biologically-based modeling of formaldehyde-induced cancer risk: identification of key issues. Risk Anal 28(4):907-923.

[196] Subramaniam, R; Chen, C; Crump, K; .et .al. (2007). Uncertainties in the CIIT 2-stage model for formaldehyde-induced nasal cancer in the F344 rat: a limited sensitivity analysis-I. Risk Anal 27:1237

[197] Crump, K; Chen, C; Fox, J; .et .al. (2008) Sensitivity analysis of biologically motivated model for formaldehyde-induced respiratory cancer in humans. Ann Occup Hyg 52:481-495.

[198] International Agency for Research on Cancer (2006) Formaldehyde, 2-Butoxyethanol and 1-tert-Butoxypropan-2-ol. Monographs Volume 88. World Health Organization, Lyon, France.

[199] Agency for Toxic Substances and Disease Registry (ATSDR). 1999. Toxicological profile for Formaldehyde. Atlanta, GA: U.S. Department of Health and Human Services, Public Health Service. http://www.atsdr.cdc.gov/toxprofiles/tp111.html

[200] WHO (2002) Concise International Chemical Assessment Document 40: Formaldehyde. Published under the joint sponsorship of the United Nations Environment Programme, the International Labour Organization, and the World Health Organization, and produced within the framework of the Inter-Organization Programme for the Sound Management of Chemicals. Geneva.

[201] U.S. EPA (1988). Integrated Risk Information System File of Acetaldehyde. Research and Development, National Center for Environmental Assessment, Washington, DC. This material is available electronically at http://www.epa.gov/iris/subst/0290.htm.

---

[202] U.S. Department of Health and Human Services National Toxicology Program 11th Report on Carcinogens available at: http://ntp.niehs.nih.gov/go/16183.

[203] International Agency for Research on Cancer (IARC). 1999. Re-evaluation of some organic chemicals, hydrazine, and hydrogen peroxide. IARC Monographs on the Evaluation of Carcinogenic Risk of Chemical to Humans, Vol 71. Lyon, France.

[204] U.S. EPA (1988). Integrated Risk Information System File of Acetaldehyde. This material is available electronically at http://www.epa.gov/iris/subst/0290.htm.

[205] U.S. EPA. 2003. Integrated Risk Information System File of Acrolein. Research and Development, National Center for Environmental Assessment, Washington, DC. This material is available electronically at http://www.epa.gov/iris/subst/0364.htm.

[206] Appleman, L.M., R.A. Woutersen, and V.J. Feron. (1982). Inhalation toxicity of acetaldehyde in rats. I. Acute and subacute studies. Toxicology. 23: 293-297.

[207] Myou, S.; Fujimura, M.; Nishi K.; Ohka, T.; and Matsuda, T. (1993) Aerosolized acetaldehyde induces histamine-mediated bronchoconstriction in asthmatics. Am. Rev. Respir.Dis.148(4 Pt 1): 940-943.

[208] Integrated Risk Information System File of Acrolein. Research and Development, National Center for Environmental Assessment, Washington, DC. This material is available at http://www.epa.gov/iris/subst/0364.htm

[209] International Agency for Research on Cancer (IARC). 1995. Monographs on the evaluation of carcinogenic risk of chemicals to humans, Volume 63, Dry cleaning, some chlorinated solvents and other industrial chemicals, World Health Organization, Lyon, France.

[210] Weber-Tschopp, A; Fischer, T; Gierer, R; et al. (1977) Experimentelle reizwirkungen von Acrolein auf den Menschen. Int Arch Occup Environ Hlth 40(2):117-130. In German

[211] Sim, VM; Pattle, RE. (1957) Effect of possible smog irritants on human subjects. J Am Med Assoc 165(15):1908-1913.

[212] Morris JB, Symanowicz PT, Olsen JE, et al. 2003. Immediate sensory nerve-mediated respiratory responses to irritants in healthy and allergic airway-diseased mice. J Appl Physiol 94(4):1563-1571.

[213] Sim VM, Pattle RE. Effect of possible smog irritants on human subjects JAMA165: 1980-2010, 1957.

[214] Perera, F.P.; Rauh, V.; Tsai, W-Y.; et al. (2002) Effect of transplacental exposure to environmental pollutants on birth outcomes in a multiethnic population. Environ Health Perspect. 111: 201-205.

[215] Perera, F.P.; Rauh, V.; Whyatt, R.M.; Tsai, W.Y.; Tang, D.; Diaz, D.; Hoepner, L.; Barr, D.; Tu, Y.H.; Camann, D.; Kinney, P. (2006) Effect of prenatal exposure to airborne polycyclic aromatic hydrocarbons on neurodevelopment in the first 3 years of life among inner-city children. Environ Health Perspect 114: 1287-1292.

[216] U. S. EPA. 2004. Toxicological Review of Naphthalene (Reassessment of the Inhalation Cancer Risk), Environmental Protection Agency, Integrated Risk Information System, Research and Development, National Center for Environmental Assessment, Washington, DC. This material is available electronically at http://www.epa.gov/iris/subst/0436.htm.

[217] Oak Ridge Institute for Science and Education. (2004). External Peer Review for the IRIS Reassessment of the Inhalation Carcinogenicity of Naphthalene. August 2004. http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=84403

[218] National Toxicology Program (NTP). (2004). 11th Report on Carcinogens. Public Health Service, U.S. Department of Health and Human Services, Research Triangle Park, NC. Available from: http://ntp-server.niehs.nih.gov.

[219] International Agency for Research on Cancer (IARC). (2002). Monographs on the Evaluation of the

---

Carcinogenic Risk of Chemicals for Humans. Vol. 82. Lyon, France.

[220] U. S. EPA. 1998. Toxicological Review of Naphthalene, Environmental Protection Agency, Integrated Risk Information System, Research and Development, National Center for Environmental Assessment, Washington, DC. This material is available electronically at http://www.epa.gov/iris/subst/0436.htm

[221] U.S. EPA Integrated Risk Information System (IRIS) database is available at: www.epa.gov/iris

[222] U.S. EPA (2004). *Air Quality Criteria for Particulate Matter*. Volume I EPA600/P-99/002aF and Volume II EPA600/P-99/002bF. Retrieved on March 19, 2009 from Docket EPA-HQ-OAR-2003-0190 at http://www.regulations.gov/. p. 4-179.

[223] U.S. EPA (2004). *Air Quality Criteria for Particulate Matter*. Volume I EPA600/P-99/002aF and Volume II EPA600/P-99/002bF. Retrieved on March 19, 2009 from Docket EPA-HQ-OAR-2003-0190 at http://www.regulations.gov/. p. 4-236.

[224] U.S. EPA (2004). *Air Quality Criteria for Particulate Matter*. Volume I EPA600/P-99/002aF and Volume II EPA600/P-99/002bF. Retrieved on March 19, 2009 from Docket EPA-HQ-OAR-2003-0190 at http://www.regulations.gov/. p. 4-182.

[225] Sisler, J.F. (1996) *Spatial and seasonal patterns and long term variability of the composition of the haze in the United States: an analysis of data from the IMPROVE network*. CIRA Report, ISSN 0737-5352-32, Colorado State University.

[226] U.S. EPA. 1999. *The Benefits and Costs of the Clean Air Act, 1990-2010.* Prepared for U.S. Congress by U.S. EPA, Office of Air and Radiation, Office of Policy Analysis and Review, Washington, DC, November; EPA report no. EPA410-R-99-001. This document is contained in Docket Identification EPA-HQ-OAR-2004-0008-0485.

[227] U.S. EPA. *Air Quality Criteria for Ozone and Related Photochemical Oxidants* (Final). U.S. EPA, Washington, DC, EPA/600/R-05/004aF-cF, 2006.

[228] Winner, W.E., and C.J. Atkinson. 1986. "Absorption of air pollution by plants, and consequences for growth." *Trends in Ecology and Evolution 1*:15-18.

[229] U.S. EPA. *Air Quality Criteria for Ozone and Related Photochemical Oxidants* (Final). U.S. EPA, Washington, DC, EPA/600/R-05/004aF-cF, 2006. This document is contained in Docket Identification EPA-HQ-OAR-2004-0008-0455 to 0457.

[230] Tingey, D.T., and Taylor, G.E. (1982) Variation in plant response to ozone: a conceptual model of physiological events. In M.H. Unsworth & D.P. Omrod (Eds.), *Effects of Gaseous Air Pollution in Agriculture and Horticulture*. (pp.113-138). London, UK: Butterworth Scientific.

[231] U.S. EPA. *Air Quality Criteria for Ozone and Related Photochemical Oxidants* (Final). U.S. EPA, Washington, DC, EPA/600/R-05/004aF-cF, 2006. This document is contained in Docket Identification EPA-HQ-OAR-2004-0008-0455 to 0457.

[232] U.S. EPA. *Air Quality Criteria for Ozone and Related Photochemical Oxidants* (Final). U.S. EPA, Washington, DC, EPA/600/R-05/004aF-cF, 2006. This document is contained in Docket Identification EPA-HQ-OAR-2004-0008-0455 to 0457.

[233] U.S. EPA. *Air Quality Criteria for Ozone and Related Photochemical Oxidants* (Final). U.S. EPA, Washington, DC, EPA/600/R-05/004aF-cF, 2006. This document is contained in Docket Identification EPA-HQ-OAR-2004-0008-0455 to 0457.

[234] U.S. EPA. *Air Quality Criteria for Ozone and Related Photochemical Oxidants* (Final). U.S. EPA, Washington, DC, EPA/600/R-05/004aF-cF, 2006. This document is contained in Docket Identification EPA-HQ-OAR-2004-0008-0455 to 0457.

[235] Ollinger, S.V., Aber, J.D., Reich, P.B. (1997). Simulating ozone effects on forest productivity: interactions between leaf canopy and stand level processes. *Ecological Applications, 7,* 1237-1251.

---

[236] Winner, W.E. (1994). Mechanistic analysis of plant responses to air pollution. *Ecological Applications, 4(4),* 651-661.

[237] U.S. EPA. *Air Quality Criteria for Ozone and Related Photochemical Oxidants* (Final). U.S. EPA, Washington, DC, EPA/600/R-05/004aF-cF, 2006. This document is contained in Docket Identification EPA-HQ-OAR-2004-0008-0455 to 0457.

[238] U.S. EPA. *Air Quality Criteria for Ozone and Related Photochemical Oxidants* (Final). U.S. EPA, Washington, DC, EPA/600/R-05/004aF-cF, 2006. This document is contained in Docket Identification EPA-HQ-OAR-2004-0008-0455 to 0457.

[239] Fox, S., Mickler, R. A. (Eds.). (1996). *Impact of Air Pollutants on Southern Pine Forests, Ecological Studies.* (Vol. 118, 513 pp.) New York: Springer-Verlag.

[240] De Steiguer, J., Pye, J., Love, C. (1990). Air Pollution Damage to U.S. Forests. *Journal of Forestry, 88(8),* 17-22.

[241] Pye, J.M. (1988). Impact of ozone on the growth and yield of trees: A review. *Journal of Environmental Quality, 17*, 347-360.

[242] U.S. EPA. *Air Quality Criteria for Ozone and Related Photochemical Oxidants* (Final). U.S. EPA, Washington, DC, EPA/600/R-05/004aF-cF, 2006.

[243] U.S. EPA. *Air Quality Criteria for Ozone and Related Photochemical Oxidants* (Final). U.S. EPA, Washington, DC, EPA/600/R-05/004aF-cF, 2006.

[244] McBride, J.R., Miller, P.R., Laven, R.D. (1985). Effects of oxidant air pollutants on forest succession in the mixed conifer forest type of southern California. In: *Air Pollutants Effects On Forest Ecosystems, Symposium Proceedings, St. P,* 1985, p. 157-167.

[245] Miller, P.R., O.C. Taylor, R.G. Wilhour. 1982. *Oxidant air pollution effects on a western coniferous forest ecosystem*. Corvallis, OR: U.S. Environmental Protection Agency, Environmental Research Laboratory (EPA600-D-82-276).

[246] U.S. EPA. *Air Quality Criteria for Ozone and Related Photochemical Oxidants* (Final). U.S. EPA, Washington, DC, EPA/600/R-05/004aF-cF, 2006.

[247] Kopp, R. J., Vaughn, W. J., Hazilla, M., Carson, R. (1985). Implications of environmental policy for U.S. agriculture: the case of ambient ozone standards. *Journal of Environmental Management, 20*, 321-331.

[248] Adams, R. M., Hamilton, S. A., McCarl, B. A. (1986). The benefits of pollution control: the case of ozone and U.S. agriculture. *American Journal of Agricultural Economics, 34,* 3-19.

[249] Adams, R. M., Glyer, J. D., Johnson, S. L., McCarl, B. A. (1989). A reassessment of the economic effects of ozone on U.S. agriculture. *Journal of the Air Pollution Control Association, 39,* 960-968.

[250] Abt Associates, Inc. 1995. *Urban ornamental plants: sensitivity to ozone and potential economic losses.* U.S. EPA, Office of Air Quality Planning and Standards, Research Triangle Park. Under contract to RADIAN Corporation, contract no. 68-D3-0033, WA no. 6. pp. 9-10.

[251] U.S. EPA. *Air Quality Criteria for Ozone and Related Photochemical Oxidants* (Final). U.S. EPA, Washington, DC, EPA/600/R-05/004aF-cF, 2006.This document is available in Docket EPA-HQ-OAR-2005-0036

[252] Grulke, N.E. (2003). The physiological basis of ozone injury assessment attributes in Sierran conifers. In A. Bytnerowicz, M.J. Arbaugh, & R. Alonso (Eds.), *Ozone air pollution in the Sierra Nevada: Distribution and effects on forests*. (pp. 55-81). New York, NY: Elsevier Science, Ltd.

[253] White, D., Kimerling, A.J., Overton, W.S. (1992). Cartographic and geometric component of a global sampling design for environmental monitoring. *Cartography and Geographic Information Systems, 19*, 5-22.

---

[254] Smith, G., Coulston, J., Jepsen, E., Prichard, T. (2003). A national ozone biomonitoring program—results from field surveys of ozone sensitive plants in Northeastern forests (1994-2000). *Environmental Monitoring and Assessment, 87*, 271-291.

[255] White, D., Kimerling, A.J., Overton, W.S. (1992). Cartographic and geometric component of a global sampling design for environmental monitoring. *Cartography and Geographic Information Systems, 19,* 5-22.

[256] Smith, G., Coulston, J., Jepsen, E., Prichard, T. (2003). A national ozone biomonitoring program—results from field surveys of ozone sensitive plants in Northeastern forests (1994-2000). *Environmental Monitoring and Assessment, 87*, 271-291.

[257] Coulston, J.W., Riitters, K.H., Smith, G.C. (2004). A preliminary assessment of the Montréal process indicators of air pollution for the United States. *Environmental Monitoring and Assessment, 95,* 57-74.

[258] U.S. EPA (United States Environmental Protection Agency). 2006. *Air quality criteria for ozone and related photochemical oxidants.* EPA/600/R-05/004aF-cF. Research Triangle Park, NC. <http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=149923>

[259] Smith, G., Coulston, J., Jepsen, E., Prichard, T. (2003). A national ozone biomonitoring program—results from field surveys of ozone sensitive plants in Northeastern forests (1994-2000). *Environmental Monitoring and Assessment, 87*, 271-291.

[260] U.S. EPA (United States Environmental Protection Agency). 2006. *Air quality criteria for ozone and related photochemical oxidants.* EPA/600/R-05/004aF-cF. Research Triangle Park, NC. <http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=149923>

[261] US EPA. (2007) *Review of the National Ambient Air Quality Standards for Ozone: Policy assessment of scientific and technical information*. Office of Air Quality Planning and Standards staff paper. EPA-452/R-07-003.

[262] Chappelka, A.H., Samuelson, L.J. (1998). Ambient ozone effects on forest trees of the eastern United States: a review. New Phytologist, 139, 91-108.

[263] U.S. EPA (2004) Air Quality Criteria for Particulate Matter (Oct 2004), Volume I Document No. EPA600/P-99/002aF and Volume II Document No. EPA600/P-99/002bF. This document is available in Docket EPA-HQ-OAR-2005-0161.

[264] U.S. EPA (2005) Review of the National Ambient Air Quality Standard for Particulate Matter: Policy Assessment of Scientific and Technical Information, OAQPS Staff Paper. EPA-452/R-05-005. This document is available in Docket EPA-HQ-OAR-2005-0161.

[265] U.S. EPA, 2008. Integrated Science Assessment for Oxides of Nitrogen and Sulfur- Ecological Criteria (Final). U.S. EPA, Washington D.C., EPA/600/R-08/082F.

[266] Environmental Protection Agency (2003). Response Of Surface Water Chemistry to the Clean Air Act Amendments of 1990. National Health and Environmental Effects Research Laboratory, Office of Research and Development, U.S. Environmental Protection Agency. Research Triangle Park, NC. EPA 620/R–03/001.

[267] Fenn, M.E. and Blubaugh, T.J. (2005) Winter Deposition of Nitrogen and Sulfur in the Eastern Columbia River Gorge National Scenic Area, USDA Forest Service.

[268] Galloway, J. N.; Cowling, E. B. (2002). Reactive nitrogen and the world: 200 years of change. Ambio 31: 64–71.

[269] Bricker, Suzanne B., et al., National Estuarine Eutrophication Assessment, Effects of Nutrient Enrichment in the Nation's Estuaries, National Ocean Service, National Oceanic and Atmospheric Administration, September, 1999.

---

[270] Smith, W.H. 1991. "Air pollution and Forest Damage." Chemical Engineering News, 69(45): 30-43.

[271] Gawel, J.E.; Ahner, B.A.; Friedland, A.J.; and Morel, F.M.M. 1996. "Role for heavy metals in forest decline indicated by phytochelatin measurements." Nature, 381: 64-65.

[272] Cotrufo, M.F.; DeSanto, A.V.; Alfani, A.; et al. 1995. "Effects of urban heavy metal pollution on organic matter decomposition in Quercus ilix L. woods." Environmental Pollution, 89: 81-87.

[273] Niklinska, M.; Laskowski, R.; Maryanski, M. 1998. "Effect of heavy metals and storage time on two types of forest litter: basal respiration rate and exchangeable metals." Ecotoxicological Environmental Safety, 41: 8-18.

[274] Mason, R.P. and Sullivan, K.A. 1997. "Mercury in Lake Michigan." Environmental Science & Technology, 31: 942-947. (from Delta Report "Atmospheric deposition of toxics to the Great Lakes").

[275] Landis, M.S. and Keeler, G.J. 2002. "Atmospheric mercury deposition to Lake Michigan during the Lake Michigan Mass Balance Study." Environmental Science & Technology, 21: 4518-24.

[276] U.S. EPA. 2000. EPA453/R-00-005, "Deposition of Air Pollutants to the Great Waters: Third Report to Congress," Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina. **Error! Main Document Only.**This document is available in Docket EPA-HQ-OAR-2004-0008.

[277] NSTC 1999

[278] Callender, E. and Rice, K.C. 2000. "The Urban Environmental Gradient: Anthropogenic Influences on the Spatial and Temporal Distributions of Lead and Zinc in Sediments." Environmental Science & Technology, 34: 232-238.

[279] Rice, K.C. 1999. "Trace Element Concentrations in Streambed Sediment Across the Conterminous United States." Environmental Science & Technology, 33: 2499-2504.

[280] Ely, JC; Neal, CR; Kulpa, CF; et al. 2001. "Implications of Platinum-Group Element Accumulation along U.S. Roads from Catalytic-Converter Attrition." Environ. Sci. Technol. 35: 3816-3822.

[281] U.S. EPA. 1998. EPA454/R-98-014, "Locating and Estimating Air Emissions from Sources of Polycyclic Organic Matter," Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina. This document is available in Docket EPA-HQ-OAR-2004-0008.

[282] U.S. EPA. 1998. EPA454/R-98-014, "Locating and Estimating Air Emissions from Sources of Polycyclic Organic Matter," Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina. **Error! Main Document Only.**This document is available in Docket EPA-HQ-OAR-2004-0008.

[283] Simcik, M.F.; Eisenreich, S.J.; Golden, K.A.; et al. 1996. "Atmospheric Loading of Polycyclic Aromatic Hydrocarbons to Lake Michigan as Recorded in the Sediments." Environmental Science and Technology, 30: 3039-3046.

[284] Simcik, M.F.; Eisenreich, S.J.; and Lioy, P.J. 1999. "Source apportionment and source/sink relationship of PAHs in the coastal atmosphere of Chicago and Lake Michigan." Atmospheric Environment, 33: 5071-5079.

[285] Arzayus, K.M.; Dickhut, R.M.; and Canuel, E.A. 2001. "Fate of Atmospherically Deposited Polycyclic Aromatic Hydrocarbons (PAHs) in Chesapeake Bay." Environmental Science & Technology, 35, 2178-2183.

[286] Park, J.S.; Wade, T.L.; and Sweet, S. 2001. "Atmospheric distribution of polycyclic aromatic hydrocarbons and deposition to Galveston Bay, Texas, USA." Atmospheric Environment, 35: 3241-3249.

---

[287] Poor, N.; Tremblay, R.; Kay, H.; et al. 2002. "Atmospheric concentrations and dry deposition rates of polycyclic aromatic hydrocarbons (PAHs) for Tampa Bay, Florida, USA." Atmospheric Environment 38: 6005-6015.

[288] Arzayus, K.M.; Dickhut, R.M.; and Canuel, E.A. 2001. "Fate of Atmospherically Deposited Polycyclic Aromatic Hydrocarbons (PAHs) in Chesapeake Bay." Environmental Science & Technology, 35, 2178-2183.

[289] U.S. EPA. 2000. EPA453/R-00-005, "Deposition of Air Pollutants to the Great Waters: Third Report to Congress," Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina. This document is available in Docket EPA-HQ-OAR-2004-0008.

[290] Van Metre, P.C.; Mahler, B.J.; and Furlong, E.T. 2000. "Urban Sprawl Leaves its PAH Signature." Environmental Science & Technology, 34: 4064-4070.

[291] Cousins, I.T.; Beck, A.J.; and Jones, K.C. 1999. "A review of the processes involved in the exchange of semi-volatile organic compounds across the air-soil interface." The Science of the Total Environment, 228: 5-24.

[292] Tuhackova, J. et al. (2001) Hydrocarbon deposition and soil microflora as affected by highway traffic. Environmental Pollution, 113: 255-262.

[293] US EPA. 1991. Effects of organic chemicals in the atmosphere on terrestrial plants. EPA/600/3-91/001.

[294] Cape JN, ID Leith, J Binnie, J Content, M Donkin, M Skewes, DN Price AR Brown, AD Sharpe. 2003. Effects of VOCs on herbaceous plants in an open-top chamber experiment. Environ. Pollut. 124:341-343.

[295] Cape JN, ID Leith, J Binnie, J Content, M Donkin, M Skewes, DN Price AR Brown, AD Sharpe. 2003. Effects of VOCs on herbaceous plants in an open-top chamber experiment. Environ. Pollut. 124:341-343.

[296] Viskari E-L. 2000. Epicuticular wax of Norway spruce needles as indicator of traffic pollutant deposition. Water, Air, and Soil Pollut. 121:327-337.

[297] Ugrekhelidze D, F Korte, G Kvesitadze. 1997. Uptake and transformation of benzene and toluene by plant leaves. Ecotox. Environ. Safety 37:24-29.

[298] Kammerbauer H, H Selinger, R Rommelt, A Ziegler-Jons, D Knoppik, B Hock. 1987. Toxic components of motor vehicle emissions for the spruce Pciea abies. Environ. Pollut. 48:235-243.

[299] U.S. EPA. (2007). PM2.5 National Ambient Air Quality Standard Implementation Rule (Final). Washington, DC: U.S. EPA. Retrieved on May 14, 2009 from Docket EPA-HQ-OAR-2003-0062 at http://www.regulations.gov/.72 FR 20586.
U.S. EPA. (2006*). Air Quality Criteria for Ozone and Related Photochemical Oxidants* (Final). EPA/600/R-05/004aF-cF. Washington, DC: U.S. EPA. Retrieved on March 19, 2009 from Docket EPA-HQ-OAR-2003-0190 at http://www.regulations.gov/.

[300] PM Standards Revision – 2006: Timeline. Retrieved on March 19, 2009 from http://www.epa.gov/oar/particlepollution/naaqsrev2006.html#timeline
[301] US EPA: 8-hour Ozone Nonattainment Areas. Retrieved on March 19, 2009 http://www.epa.gov/ttn/atw/nata2002/risksum.html

[302] Carbon Monoxide Nonattainment Area Summary: http://www.epa.gov/air/oaqps/greenbk/cnsum.html

[303] U.S. EPA. (2009) 2002 National-Scale Air Toxics Assessment. http://www.epa.gov/ttn/atw/nata1999/risksum.html

[304] Control of Hazardous Air Pollutants From Mobile Sources (72 FR 8428; February 26, 2007)

---

[305] US EPA (2007) Control of Hazardous Air Pollutants from Mobile Sources Regulatory Impact Analysis. EPA document number 420-R-07-002, February 2007.

[306] U.S. Environmental Protection Agency, Byun, D.W., and Ching, J.K.S., Eds, 1999. Science algorithms of EPA Models-3 Community Multiscale Air Quality (CMAQ modeling system, EPA/600/R-99/030, Office of Research and Development).

[307] Byun, D.W., and Schere, K.L., 2006. Review of the Governing Equations, Computational Algorithms, and Other Components of the Models-3 Community Multiscale Air Quality (CMAQ) Modeling System, J. Applied Mechanics Reviews, 59 (2), 51-77.

[308] Dennis, R.L., Byun, D.W., Novak, J.H., Galluppi, K.J., Coats, C.J., and Vouk, M.A., 1996. The next generation of integrated air quality modeling: EPA's Models-3, Atmospheric Environment, 30, 1925-1938.

[309] US EPA (2007). Regulatory Impact Analysis of the Proposed Revisions to the National Ambient Air Quality Standards for Ground-Level Ozone. EPA document number 442/R-07-008, July 2007.

[310] Aiyyer, A, Cohan, D., Russell, A., Stockwell, W., Tanrikulu, S., Vizuete, W., Wilczak, J., 2007. Final Report: Third Peer Review of the CMAQ Model. p. 23.

[311] Grell, G., Dudhia, J., Stauffer, D. (1994). *A Description of the Fifth-Generation Penn State/NCAR Mesoscale Model (MM5), NCAR/TN-398+STR.*, 138 pp, National Center for Atmospheric Research, Boulder CO.

[312] Grell, G., Dudhia, J., Stauffer, D. (1994). *A Description of the Fifth-Generation Penn State/NCAR Mesoscale Model (MM5), NCAR/TN-398+STR.*, 138 pp, National Center for Atmospheric Research, Boulder CO.

[313] Yantosca, B. (2004). *GEOS-CHEMv7-01-02 User's Guide*, Atmospheric Chemistry Modeling Group, Harvard University, Cambridge, MA, October 15, 2004.

[314] U.S. Environmental Protection Agency. (2008). Final Ozone NAAQS Regulatory Impact Analysis. Prepared by: Office of Air and Radiation, Office of Air Quality Planning and Standards. March.

[315] U.S. Environmental Protection Agency. October 2006. Final Regulatory Impact Analysis (RIA) for the Proposed National Ambient Air Quality Standards for Particulate Matter. Prepared by: Office of Air and Radiation.

[316] U.S. Environmental Protection Agency (U.S. EPA). 2009a. Regulatory Impact Analysis: National Emission Standards for Hazardous Air Pollutants from the Portland Cement Manufacturing Industry. Office of Air Quality Planning and Standards, Research Triangle Park, NC. April. Available on the Internet at <http://www.epa.gov/ttn/ecas/regdata/RIAs/portlandcementria_4-20-09.pdf>.

[317] U.S. Environmental Protection Agency (U.S. EPA). 2009b. Proposed NO2 NAAQS Regulatory Impact Analysis (RIA). Office of Air Quality Planning and Standards, Research Triangle Park, NC. April. Available on the Internet at http://www.epa.gov/ttn/ecas/regdata/RIAs/proposedno2ria.pdf.

[318] U.S. Environmental Protection Agency (U.S. EPA). 2008a. Regulatory Impact Analysis, 2008 National Ambient Air Quality Standards for Ground-level Ozone, Chapter 6. Office of Air Quality Planning and Standards, Research Triangle Park, NC. March. Available at <http://www.epa.gov/ttn/ecas/regdata/RIAs/6-ozoneriachapter6.pdf>.

[319] U.S. Environmental Protection Agency (U.S. EPA). 2009a. Regulatory Impact Analysis: National Emission Standards for Hazardous Air Pollutants from the Portland Cement Manufacturing Industry. Office of Air Quality Planning and Standards, Research Triangle Park, NC. April. Available on the Internet at <http://www.epa.gov/ttn/ecas/regdata/RIAs/portlandcementria_4-20-09.pdf>.

[320] U.S. Environmental Protection Agency (U.S. EPA). 2009b. Proposed NO2 NAAQS Regulatory Impact Analysis (RIA). Office of Air Quality Planning and Standards, Research Triangle Park, NC. April. Available on the Internet at http://www.epa.gov/ttn/ecas/regdata/RIAs/proposedno2ria.pdf.

---

[321] U.S. Environmental Protection Agency (U.S. EPA). 2008b. 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>.

[322] 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.

[323] Pope, C.A., III, R.T. Burnett, M.J. Thun, E.E. Calle, D. Krewski, K. Ito, and G.D. Thurston. 2002. "Lung Cancer, Cardiopulmonary Mortality, and Long-term Exposure to Fine Particulate Air Pollution." Journal of the American Medical Association 287:1132-1141.

[324] Laden, F., J. Schwartz, F.E. Speizer, and D.W. Dockery. 2006. "Reduction in Fine Particulate Air Pollution and Mortality." American Journal of Respiratory and Critical Care Medicine 173:667-672. Estimating the Public Health Benefits of Proposed Air Pollution Regulations. Washington, DC: The National Academies Press.

[325] Roman, Henry A., Katherine D. Walker, Tyra L. Walsh, Lisa Conner, Harvey M. Richmond, Bryan J. Hubbell, and Patrick L. Kinney. 2008. Expert Judgment Assessment of the Mortality Impact of Changes in Ambient Fine Particulate Matter in the U.S. Environ. Sci. Technol., 42(7):2268-2274.

[326] Industrial Economics, Inc. 2006. Expanded Expert Judgment Assessment of the Concentration-Response Relationship Between PM2.5 Exposure and Mortality. Prepared for the U.S. EPA, Office of Air Quality Planning and Standards, September. Available on the Internet at <http://www.epa.gov/ttn/ecas/regdata/Uncertainty/pm_ee_report.pdf>

[327] Mrozek, J.R., and L.O. Taylor. 2002. "What Determines the Value of Life? A Meta-Analysis." Journal of Policy Analysis and Management 21(2):253-270.

[328] Viscusi, V.K., and J.E. Aldy. 2003. "The Value of a Statistical Life: A Critical Review of Market Estimates throughout the World." Journal of Risk and Uncertainty 27(1):5-76.

[329] Kochi, I., B. Hubbell, and R. Kramer. 2006. An Empirical Bayes Approach to Combining Estimates of the Value of Statistical Life for Environmental Policy Analysis. Environmental and Resource Economics. 34: 385-406.

[330] U.S. Environmental Protection Agency (U.S. EPA). 2000. Guidelines for Preparing Economic Analyses. EPA 240-R-00-003. National Center for Environmental Economics, Office of Policy Economics and Innovation. Washington, DC. September. Available on the Internet at <http://yosemite.epa.gov/ee/epa/eed.nsf/webpages/Guidelines.html/$file/cover.pdf>.

[331] Information on BenMAP, including downloads of the software, can be found at http://www.epa.gov/ttn/ecas/benmodels.html.

[332] Bell, M.L., et al. (2004). Ozone and short-term mortality in 95 US urban communities, 1987-2000. *JAMA*, 2004. 292(19): p. 2372-8.

[333] Huang, Y.; Dominici, F.; Bell, M. L. (2005) Bayesian hierarchical distributed lag models for summer ozone exposure and cardio-respiratory mortality. *Environmetrics*. 16: 547-562.

[334] Schwartz, J. (2005) How sensitive is the association between ozone and daily deaths to control for temperature? *Am. J. Respir. Crit. Care Med.* 171: 627-631.

[335] Bell, M.L., F. Dominici, and J.M. Samet. (2005). A meta-analysis of time-series studies of ozone and mortality with comparison to the national morbidity, mortality, and air pollution study. *Epidemiology*. 16(4): p. 436-45.

[336] Ito, K., S.F. De Leon, and M. Lippmann (2005). Associations between ozone and daily mortality: analysis and meta-analysis. *Epidemiology*. 16(4): p. 446-57.

[337] Levy, J.I., S.M. Chemerynski, and J.A. Sarnat. (2005). Ozone exposure and mortality: an empiric bayes metaregression analysis. *Epidemiology*. 16(4): p. 458-68.

[338] Pope, C.A., III, R.T. Burnett, M.J. Thun, E.E. Calle, D. Krewski, K. Ito, and G.D. Thurston. (2002). "Lung Cancer, Cardiopulmonary Mortality, and Long-term Exposure to Fine Particulate Air Pollution." *Journal of the American Medical Association* 287:1132-1141.

[339] Laden, F., J. Schwartz, F.E. Speizer, and D.W. Dockery. (2006). Reduction in Fine Particulate Air Pollution and Mortality. *American Journal of Respiratory and Critical Care Medicine*. 173: 667-672.

[340] Industrial Economics, Incorporated (IEc). (2006). *Expanded Expert Judgment Assessment of the Concentration-Response Relationship Between PM2.5 Exposure and Mortality. Peer Review Draft.* Prepared for: Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, Research Triangle Park, NC. August.

[341] Woodruff, T.J., J. Grillo, and K.C. Schoendorf. (1997). The Relationship Between Selected Causes of Postneonatal Infant Mortality and Particulate Air Pollution in the United States. *Environmental Health Perspectives.* 105(6):608-612.

[342] Abbey, D.E., B.L. Hwang, R.J. Burchette, T. Vancuren, and P.K. Mills. (1995). Estimated Long-Term Ambient Concentrations of PM(10) and Development of Respiratory Symptoms in a Nonsmoking Population. *Archives of Environmental Health.* 50(2): 139-152.

[343] Peters, A., D.W. Dockery, J.E. Muller, and M.A. Mittleman. (2001). Increased Particulate Air Pollution and the Triggering of Myocardial Infarction. *Circulation.* 103:2810-2815.

[344] Schwartz J. (1995). Short term fluctuations in air pollution and hospital admissions of the elderly for respiratory disease. *Thorax.* 50(5):531-538.

[345] Schwartz J. (1994a). PM(10) Ozone, and Hospital Admissions For the Elderly in Minneapolis St Paul, Minnesota. *Arch Environ Health.* 49(5):366-374.

[346] Schwartz J. (1994b). Air Pollution and Hospital Admissions For the Elderly in Detroit, Michigan. *Am J Respir Crit Care Med.* 150(3):648-655.

[347] Moolgavkar SH, Luebeck EG, Anderson EL. (1997). Air pollution and hospital admissions for respiratory causes in Minneapolis St. Paul and Birmingham. *Epidemiology*. 8(4):364-370.

[348] Burnett RT, Smith-Doiron M, Stieb D, Raizenne ME, Brook JR, Dales RE, et al. (2001). Association between ozone and hospitalization for acute respiratory diseases in children less than 2 years of age. *Am J Epidemiol*. 153(5):444-452.

[349] Moolgavkar, S.H. (2003). "Air Pollution and Daily Deaths and Hospital Admissions in Los Angeles and Cook Counties." In *Revised Analyses of Time-Series Studies of Air Pollution and Health*. Special Report. Boston, MA: Health Effects Institute.

[350] Ito, K. (2003). "Associations of Particulate Matter Components with Daily Mortality and Morbidity in Detroit, Michigan." In *Revised Analyses of Time-Series Studies of Air Pollution and Health.* Special Report. Health Effects Institute, Boston, MA.

[351] Moolgavkar, S.H. (2000). Air Pollution and Hospital Admissions for Diseases of the Circulatory System in Three U.S. Metropolitan Areas. *Journal of the Air and Waste Management Association* 50:1199-1206.

[352] Sheppard, L. (2003). Ambient Air Pollution and Nonelderly Asthma Hospital Admissions in Seattle, Washington, 1987-1994. In *Revised Analyses of Time-Series Studies of Air Pollution and Health.* Special Report. Boston, MA: Health Effects Institute.

[353] Jaffe DH, Singer ME, Rimm AA. (2003). Air pollution and emergency department visits for asthma among Ohio Medicaid recipients, 1991-1996. *Environ Res* 91(1):21-28.

---

[354] Peel, J. L., P. E. Tolbert, M. Klein, et al. (2005). Ambient air pollution and respiratory emergency department visits. *Epidemiology*. Vol. 16 (2): 164-74.

[355] Wilson, A. M., C. P. Wake, T. Kelly, et al. (2005). Air pollution, weather, and respiratory emergency room visits in two northern New England cities: an ecological time-series study. *Environ Res*. Vol. 97 (3): 312-21.

[356] Norris, G., S.N. YoungPong, J.Q. Koenig, T.V. Larson, L. Sheppard, and J.W. Stout. (1999). An Association between Fine Particles and Asthma Emergency Department Visits for Children in Seattle. *Environmental Health Perspectives* 107(6):489-493.

[357] Dockery, D.W., J. Cunningham, A.I. Damokosh, L.M. Neas, J.D. Spengler, P. Koutrakis, J.H. Ware, M. Raizenne, and F.E. Speizer. (1996). Health Effects of Acid Aerosols On North American Children-Respiratory Symptoms. *Environmental Health Perspectives* 104(5):500-505.

[358] Pope, C.A., III, D.W. Dockery, J.D. Spengler, and M.E. Raizenne. (1991). Respiratory Health and PM_{10} Pollution: A Daily Time Series Analysis. *American Review of Respiratory Diseases* 144:668-674.

[359] Schwartz, J., and L.M. Neas. (2000). Fine Particles are More Strongly Associated than Coarse Particles with Acute Respiratory Health Effects in Schoolchildren. *Epidemiology* 11:6-10.

[360] Ostro, B., M. Lipsett, J. Mann, H. Braxton-Owens, and M. White. (2001). Air Pollution and Exacerbation of Asthma in African-American Children in Los Angeles. *Epidemiology* 12(2):200-208.

[361] Vedal, S., J. Petkau, R. White, and J. Blair. (1998). Acute Effects of Ambient Inhalable Particles in Asthmatic and Nonasthmatic Children. *American Journal of Respiratory and Critical Care Medicine* 157(4):1034-1043.

[362] Ostro, B.D. (1987). Air Pollution and Morbidity Revisited: A Specification Test. *Journal of Environmental Economics Management* 14:87-98.

[363] Gilliland FD, Berhane K, Rappaport EB, Thomas DC, Avol E, Gauderman WJ, et al. (2001). The effects of ambient air pollution on school absenteeism due to respiratory illnesses. *Epidemiology* 12(1):43-54.

[364] Chen L, Jennison BL, Yang W, Omaye ST. (2000). Elementary school absenteeism and air pollution. *Inhal Toxicol* 12(11):997-1016.

[365] Ostro, B.D. and S. Rothschild. (1989). Air Pollution and Acute Respiratory Morbidity: An Observational Study of Multiple Pollutants. *Environmental Research* 50:238-247.

[366] Russell, M.W., D.M. Huse, S. Drowns, E.C. Hamel, and S.C. Hartz. (1998). Direct Medical Costs of Coronary Artery Disease in the United States. *American Journal of Cardiology* 81(9):1110-1115.

[367] Wittels, E.H., J.W. Hay, and A.M. Gotto, Jr. (1990). Medical Costs of Coronary Artery Disease in the United States. *American Journal of Cardiol*ogy 65(7):432-440.

[368] Smith, D.H., D.C. Malone, K.A. Lawson, L.J. Okamoto, C. Battista, and W.B. Saunders. (1997). A National Estimate of the Economic Costs of Asthma. *American Journal of Respiratory and Critical Care Medicine* 156(3 Pt 1):787-793.

[369] Stanford, R., T. McLaughlin, and L.J. Okamoto. (1999). The Cost of Asthma in the Emergency Department and Hospital. *American Journal of Respiratory and Critical Care Medicine* 160(1):211-215.

[370] Rowe, R.D., and L.G. Chestnut. (1986). *Oxidants and Asthmatics in Los Angeles: A Benefits Analysis—Executive Summary.* Prepared by Energy and Resource Consultants, Inc. Report to the U.S. Environmental Protection Agency, Office of Policy Analysis. EPA-230-09-86-018. Washington, DC.

[371] Science Advisory Board. 2001. NATA – Evaluating the National-Scale Air Toxics Assessment for 1996 – an SAB Advisory. http://www.epa.gov/ttn/atw/sab/sabrev.html.

[372] MiniCAM 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. MiniCAM 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.

Brenkert A, S. Smith, S. Kim, and H. Pitcher, 2003: Model Documentation for the MiniCAM. PNNL-14337, Pacific Northwest National Laboratory, Richland, Washington.

[373] MAGICC consists of a suite of coupled gas-cycle, climate and ice-melt models integrated into a single framework. The framework allows the user to determine changes in greenhouse-gas concentrations, global-mean surface air temperature and sea-level resulting from anthropogenic emissions of carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O), reactive gases (CO, NOx, VOCs), the halocarbons (e.g. HCFCs, HFCs, PFCs) and sulfur dioxide (SO2). MAGICC emulates the global-mean temperature responses of more sophisticated coupled Atmosphere/Ocean General Circulation Models (AOGCMs) with high accuracy.

Wigley, T.M.L. and Raper, S.C.B. 1992. Implications for Climate And Sea-Level of Revised IPCC Emissions Scenarios Nature 357, 293-300. Raper, S.C.B., Wigley T.M.L. and Warrick R.A. 1996. in Sea-Level Rise and Coastal Subsidence: Causes, Consequences and Strategies J.D. Milliman, B.U. Haq, Eds., Kluwer Academic Publishers, Dordrecht, The Netherlands, pp. 11-45.

Wigley, T.M.L. and Raper, S.C.B. 2002. Reasons for larger warming projections in the IPCC Third Assessment Report J. Climate 15, 2945-2952.

[374] This scenario is used because it contains a comprehensive suite of greenhouse and pollutant gas emissions. The four RCP scenarios will be used as common inputs into a variety of Earth System Models for inter-model comparisons leading to the IPCC AR5 (Moss et al. 2008). The MiniCAM RCP4.5 is based on the scenarios presented in Clarke et al. (2007) with non-CO2 and pollutant gas emissions implemented as described in Smith and Wigley (2006). Base-year information has been updated to the latest available data for the RCP process. The final RCP4.5 scenario will be available at the IAMC scenario Web site (www.iiasa.ac.at/web-apps/tnt/RcpDb/).

Clarke, L., J. Edmonds, H. Jacoby, H. Pitcher, J. Reilly, R. Richels, (2007) Scenarios of Greenhouse Gas Emissions and Atmospheric Concentrations. Sub-report 2.1A of Synthesis and Assessment Product 2.1 by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research (Department of Energy, Office of Biological & Environmental Research, Washington, DC., USA, 154 pp.).

Moss, Richard, Mustafa Babiker, Sander Brinkman, Eduardo Calvo, Tim Carter, Jae Edmonds, Ismail Elgizouli, Seita Emori, Lin Erda, Kathy Hibbard, Roger Jones, Mikiko Kainuma, Jessica Kelleher, Jean Francois Lamarque, Martin Manning, Ben Matthews, Jerry Meehl, Leo Meyer, John Mitchell, Nebojsa Nakicenovic, Brian O'Neill, Ramon Pichs, Keywan Riahi, Steven Rose, Paul Runci, Ron Stouffer, Detlef van Vuuren, John Weyant, Tom Wilbanks, Jean Pascal van Ypersele, and Monika Zurek (2008) Towards New Scenarios for Analysis of Emissions, Climate Change, Impacts, and Response Strategies (Intergovernmental Panel on Climate Change, Geneva) 132 pp.

Smith, Steven J. and T.M.L. Wigley (2006) "Multi-Gas Forcing Stabilization with the MiniCAM" Energy Journal (Special Issue #3).

[375] 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/.

[376] IPCC WGI, 2007. The baseline temperature increases by 2100 from our MiniCAM-MAGICC runs are 1.8°C to 4.5°C.

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[377] IPCC WGII. 2007. *Climate Change 2007 - Impacts, Adaptation and Vulnerability Contribution of Working Group II to the Fourth Assessment Report of the IPCC.*

[378] "Light-Duty Automotive Technology and Fuel Economy Trends: 1975 Through 2008", EPA420-R-08-015, U.S. Environmental Protection Agency Office of Transportation and Air Quality, September 2008

[379] "Future Generation Passenger Compartment-Validation" in "Lightweighting Materials – FY 2008 Progress Report", U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Vehicle Technologies Program, May 2009.

[380] "Relationship between Vehicle Size and Fatality Risk in Model Year 1985-93 Passenger cars and Light Trucks", DOT HS 808 570, NHTSA Technical Report, January 1997

[381] "Vehicle Weight, Fatality Risk and Crash Compatibility of Model Year 1991-99 Passenger Cars and Light Trucks", DOT HS 809 663, NHTSA Technical Report, October 2003

[382] "Supplemental Results on the Independent Effects of Curb Weight, Wheelbase and Track on Fatality Risk", Dynamic Research, Inc., DRI-TR-05-01, May 2005

[383] "An Assessment of the Effects of Vehicle Weight and Size on Fatality Risk in 1985 to 1998 Model Year Passenger Cars and 1985 to 1997 Model Year Light Trucks and Vans", Van Auken, M., Zellner J.W., SAE Technical Paper Number 2005-01-1354, 2005.

[384] FR Vol. 74, No. 59, beginning on pg. 14402

CHAPTER 8: Other Economic and Social Impacts

8.1 Vehicle Sales Impacts

8.1.1 How Vehicle Sales Impacts were Estimated for this Rule

The vehicle sales impacts discussed in Section III.H.4 of the preamble to the proposal and presented below in Table 8-1 and Table 8-2 were derived using the following methodology. For additional discussion of the assumptions used in the vehicles sales impacts, see Section III.H of the preamble. The calculation is performed for an average car and an average truck, rather than for individual vehicles. The analysis conducted for this rule does not have the precision to examine effects on individual manufacturers or different vehicle classes. Chapter 8.1.2 provides our assessment of models that examine these questions.

The analysis starts with the increase in costs estimated by OMEGA. 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 likely that the cost increase is split between consumers and automakers, and the price is not likely to increase as much as costs.[385] Thus, the assumption of full cost pass-through is probably an overestimate, and price is not likely to increase as much as estimated here.

The next step in the analysis is to adjust this cost increase for other effects on the consumer. We assume that the consumer holds onto this vehicle for 5 years and then sells it. The higher vehicle price is likely to lead to an increase in sales tax, insurance, and vehicle financing costs, as well as increases in the resale value of the vehicle. These factors weigh against each other: the higher sales tax and insurance costs increase costs to consumers; the higher resale value allows consumers to recover a portion of these 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[386] provides the average value of collision plus comprehensive insurance in 2006 as $448. The average value of a new vehicle in 2006, according to the U.S. Department of Energy, was $22,651.[387] (This value is for a 2006 vehicle in 2006 and is used only for the insurance adjustment; it does not correspond to the new vehicle prices, described below, used in the vehicle sales impact calculation.) Dividing the insurance cost by the average price of a new vehicle gives the proportion of comprehensive plus collision insurance as 1.98% 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 1.98% of the increase in vehicle cost. For the five-year period, the present value of this increase in insurance cost would be worth 9.0% of the vehicle cost increase, using a 3% discount rate (8.1% at a 7% discount rate).

Calculating the average increase in sales tax starts with the vehicle sales tax for each state in 2006.[388] The sales tax per state was then multiplied by the 2006 population of the state;[389] 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% in 2006. This value is assumed to be a one-time cost incurred when the vehicle is purchased.

As of August 24, 2009, the national average interest rate for a 5 year new car loan was 7.41 percent.[390] Converting the up-front payment to an annual value paid over five years results in a consumer paying 24.7% of the up-front amount every year. The present value of these five payments results in an increase of 12.9% of the cost, using a 3% discount rate; with a 7% discount rate, the increase is 1.1%. NHTSA's PRIA notes that 70% of auto purchases use financing; applying that fraction to this cost increase results in an addition of 9.0% in financing costs with a 3% discount rate, and 0.8% for a 7% discount rate.

The average resale price of a vehicle after 5 years is about 35%[391] of the original purchase price. Because the consumer can recover that amount after 5 years, it reduces the effect of the increased cost of the vehicle. Discounted to a present value at a 3% interest rate, the increase in price should be worth about 30.2% to the vehicle purchaser (25.0% at a 7% discount rate). This approach is premised on the idea that the resale value of a vehicle is directly proportional to the initial value, and that proportion does not change.

Thus, the effect on a consumer's expenditure of the cost of the new technology (with some rounding) should be (1 + 0.090 + 0.053 + 0.090 – 0.302) = 0.932 times the cost of the technology at a 3% discount rate. At a 7% discount rate, the effect on a consumer's expenditure of the cost of the new technology should be (1 + 0.081 + 0.053 + 0.008 – 0.250) = 0.892 times the cost of the technology.

The fuel cost savings are based on the five years of consumer ownership of the vehicle. The analysis is done for each model-year for an average vehicle. Section 5.6 of this DRIA discusses the source of aggregate fuel savings, in gallons, for cars and trucks for each model year by year. These values are divided by the total number of the vehicles produced to get per-vehicle savings per year for the first five years of the vehicle's life. This method ignores the few vehicles of the new model year that are scrapped. Because incorporating scrappage would reduce the denominator, and thus increase per-vehicle fuel savings, it underestimates per-vehicle fuel savings by a small amount. The per-vehicle fuel savings in gallons are multiplied by the price of fuel to get the per-vehicle fuel savings in dollars. For each model year, then, the first five years of fuel savings are discounted and summed to produce the present value of fuel savings for that vintage vehicle. For instance, the 2016 fuel savings per vehicle are the present value in year 2016 of fuel savings estimated for 2016 through 2020.

The prices for new vehicles are assumed to be constant at the 2008 value (in 2007$) of $26,201 for a car, and $29,678 for a truck. These are the values used in NHTSA's 2011 rule on CAFE standards.

The fuel cost savings are subtracted from the increase in costs associated with the rule to get the net effect of the rule on consumer expenditure. The higher cost leads consumers to purchase fewer new vehicles, but the fuel savings can counteract this effect. This calculation uses an elasticity of demand for new vehicles of -1[392]: that is, an increase of 1% in the price of a new vehicle will lead to a 1% reduction in new vehicle sales. Using this value assumes that the demand elasticity for new vehicles under this rule is the same as the elasticity for older vehicles. This change in consumer expenditure as a percent of the average price of a new vehicle, with the elasticity of demand of -1, is the negative of the percent change in vehicle purchases. The net effect of this calculation on vehicle purchases is in Table 8-1 and Table 8-2.

Table 8-1 Vehicle Sales Impacts Using a 3% Discount Rate

	CHANGE IN CAR SALES	% CHANGE	CHANGE IN TRUCK SALES	% CHANGE
2012	66,600	0.7	27,300	0.5
2013	93,300	0.9	161,300	2.8
2014	134,400	1.3	254,400	4.4
2015	236,300	2.2	368,400	6.5
2016	375,400	3.4	519,000	9.4

Table 8-1shows vehicle sales increasing. Because the fuel savings associated with this rule are expected to exceed the technology costs, the effective prices of vehicles – the adjusted increase in technology cost less the fuel savings over five years -- to consumers will fall, and consumers will buy more new vehicles. This effect is expected to increase over time. As a result, if consumers consider fuel savings at the time that they make their vehicle purchases, the lower net cost of the vehicles is expected to lead to an increase in sales for both cars and trucks. Both the absolute and the percent increases for truck sales are larger than those for cars (except in 2012).

Table 8-2 Vehicle Sales Impacts Using a 7% Discount Rate

	CHANGE IN CAR SALES	% CHANGE	CHANGE IN TRUCK SALES	% CHANGE
2012	61,900	0.7	25,300	0.5
2013	86,600	0.9	60,000	1
2014	125,200	1.2	122,900	2.1
2015	221,400	2	198,100	3.5
2016	353,100	3.2	291,500	5.3

Table 8-2 shows the same calculations using a 7% discount rate. Qualitatively, the results are identical to those using a 3% discount rate: the fuel savings outweigh the increase in technology costs for all years. As a result, vehicle sales are expected to be higher under this rule than in the absence of the rule. In addition, while the increased numbers of car sales are larger than the numbers for trucks, the percent increases are larger for trucks.

This calculation focuses on changes in consumer expenditures as the explanatory variable for changes in aggregate new vehicle sales. This is a simplification, since consumers typically consider a number of factors in addition to expenditures when they decide on purchasing a vehicle. In addition, it does not consider changes in the mix of vehicles sold that may result from this rule. The next section discusses more complex modeling of the vehicle purchase decision.

8.1.2 Consumer Vehicle Choice Modeling

In this section we describe some of the consumer vehicle choice models EPA has reviewed in the literature, and we describe the models' results and limitations that we have identified. The evidence from consumer vehicle choice models indicates a huge range of estimates for consumers' willingness to pay for additional fuel economy. Because consumer surplus estimates from consumer vehicle choice models depend critically on this value, we would consider any consumer surplus estimates of the effect of our rule from such models to be unreliable. In addition, the predictive ability of consumer vehicle choice models 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 proposed 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. Like NHTSA, EPA will continue its efforts to review the literature, but, given the known difficulties, neither NHTSA nor EPA has 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 some 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 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. 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,[393] Greene et al.,[394] and McManus.[395]

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,[396] Bento et al.,[397] and Train and Winston.[398]

While discrete choice modeling appears to be the primary method for consumer choice modeling, others (such as Kleit[399] and Austin and Dinan[400]) 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.[401] Because they draw on the behavior of individuals, they provide what is sometimes called micro-level data. Other studies, that estimate market shares instead of discrete purchase decisions, use aggregated data that can cover long time periods.[402]

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[403] and the New Vehicle Market Model developed by NERA Economic Consulting[404] 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;[405] others consider the choice between new vehicles and an outside good (possibly including a used vehicle);[406] others explicitly consider the relationship between the new and used vehicle markets.[407] Some models include consideration of vehicle miles traveled,[408] 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;[409] others include varying numbers and kinds of vehicle and consumer attributes.

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,[410] 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 a stakeholder 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,[411] the market acceptability of alternative-fuel vehicles,[412] the effects of introduction and exit of vehicles from markets,[413] causes of the decline in market shares of U.S. automakers,[414] and the effects of gasoline taxes[415] and "feebates"[416] (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[417] 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[418] 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, the miles per gallon of vehicles 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:[419] since consumers pay for gallons of fuel, then this measure can assess fuel savings relatively directly.[420] Yet other models multiply fuel consumption per mile by the cost of fuel to get the price of driving a mile,[421] or they divide fuel economy by fuel cost to get miles per dollar.[422] 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. 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, it is also a way to recognize the role of fuel prices in consumers' purchase of fuel economy: Busse et al.[423] present results that higher fuel prices play a major role in that decision.

Greene and Liu,[424] in a paper published in 1988, reviewed 10 papers using consumer vehicle choice models and estimated for each one how much consumers would be willing to pay at time of purchase to reduce vehicle operating costs by \$1 per year. They found that people were willing to pay between \$0.74 and \$25.97 for a \$1 decrease in annual operating costs for a vehicle. This is clearly a very wide range: while the lowest estimate suggests that people are not willing to pay \$1 once to get \$1 per year reduced costs of operating their vehicles, the maximum suggests a willingness to pay 35 times as high. For comparison, the present value of saving \$1 per year for 15 years at a 3% discount rate is \$11.94, while a 7% discount rate produces a present value of \$8.78. While this study is quite old, it suggests that, at least as of that time, consumer vehicle choice models produced widely varying estimates of the value of reduced vehicle operating costs.

More recent studies do not suggest agreement on the value of increased fuel economy to consumers. For instance, some papers[425] find that the role of fuel cost (price per gallon divided by miles per gallon, or the cost of driving one mile) decreases for larger vehicles; in contrast, Gramlich[426] finds that owners of fuel-inefficient vehicles have the greatest willingness to pay for improved fuel economy. 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[427] 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.

Espey and Nair[428] find, using data from model year 2001, that consumers might be willing to pay roughly $500 for a 1-mpg increase in city driving, approximately $250 for a 1-mpg increase in highway driving, or approximately $600 for an increase in combined fuel economy; they argue that these values approximately correspond to the fuel savings that consumers might expect over the lifetime of the vehicle. McManus[429] finds, in 2005, that consumers were willing to pay $578 for a 1-mpg increase in fuel economy. Gramlich[430] finds willingness to pay for an increase from 25 mpg to 30 mpg to range between $4100 (for luxury cars, when gasoline costs $2/gallon) to $20,600 (for SUVs when gasoline costs $3.50/gallon).

Some studies[431] 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[432] 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[433] 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 Consumers May Not Buy, and Producers May Not Provide, Fuel Economy that Pays for Itself

If consumers are willing to pay for fuel-saving technologies, why does the market not already take advantage of these low-cost technologies? Why aren’t consumers demanding these vehicle improvements, and manufacturers supplying them, when they appear to “pay for themselves” even in the absence of regulation?

On the consumer side, 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,[434] since consumers appear to routinely undervalue a wide range of investments in energy conservation. Some possible explanations for the paradox include:

- Consumers put little weight on benefits from fuel savings in the future;
- Consumers consider other attributes more important than fuel economy at the time of vehicle purchase;
- Consumers may not be able to find the vehicles they want with improved fuel economy;

- Consumers have difficulty in calculating expected fuel savings;
- Consumers may use imprecise rules of thumb when deciding how much fuel economy to purchase;
- Fuel savings in the future are uncertain; in contrast, at the time of purchase the increased costs of fuel-saving technologies are certain and immediate;
- 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.

The producer side of this paradox is much less studied. Hypotheses for underprovision of fuel economy by producers include:

- Producers put more effort into attributes that consumers have regularly sought in the past, such as size and power, rather than fuel savings with uncertain future returns;
- In selecting a limited number of vehicle attributes among which consumers can choose, producers may aim to provide choices related to characteristics (such as numbers of doors or transmission types) that strongly influence what vehicle a consumer will buy, and fuel economy may not make that list;
- While consumer preferences for fuel economy may change rapidly as fuel prices fluctuate, producers cannot change their design or production decisions as rapidly; as a result, vehicle designs may end up not satisfying consumer desires at a particular time;
- Producers may have misestimated the value that consumers place on fuel economy.

How consumers buy, and producers provide, fuel economy involves complex decisions on both sides of the market. Both sides of the market rely heavily in their calculations on the uncertain benefits of fuel savings. In addition, consumers trade off fuel economy with many other vehicle attributes, and producers do not provide the full range of attributes possible for consumers. From this perspective, it may not be a surprise that, at a given point in time, consumer preferences for fuel economy may not match up with producer provision of it.

8.1.2.7 Assessment of the Literature

Consumer vehicle choice modeling in principle can provide a great deal of useful information for regulatory analysis. All models estimate changes in fleet mix of new vehicles; some also provide estimates of total new vehicle sales; and a few incorporate the used vehicle market, potentially to the decision on when a vehicle is scrapped. Being able to model these changes has several advantages.

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 vehicle emissions or vehicle miles traveled. The predictive ability of models, though, is not proven. It is likely that, in coming years, new vehicles will be developed, and existing vehicles will be redesigned, perhaps to have improvements in both fuel economy and safety factors in combinations that consumers have not previously been offered. Welch,[435] for instance, argues that auto producers are likely to increase the sizes of vehicles in response to the footprint-based fuel economy standard. Models based on the existing vehicle fleet may, however, not do well in predicting consumers' choices among the new vehicles offered. One attempt to analyze the effect of the oil shock of 1973 on consumer vehicle choice found that, after two years, the particular model did not predict well due to changes in the vehicle fleet.[436] Thus, consumer vehicle choice models, even if they did produce robust results in analyzing the short-term effects of policy changes, may miss changes associated with new and redesigned vehicles.

The modeling may improve estimates of the compliance costs of a rule. Most current modeling is based on a fleet mix determined outside the model; neither vehicle manufacturers nor consumers respond directly to cost increases and other vehicle changes by a change in the fleet mix. With the use of consumer vehicle choice modeling, both consumers and producers have greater choices in response to these changes: they can either accept the new costs and vehicle characteristics, or they can change which vehicles are sold. The fact that consumers and producers have additional options suggests that compliance costs are likely to be lower through incorporation of a consumer choice model than through use of a technology-cost model alone. On the other hand, the effect may not be large: in the context of "feebates" (subsidizing fuel-efficient cars with revenue collected by taxing fuel-inefficient vehicles), Greene et al. found that 95% of the increase in fuel economy was due to addition of technology rather than changes in vehicles sold.[437] Consideration of consumer behavior in welfare estimates will improve regulatory analysis, but only to the extent that the predicted changes in consumer purchase patterns reflect actual changes.

An additional feature of consumer choice models, as noted above, is that they can be used to calculate consumer surplus impacts. Consumer surplus is a standard measurement of consumer impacts in benefit-cost analysis. Consumer surplus calculations from these models estimate how much consumers appreciate the gains in fuel economy relative to the increased vehicle costs that they face, based on the assumption that consumers, at the time of vehicle purchase, have made the best decisions for themselves on the amount of fuel economy in the vehicles they purchase. These values, though, are based on the relationship between consumer willingness to pay for fuel economy and the costs of improved fuel economy. Because the estimates of consumer willingness to pay for fuel economy appear to be highly inconsistent, consumer surplus measures from any one model are unlikely to be reliable.

At this point, it is unclear whether two models given the same scenario would produce similar results in either prediction of changes in the vehicles purchased or in estimates of consumer surplus effects. The estimates of consumer surplus from consumer vehicle choice models depend heavily on the value to consumers of improved fuel economy, a value for which estimates are highly varied. In addition, the predictive ability of consumer vehicle choice models may be limited as consumers face new vehicle choices that they previously did not have. If the results across models are not consistent or are highly sensitive to parameters or other features, then careful thought needs to be given to model selection and development.

Nonetheless, because there are potential advantages to using consumer vehicle choice models if these difficulties can be addressed, EPA is continuing 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 and the estimates of consumers' willingness to pay for increased fuel economy. In addition, EPA is developing capacity to examine the factors that may affect the results of consumer vehicle choice models, and to explore their impact on analysis of regulatory scenarios. Under contract with EPA, Resources for the Future (RFF) is developing a model of the vehicle market that can be used to evaluate different policy designs and compare regulatory scenarios on the basis of changes in cost, changes in the prices paid by consumers, changes in consumer welfare, and changes in industry profits. It should help to shed light on whether it is more costly to rely solely on the application of technologies to vehicles to meet a given fuel standard than when consumer and producer behavior is taken into account. EPA plans to evaluate this work within the context of the overall literature on consumer vehicle choices, to determine its usefulness in informing the analysis for the final rule. We seek comment on the usefulness of consumer choice modeling results and the consistency and reliability of results from these models.

8.1.3 Consumer Payback Period and Lifetime Savings on New Vehicle Purchases

Another factor of interest is the payback period on the purchase of a new vehicle that complies with 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 2016 MY vehicle is estimated to cost $1,050 more (on average, and relative to the reference case vehicle) due to the addition of new GHG reducing technology (see Chapter 4 for details on this cost estimate). This new technology will result in lower fuel consumption and, therefore, savings in fuel expenditures (see Chapter 5 for details on fuel savings). But how many months or years would pass before the fuel savings exceed the upfront cost of $1,050?

Table 8-3 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. We have included rebound VMT in the control case but not in the reference case, consistent with other parts of our analysis. We have also included fuel savings associated with A/C controls (in the control case only), but have not included expected A/C-related maintenance savings. We discuss the likely maintenance savings in Chapter 2 of this DRIA. Further, this analysis does not include other societal impacts such as the value of increased driving, or noise, congestion and accidents since we really want to focus on those factors consumers consider most while in the showroom considering a new car purchase. Car/truck fleet weighting is handled as described in Chapter 1 of the draft joint TSD. As can be seen in the table, it will take under 3 years (2 years and 8 months at a 3% discount rate, 2 years and 10 months at a 7% discount rate) for the cumulative fuel savings to exceed the upfront increase in vehicle cost. For the average driver, this payback would occur at around 46,000 to 48,000 miles, depending on the discount rate. For the driver that drives more than the average, the payback would come sooner. For the driver that drives less than the average, the payback would come later.

Table 8-3 Payback Period on a 2016MY New Vehicle Purchase via Cash (2007 dollars)

Year of Ownership	Increased Vehicle Cost[a] ($)	Fuel Price[b] ($/gal)	Reference VMT[c] (miles)	Control VMT[c] (miles)	Reference Fuel Costs[d] ($)	Control Fuel Costs[d] ($)	Annual Fuel Savings ($)	Cumulative Discounted Fuel Savings at 3% ($)	Cumulati Discount Fuel Savings 7% ($)
1	-$1,128	$3.27	17,481	17,813	$2,544	$2,101	$443	$436	$428
2		$3.39	16,934	17,256	$2,549	$2,106	$444	$860	$829
3		$3.48	16,432	16,744	$2,545	$2,102	$443	$1,272	$1,203
4		$3.56	15,777	16,077	$2,495	$2,061	$434	$1,663	$1,546

[a] Increased cost of the proposed rule is $1,050; the value here includes nationwide average sales tax of 5.3% and increased insurance premiums of 1.98%; both of these percentages are discussed in section 8.1.1.

[b] AEO 2009 reference case fuel price including taxes.

[c] VMT is calculated as the weighted car/truck VMT with cars estimated to account for 67% of the fleet and trucks 33%; VMT shown here includes survival fraction and, for the control case, rebound VMT.

[d] Fuel costs calculated using the reference and control case achieved CO2 levels as presented in Chapter 5 with 8887 grams of CO2 p gallon of gasoline and include the 20 percent road fuel economy gap, as discussed in Chapter 5; the control case also includes the effects of A/C controls on CO2 emissions but not the expected A/C-related maintenance savings.

Most people purchase a new vehicle using credit rather than paying cash up front. The typical car loan today is a five year, 60 month loan. As of August 24, 2009, the national average interest rate for a 5 year new car loan was 7.41 percent. If the increased vehicle cost is spread out over 5 years at 7.41 percent, the analysis would look like that shown in Table 8-4. As can be seen in this table, the fuel savings immediately outweigh the increased payments on the car loan, amounting to $162 in discounted net savings (3% discount rate) saved in the first year and similar savings for the next two years before reduced VMT starts to cause the fuel savings to fall. 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 $9 to $14 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 (as would be the case for the remaining years of ownership).

Table 8-4 Payback Period on a 2016 MY New Vehicle Purchase via Credit (2007 dollars)

Year of Ownership	Increased Vehicle Cost[a] ($)	Fuel Price[b] ($/gal)	Reference VMT[c] (miles)	Control VMT[c] (miles)	Reference Fuel Costs[d] ($)	Control Fuel Costs[d] ($)	Annual Fuel Savings ($)	Annual Discounted Net Savings at 3% ($)	Annua Discount Net Savings 7% ($)
1	$278	$3.27	17,481	17,813	$2,544	$2,101	$443	$162	$159
2	$278	$3.39	16,934	17,256	$2,549	$2,106	$444	$158	$150
3	$278	$3.48	16,432	16,744	$2,545	$2,102	$443	$153	$139
4	$278	$3.56	15,777	16,077	$2,495	$2,061	$434	$141	$123
5	$278	$3.62	15,109	15,396	$2,432	$2,009	$423	$127	$107
6		$3.64	14,338	14,611	$2,318	$1,914	$403	$343	$278

[a] This uses the same increased cost as Table 8-3 but spreads it out over 5 years assuming a 5 year car loan at 7.41 percent.

[b] AEO 2009 reference case fuel price including taxes.

[c] VMT is calculated as the weighted car/truck VMT with cars estimated to account for 67% of the fleet and trucks 33%; VMT shown here includes survival fraction and, for the control case, rebound VMT.

[d] Fuel costs calculated using the reference and control case achieved CO2 levels as presented in Chapter 5 with 8887 grams of CO2 p gallon of gasoline and include the 20 percent road fuel economy gap, as discussed in Chapter 5; the control case also includes the effects of A/C controls on CO2 emissions but not the expected A/C-related maintenance savings.

We can also calculate the lifetime fuel savings and net savings 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 8-5. In either case, the present value of the lifetime net savings is greater than $3,200 at a 3% discount rate, or $2,400 at a 7% discount rate.Table 8-5 Lifetime Discounted Net Savings on a 2016 MY New Vehicle Purchase (2007 dollars)

Purchase Option	Increased Discounted Vehicle Cost ($)	Lifetime Discounted Fuel Savings[b,c] ($)	Lifetime Discounted Net Savings ($)
3% discount rate			
Cash	$1,128	$4,558	$3,446
Credit[a]	$1,293	$4,558	$3,265
7% discount rate			
Cash	$1,128	$3,586	$2,495
Credit[a]	$1,180	$3,586	$2,406

[a] Assumes a 5 year loan at 7.41 percent.

[b] VMT is calculated as the weighted car/truck VMT with cars estimated to account for 67% of the fleet and trucks 33%; VMT shown here includes survival fraction and, for the control case, rebound VMT.

[c] Fuel savings here were calculated using AEO 2009 reference case fuel price including taxes.

8.2

8.3 Energy Security Impacts

This chapter will only describe the energy security analysis that was conducted beyond that described in Chapter 4.B.10 of the TSD. Additional analysis was conducted to provide inputs to EPA's OMEGA model. For a detailed discussion of the development of the energy security estimates, please refer to Chapter 4.B.10 of the TSD.

After the EPA-sponsored peer review of the Oak Ridge National Laboratory's (ORNL) Energy Security Analysis was completed in 2008, ORNL, at EPA's request, updated the analysis using values from the AEO 2009 rather than the 2007 values. The methodology used to update this analysis was the same one that was peer-reviewed.[438] The results are shown in Table 8-6. ORNL estimated the energy security premium for 2015, 2020, and 2030. Since the AEO 2009 forecasts ends in 2030, EPA assumed that the post-2030 energy security premium did not change through 2040.

Table 8-6 Energy Security Premium in 2015, 2020, 2030, and 2040 (2007$/Barrel)

YEAR	MONOPSONY (RANGE)	MACROECONOMIC DISRUPTION/ADJUSTMENT COSTS (RANGE)	TOTAL MID-POINT (RANGE)
2015	$11.79 ($4.26 - $21.37)	$6.70 ($3.11 - $10.67)	$18.49 ($9.80 - $28.08)
2020	$12.31 ($4.46 - $22.53)	$7.62 ($3.77 - $12.46)	$19.94 ($10.58 - $30.47)
2030	$10.57 ($3.84 - $18.94)	$8.12 ($3.90 - $13.04)	$18.69 ($10.52 - $27.89)
2040	$10.57 ($3.84 - $18.94)	$8.12 ($3.90 - $13.04)	$18.69 ($10.52 - $27.89)

EPA linearly interpolated the values for the years 2016 through 2019, using the 2015 and 2020 values as endpoints. EPA followed the same procedure to estimate the 2021 through 2029 estimates, using the 2020 and 2030 values as endpoints. Post-2030, EPA assumed that the energy security estimate did not change. The final set of values that was used by the OMEGA model is shown in Table 8-7.

Table 8-7 Energy Security Premium Estimates for Years 2015-2040 (2007$/Barrel)

YEAR	MONOPSONY	MACRO/DISRUPT	TOTAL
2015	$11.79	$6.70	$18.49
2016	$11.89	$6.88	$18.78
2017	$12.00	$7.07	$19.07
2018	$12.10	$7.25	$19.36
2019	$12.21	$7.44	$19.65
2020	$12.31	$7.62	$19.94
2021	$12.14	$7.67	$19.82
2022	$11.96	$7.72	$19.69
2023	$11.79	$7.77	$19.57
2024	$11.61	$7.82	$19.44
2025	$11.44	$7.87	$19.32
2026	$11.27	$7.92	$19.19
2027	$11.09	$7.97	$19.07
2028	$10.92	$8.02	$18.94
2029	$10.74	$8.07	$18.82
2030	$10.57	$8.12	$18.69
2031	$10.57	$8.12	$18.69
2032	$10.57	$8.12	$18.69
2033	$10.57	$8.12	$18.69
2034	$10.57	$8.12	$18.69
2035	$10.57	$8.12	$18.69
2036	$10.57	$8.12	$18.69
2037	$10.57	$8.12	$18.69
2038	$10.57	$8.12	$18.69
2039	$10.57	$8.12	$18.69
2040	$10.57	$8.12	$18.69

The total energy security benefits are derived from the estimated reductions in imports of finished petroleum products and crude oil using only the macroeconomic disruption/adjustment portion of the energy security premium price. These values are shown in Table 8-8.[439] The reduced oil estimates were derived from the OMEGA model, as explained in Chapter 5 of EPA's DRIA. EPA used the same assumption that NHTSA used in its Corporate Average Fuel Economy and CAFE Reform for MY 2008-2011 Light Trucks proposal, which assumed each gallon of fuel saved reduces total U.S. imports of crude oil or refined products by 0.95 gallons[440] . Section 5.3 of this RIA contains a discussion regarding caveats for the fuel savings estimated due to implementation of this rule. Section III.H.8.b of the preamble contains a detailed discussion of how the monopsony and macroeconomic disruption/adjustment components were treated for this analysis. Note that if the monopsony effects were included in this analysis, they could be significant.

Table 8-8 Total Annual Energy Security Benefits in 2015, 2020, 2030, and 2040 (Billions of 2007 dollars)

YEAR	BENEFITS
2015	\$0.59
2020	\$2.30
2030	\$4.81
2040	\$6.23

8.4 Other Externalities

There are other impacts associated with the proposed 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 proposed standards, but they are nevertheless important to include. We summarize the value of these other impacts in section 8.4.4 of this DRIA. Please refer to the draft joint TSD that accompanies this proposal for more information about these impacts and how EPA and NHTSA use them in their analyses.

8.4.1 Reduced Refueling Time

Improving the fuel economy of passenger cars and light-duty trucks may also increase their driving range before they require refueling. By reducing the frequency with which drivers typically refuel their vehicles and extending the upper limit of the range they can travel before requiring refueling, improving fuel economy provides some additional benefits to their owners. Alternatively, if manufacturers respond to improved fuel economy by reducing the size of fuel tanks to maintain a constant driving range, the resulting cost saving will presumably be reflected in lower vehicle sales prices. If manufacturers respond by doing so, this presumably reflects their judgment that the value to economic benefits to vehicle buyers from lower purchase prices exceeds that from extended refueling range.

No direct estimates of the value of extended vehicle range are readily available, so this analysis calculates the reduction in the annual number of required refueling cycles that results from improved fuel economy, and applies DOT-recommended values of travel time savings to convert the resulting time savings to their economic value.[441]

Weighted by the nationwide mix of urban (about 2/3) and rural (about 1/3) driving and average vehicle occupancy for all driving trips (1.6 persons), the DOT-recommended value of travel time per vehicle-hour is \$24.00 (in 2006 dollars). We assume that the average tank refill is 55%, that the average fuel tank is 19.3 gallons, and that the average time to find and use a gas station is five minutes.[442,443]

8.4.2 Value of Additional Driving

The increase in travel associated with the rebound effect produces additional benefits to vehicle owners, which reflect the value to drivers and other vehicle occupants of the added (or more desirable) social and economic opportunities that become accessible with additional travel. As evidenced by the fact that they elect to make more frequent or longer trips when the cost of driving declines, the benefits from this added travel exceed drivers' added outlays for the fuel it consumes (measured at the improved level of fuel economy resulting from stricter GHG standards).[444] The amount by which the benefits from this increased driving travel exceed its increased fuel costs measures the net benefits they receive from the additional travel, usually referred to as increased consumer surplus.

EPA estimates the economic value of the increased consumer surplus provided by added driving using the conventional approximation, which is one half of the product of the decline in vehicle operating costs per vehicle-mile and the resulting increase in the annual number of miles driven. Because it depends on the extent of improvement in fuel economy, the value of benefits from increased vehicle use changes by model year

We discuss the rebound effect in more detail in Chapter 4 of the draft joint TSD. Again, the negative effect that rebound driving has on the fuel consumption savings associated with the proposed GHG standards is included in the fuel economy savings presented in section 8.5 of this DRIA. Note that in section 8.4.4 below, where we present the benefit associated with rebound driving, we have used pre-tax fuel prices since those prices reflect the societal value of the driving.

8.4.3 Noise, Congestion, and Accidents

Although it provides some benefits to drivers, increased vehicle use associated with the rebound effect also contributes to increased traffic congestion, motor vehicle accidents, and highway noise. Depending on how the additional travel is distributed over the day and on where it takes place, additional vehicle use can contribute to traffic congestion and delays by increasing traffic volumes on facilities that are already heavily traveled during peak periods. These added delays impose higher costs on drivers and other vehicle occupants in the form of increased travel time and operating expenses. Because drivers do not take these added costs into account in deciding when and where to travel, they must be accounted for separately as a cost of the added driving associated with the rebound effect.

Increased vehicle use due to the rebound effect may also increase the costs associated with traffic accidents. Drivers may take account of the potential costs they (and their passengers) face from the possibility of being involved in an accident when they decide to make additional trips. However, they probably do not consider all of the potential costs they impose on occupants of other vehicles and on pedestrians when accidents occur, so any increase in these "external" accident costs must be considered as another cost of additional rebound-effect driving. Like increased delay costs, any increase in these external accident costs caused by added driving is likely to depend on the traffic conditions under which it takes place, since accidents are more frequent in heavier traffic (although their severity may be reduced by the slower speeds at which heavier traffic typically moves).

Finally, added vehicle use from the rebound effect may also increase traffic noise. Noise generated by vehicles causes inconvenience, irritation, and potentially even discomfort to occupants of other vehicles, to pedestrians and other bystanders, and to residents or occupants of surrounding property. Because these effects are unlikely to be taken into account by the drivers whose vehicles contribute to traffic noise, they represent additional externalities associated with motor vehicle use. Although there is considerable uncertainty in measuring their value, any increase in the economic costs of traffic noise resulting from added vehicle use must be included together with other increased external costs from the rebound effect.

EPA relies on estimates of congestion, accident, and noise costs caused by automobiles and light trucks developed by the Federal Highway Administration to estimate the increased external costs caused by added driving due to the rebound effect.[445] NHTSA employed these estimates previously in its analysis accompanying the MY 2011 final rule, and continues to find them appropriate for this analysis after reviewing the procedures used by FHWA to develop them and considering other available estimates of these values. They are intended to measure the increases in costs from added congestion, property damages and injuries in traffic accidents, and noise levels caused by automobiles and light trucks that are borne by persons other than their drivers (or “marginal” external costs).

Updated to 2007 dollars, FHWA’s “Middle” estimates for marginal congestion, accident, and noise costs caused by automobile use amount to 5.2 cents, 2.3 cents, and 0.1 cents per vehicle-mile (for a total of 7.6 cents per mile), while those for pickup trucks and vans are 4.7 cents, 2.5 cents, and 0.1 cents per vehicle-mile (for a total of 7.3 cents per mile).[446, 447] These costs are multiplied by the annual increases in automobile and light truck use from the rebound effect to yield the estimated increases in congestion, accident, and noise externality costs during each future year.

EPA uses a single value for both cars and trucks, as shown in Table 8-9.

Table 8-9 $/mile Inputs used for External Costs

EXTERNAL COSTS	$/VMT
Congestion	$ 0.052
Accidents	$ 0.023
Noise	$ 0.001

8.4.4 Summary of Other Externalities

Table 8-10 summarizes the other economic impacts discussed in sections 8.4.1 through 8.4.3.

Table 8-10. Estimated Economic Externalities Associated with the Proposed Light-Duty Vehicle GHG Program (Millions of 2007 dollars)

YEAR	REDUCED REFUELING	VALUE OF INCREASED DRIVING	ACCIDENTS, NOISE, CONGESTION	ANNUAL QUANTIFIED BENEFITS
2012	$100	$100	-$100	$200
2013	$200	$400	-$200	$400
2014	$500	$700	-$400	$800
2015	$700	$1,200	-$700	$1,300
2016	$1,100	$2,000	-$1,100	$2,000
2017	$1,500	$2,700	-$1,400	$2,800
2018	$1,800	$3,400	-$1,800	$3,500
2019	$2,200	$4,200	-$2,100	$4,200
2020	$2,500	$4,900	-$2,400	$5,000
2021	$2,800	$5,500	-$2,700	$5,600
2022	$3,100	$6,100	-$3,000	$6,200
2023	$3,400	$6,700	-$3,300	$6,800
2024	$3,700	$7,200	-$3,600	$7,300
2025	$3,900	$7,700	-$3,900	$7,800
2026	$4,200	$8,200	-$4,100	$8,300
2027	$4,400	$8,600	-$4,300	$8,700
2028	$4,600	$9,100	-$4,500	$9,200
2029	$4,800	$9,800	-$4,700	$9,800
2030	$4,900	$10,000	-$4,900	$10,000
2031	$5,100	$10,400	-$5,000	$10,400
2032	$5,200	$10,700	-$5,200	$10,800
2033	$5,400	$11,100	-$5,300	$11,100
2034	$5,500	$11,400	-$5,500	$11,500
2035	$5,700	$11,800	-$5,600	$11,800
2036	$5,800	$12,100	-$5,800	$12,200
2037	$6,000	$12,500	-$5,900	$12,600
2038	$6,100	$12,900	-$6,000	$12,900
2039	$6,200	$13,200	-$6,200	$13,300
2040	$6,400	$13,600	-$6,300	$13,700
2041	$6,500	$14,000	-$6,500	$14,100
2042	$6,700	$14,400	-$6,600	$14,500
2043	$6,800	$14,800	-$6,800	$14,900
2044	$7,000	$15,200	-$6,900	$15,300
2045	$7,200	$15,700	-$7,100	$15,700
2046	$7,300	$16,100	-$7,200	$16,200
2047	$7,500	$16,600	-$7,400	$16,700
2048	$7,700	$17,000	-$7,600	$17,100
2049	$7,800	$17,500	-$7,800	$17,600
2050	$8,000	$18,000	-$7,900	$18,100
NPV, 3%	$89,600	$184,700	-$88,200	$186,100
NPV, 7%	$41,000	$82,700	-$40,200	$83,500

8.5 Summary of Costs and Benefits

In this section we present a summary of costs, benefits, and net benefits of the proposal. We present fuel consumption impacts as negative costs of the vehicle program.

Table 8-11 shows the estimated annual societal costs of the vehicle 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 a 3 percent and a seven percent discount rate. In this table, fuel savings are calculated using pre-tax fuel prices and are presented as negative costs associated with the vehicle program (rather than positive savings).

Table 8-11 Estimated Societal Costs of the Light-Duty Vehicle GHG Program (Millions of 2007 dollars)

COSTS	2020	2030	2040	2050	NPV, 3%	NPV, 7%
Vehicle Compliance Costs	$18,000	$17,900	$19,300	$20,900	$390,000	$216,600
Fuel Savings [a]	-$43,100	-$90,400	-$125,000	-$167,000	-$1,677,600	-$746,100
Quantified Annual Costs	-$25,100	-$72,500	-$105,700	-$146,100	-$1,287,600	-$529,500

[a] Calculated using pre-tax fuel prices.

Table 8-12 presents estimated annual societal 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 a 3 percent and a 7 percent discount rate. The table shows the benefits of reduced GHG emissions—and consequently the annual quantified benefits (i.e., total benefits)—for each of five interim SCC values considered by EPA.

The interim SCC values are derived using several discount rates and include:

- $5 (based on a 5% discount rate);
- $10 (5% using Newell-Pizer adjustment);,
- $20 (average SCC value from the average SCC estimates based on 5% and 3%);
- $34 (3%);
- $56 (3% using Newell-Pizer adjustment).

These interim SCC values are in 2007 dollars, and are based on a CO_2 emissions change of 1 metric ton in 2007. Section III.H.2.a of the Preamble provides a complete discussion about SCC and the interim set of values.

Section III.H.2.a of the preamble to this rule also notes that there is a very high probability (very likely according to the IPCC) that the benefit estimates from GHG reductions are underestimates. One of the primary reasons is that models used to calculate SCC values do not include information about impacts that have not been quantified.

In addition, the total GHG reduction benefits presented below likely underestimate the value of GHG reductions because they were calculated using the marginal values for CO_2 emissions. The impacts of non-CO_2 emissions vary from those of CO_2 emissions because of differences in atmospheric lifetimes and radiative forcing. As a result, the marginal benefit values of non-CO_2 GHG reductions and their growth rates over time will not be the same as the marginal benefits measured on a CO_2–equivalent scale. Marginal benefit estimates per metric ton of non- CO_2 GHGs are currently unavailable, but work is on-going to monetize benefits related to the mitigation of other non-CO_2 GHGs.

Table 8-12 Use Estimated Societal Benefits Associated with the Proposed Light-Duty Vehicle GHG Program (Millions of 2007 dollars)

BENEFITS	2020	2030	2040	2050	NPV, 3%	NPV, 7%
Reduced GHG Emissions at each assumed SCC value						
SCC 5%	$1,200	$3,300	$5,700	$9,500	$69,200	$28,600
SCC 5% Newell-Pizer	$2,500	$6,600	$11,000	$19,000	$138,400	$57,100
SCC from 3% and 5%	$4,700	$12,000	$22,000	$36,000	$263,000	$108,500
SCC 3%	$8,200	$22,000	$38,000	$63,000	$456,900	$188,500
SCC 3% Newell-Pizer	$14,000	$36,000	$63,000	$100,000	$761,400	$314,200
$PM_{2.5}$ Related Benefits[a,b,c]	$1,400	$3,000	$4,600	$6,700	$59,800	$26,300
Energy Security Impacts (price shock)	$2,300	$4,800	$6,200	$7,800	$85,800	$38,800
Reduced Refueling	$2,500	$4,900	$6,400	$8,000	$89,600	$41,000
Value of Increased Driving[d]	$4,900	$10,000	$13,600	$18,000	$184,700	$82,700
Accidents, Noise, Congestion	-$2,400	-$4,900	-$6,300	-$7,900	-$88,200	-$40,200
Quantified Annual Benefits at each assumed SCC value						
SCC 5%	$9,900	$21,100	$30,200	$42,100	$400,900	$177,200
SCC 5% Newell-Pizer	$11,200	$24,400	$35,500	$51,600	$470,100	$205,700
SCC from 3% and 5%	$13,400	$29,800	$46,500	$68,600	$594,700	$257,100
SCC 3%	$16,900	$39,800	$62,500	$95,600	$788,600	$337,100
SCC 3% Newell-Pizer	$22,700	$53,800	$87,500	$132,600	$1,093,100	$462,800

[a] Note that the co-pollutant impacts associated with the 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 PM2.5 exposure. Ideally, human health and environmental benefits would be based on changes in ambient PM2.5 and ozone as determined by full-scale air quality modeling. However, we were 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.

[b] The PM2.5-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). If the benefit-per-ton estimates were based on the Six Cities study (Laden et al., 2006), the values would be approximately 145% (nearly two-and-a-half times) larger

[c] The PM2.5-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.

[d] Calculated using pre-tax fuel prices.

Table 8-13 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 a 3 percent and a 7 percent discount rate. The table includes the benefits of reduced GHG emissions—and consequently the annual net benefits—for each of five interim SCC values considered by EPA. As noted above, there is a very high probability (very likely according to the IPCC) that the benefit estimates from GHG reductions are underestimates because, in part, models used to calculate SCC values do not include information about impacts that have not been quantified.

Table 8-13. Quantified Net Benefits Associated with the Proposed Light-Duty Vehicle GHG Program[a, b]

(Millions of 2007 dollars)

	2020	2030	2040	2050	NPV, 3%	NPV, 7%
Quantified Annual Costs	-$25,100	-$72,500	-$105,700	-$146,100	-$1,287,600	-$529,500
Quantified Annual Benefits at each assumed SCC value						
SCC 5%	$9,900	$21,100	$30,200	$42,100	$400,900	$177,200
SCC 5% Newell-Pizer	$11,200	$24,400	$35,500	$51,600	$470,100	$205,700
SCC from 3% and 5%	$13,400	$29,800	$46,500	$68,600	$594,700	$257,100
SCC 3%	$16,900	$39,800	$62,500	$95,600	$788,600	$337,100
SCC 3% Newell-Pizer	$22,700	$53,800	$87,500	$132,600	$1,093,100	$462,800
Quantified Net Benefits at each assumed SCC value						
SCC 5%	$35,000	$93,600	$135,900	$188,200	$1,688,500	$706,700
SCC 5% Newell-Pizer	$36,300	$96,900	$141,200	$197,700	$1,757,700	$735,200
SCC from 3% and 5%	$38,500	$102,300	$152,200	$214,700	$1,882,300	$786,600
SCC 3%	$42,000	$112,300	$168,200	$241,700	$2,076,200	$866,600
SCC 3% Newell-Pizer	$47,800	$126,300	$193,200	$278,700	$2,380,700	$992,300

[a] Note that the co-pollutant impacts associated with the 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 PM2.5 exposure. Ideally, human health and environmental benefits would be based on changes in ambient PM2.5 and ozone as determined by full-scale air quality modeling. However, we were 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.

[b] Fuel impacts were calculated using pre-tax fuel prices.

EPA also conducted a separate analysis of the total benefits over the model year lifetimes of the 2012 through 2016 model year vehicles. In contrast to the calendar year analysis, the model year lifetime analysis shows the lifetime impacts of the program on each of these MY fleets over the course of its lifetime. Full details of the inputs to this analysis can be found in DRIA chapter 5. The societal benefits of the full life of each of the five model years from 2012 through 2016 are shown in Table 8-14 and Table 8-15 at both a 3 percent and a 7 percent discount rate, respectively. The net benefits are shown in Table 8-16 and Table 8-17 for both a 3 percent and a 7 percent discount rate, respectively. Note that the quantified annual benefits shown in Table 8-14 and Table 8-15include fuel savings as a positive benefit. As such, the quantified annual costs as shown in Table 8-16 and Table 8-17 do not include fuel savings since those are included as benefits. Also note that Table 8-14 through Table 8-17 include the benefits of reduced CO_2 emissions—and consequently the total benefits—for each of five interim SCC values considered by EPA. As noted above, there is a very high probability (*very likely* according to the IPCC) that the benefit estimates from GHG reductions are underestimates because, in part, models used to calculate SCC values do not include information about impacts that have not been quantified.

Table 8-14 Estimated Societal Benefits Associated with the Proposed Light-Duty Vehicle GHG Program, Model Year Analysis (Millions of 2007 dollars; 3% Discount Rate)

MONETIZED VALUES	2012MY	2013MY	2014MY	2015MY	2016MY	SUM
Cost of Noise, Accident, Congestion ($)	-$900	-$1,400	-$1,900	-$2,800	-$3,900	-$11,000
Pretax Fuel Savings ($)	$15,600	$24,400	$34,800	$49,800	$68,500	$193,300
Energy Security ($) (price shock)	$400	$600	$900	$1,200	$1,600	$4,700
Change in no. of Refueling (#)	500	700	1,000	1,300	1,800	5,300
Change in Refueling Time (hours)	0	100	100	100	200	400
Value of Reduced Refueling time ($)	$900	$1,400	$1,900	$2,700	$3,700	$10,500
Value of Additional Driving ($)	$2,000	$3,000	$4,100	$5,700	$7,900	$22,700
Value of $PM_{2.5}$ related Health Impacts ($)[a,b,c]	$600	$900	$1,200	$1,700	$2,200	$6,600
Social Cost of Carbon (SCC) at each assumed SCC value						
SCC 5%	$500	$700	$1,000	$1,400	$1,900	$5,600
SCC 5% Newell-Pizer	$1,000	$1,500	$2,000	$2,900	$3,800	$11,000
SCC from 3% and 5%	$1,800	$2,800	$3,900	$5,400	$7,200	$21,000
SCC 3%	$3,200	$4,800	$6,700	$9,400	$13,000	$37,000
SCC 3% Newell-Pizer	$5,300	$8,100	$11,000	$16,000	$21,000	$61,000
Total Benefits at each assumed SCC value						
SCC 5%	$19,100	$29,600	$42,000	$59,700	$81,900	$232,400
SCC 5% Newell-Pizer	$19,600	$30,400	$43,000	$61,200	$83,800	$237,800
SCC from 3% and 5%	$20,400	$31,700	$44,900	$63,700	$87,200	$247,800
SCC 3%	$21,800	$33,700	$47,700	$67,700	$93,000	$263,800
SCC 3% Newell-Pizer	$23,900	$37,000	$52,000	$74,300	$101,000	$287,800

[a] Note that the co-pollutant impacts associated with the 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 PM2.5 exposure. Ideally, human health and environmental benefits would be based on changes in ambient PM2.5 and ozone as determined by full-scale air quality modeling. However, we were 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.

[b] The PM2.5-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). If the benefit-per-ton estimates were based on the Six Cities study (Laden et al., 2006), the values would be approximately 145% (nearly two-and-a-half times) larger.

[c] The PM2.5-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.

Table 8-15. Estimated Societal Benefits Associated with the Proposed Light-Duty Vehicle GHG Program, Model Year Analysis (Millions of 2007 dollars; 7% Discount Rate)

MONETIZED VALUES	2012MY	2013MY	2014MY	2015MY	2016MY	SUM
Cost of Noise, Accident, Congestion ($)	-$700	-$1,100	-$1,500	-$2,200	-$3,100	-$8,700
Pretax Fuel Savings ($)	$12,100	$19,000	$27,200	$39,000	$53,700	$150,900
Energy Security ($) (price shock)	$300	$500	$700	$900	$1,300	$3,700
Change in no. of Refueling (#)	400	500	800	1,100	1,500	4,200
Change in Refueling Time (hours)	0	0	100	100	100	300
Value of Reduced Refueling time ($)	$700	$1,100	$1,500	$2,100	$2,900	$8,300
Value of Additional Driving ($)	$1,500	$2,400	$3,200	$4,500	$6,300	$18,000
Value of $PM_{2.5}$ related Health Impacts ($)[a,b,c]	$500	$700	$1,000	$1,300	$1,800	$5,300
Social Cost of Carbon (SCC) at each assumed SCC value						
SCC 5%	$400	$500	$700	$1,000	$1,300	$3,900
SCC 5% Newell-Pizer	$700	$1,100	$1,500	$2,000	$2,500	$7,700
SCC from 3% and 5%	$1,400	$2,100	$2,800	$3,700	$4,800	$15,000
SCC 3%	$2,400	$3,600	$4,800	$6,500	$8,300	$26,000
SCC 3% Newell-Pizer	$4,000	$6,000	$8,000	$11,000	$14,000	$43,000
Total Benefits at each assumed SCC value						
SCC 5%	$14,800	$23,100	$32,800	$46,600	$64,200	$181,400
SCC 5% Newell-Pizer	$15,100	$23,700	$33,600	$47,600	$65,400	$185,200
SCC from 3% and 5%	$15,800	$24,700	$34,900	$49,300	$67,700	$192,500
SCC 3%	$16,800	$26,200	$36,900	$52,100	$71,200	$203,500
SCC 3% Newell-Pizer	$18,400	$28,600	$40,100	$56,600	$76,900	$220,500

[a] Note that the co-pollutant impacts associated with the 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 PM2.5 exposure. Ideally, human health and environmental benefits would be based on changes in ambient PM2.5 and ozone as determined by full-scale air quality modeling. However, we were 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.

[b] The PM2.5-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). If the benefit-per-ton estimates were based on the Six Cities study (Laden et al., 2006), the values would be approximately 145% (nearly two-and-a-half times) larger.

[c] The PM2.5-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.

Table 8-16. Quantified Net Benefits Associated with the Proposed Light-Duty Vehicle GHG Program, Model Year Analysis[a] (Millions of 2007 dollars; 3% Discount Rate)

	2012MY	2013MY	2014MY	2015MY	2016MY	SUM
Quantified Annual Costs (excluding fuel savings)	$5,400	$8,400	$10,900	$13,900	$17,500	$56,100
Quantified Annual Benefits at each assumed SCC value						
SCC 5%	$19,100	$29,600	$42,000	$59,700	$81,900	$232,400
SCC 5% Newell-Pizer	$19,600	$30,400	$43,000	$61,200	$83,800	$237,800
SCC from 3% and 5%	$20,400	$31,700	$44,900	$63,700	$87,200	$247,800
SCC 3%	$21,800	$33,700	$47,700	$67,700	$93,000	$263,800
SCC 3% Newell-Pizer	$23,900	$37,000	$52,000	$74,300	$101,000	$287,800
Quantified Net Benefits at each assumed SCC value						
SCC 5%	$13,700	$21,200	$31,100	$45,800	$64,400	$176,300
SCC 5% Newell-Pizer	$14,200	$22,000	$32,100	$47,300	$66,300	$181,700
SCC from 3% and 5%	$15,000	$23,300	$34,000	$49,800	$69,700	$191,700
SCC 3%	$16,400	$25,300	$36,800	$53,800	$75,500	$207,700
SCC 3% Newell-Pizer	$18,500	$28,600	$41,100	$60,400	$83,500	$231,700

[a] Note that the co-pollutant impacts associated with the 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 PM2.5 exposure. Ideally, human health and environmental benefits would be based on changes in ambient PM2.5 and ozone as determined by full-scale air quality modeling. However, we were 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.

Table 8-17. Quantified Net Benefits Associated with the Proposed Light-Duty Vehicle GHG Program, Model Year Analysis[a] (Millions of 2007 dollars; 7% Discount Rate)

	2012MY	2013MY	2014MY	2015MY	2016MY	SUM
Quantified Annual Costs (excluding fuel savings)	$5,400	$8,400	$10,900	$13,900	$17,500	$56,100
Quantified Annual Benefits at each assumed SCC value						
SCC 5%	$14,800	$23,100	$32,800	$46,600	$64,200	$181,400
SCC 5% Newell-Pizer	$15,100	$23,700	$33,600	$47,600	$65,400	$185,200
SCC from 3% and 5%	$15,800	$24,700	$34,900	$49,300	$67,700	$192,500
SCC 3%	$16,800	$26,200	$36,900	$52,100	$71,200	$203,500
SCC 3% Newell-Pizer	$18,400	$28,600	$40,100	$56,600	$76,900	$220,500
Quantified Net Benefits at each assumed SCC value						
SCC 5%	$9,400	$14,700	$21,900	$32,700	$46,700	$125,300
SCC 5% Newell-Pizer	$9,700	$15,300	$22,700	$33,700	$47,900	$129,100
SCC from 3% and 5%	$10,400	$16,300	$24,000	$35,400	$50,200	$136,400
SCC 3%	$11,400	$17,800	$26,000	$38,200	$53,700	$147,400
SCC 3% Newell-Pizer	$13,000	$20,200	$29,200	$42,700	$59,400	$164,400

[a] Note that the co-pollutant impacts associated with the 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 PM2.5 exposure. Ideally, human health and environmental benefits would be based on changes in ambient PM2.5 and ozone as determined by full-scale air quality modeling. However, we were 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.

References

All references can be found in the EPA DOCKET: EPA-HQ-OAR-2009-0472.

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[385] See, for instance, Gron, Ann, and Deborah Swenson, 2000. "Cost Pass-Through in the U.S. Automobile Market," Review of Economics and Statistics 82: 316-324.

[386] Insurance Information Institute, 2008, "Average Expenditures for Auto Insurance By State, 2005-2006," http://www.iii.org/media/facts/statsbyissue/auto/, accessed April 23, 2009.

[387] U.S. Department of Energy, 2008, "Average Price of a New Car, 1970-2006," http://www1.eere.energy.gov/vehiclesandfuels/facts/2008_fotw520.html, accessed April 23, 2009.

[388] Solheim, Mark, 2006"State Car Tax Rankings," http://www.kiplinger.com/features/archives/2006/04/cartax.html, accessed April 23, 2009.

[389] U.S. Census Bureau, "Population, Population change and estimated components of population change: April 1, 2000 to July 1, 2008" (NST-EST2008-alldata), http://www.census.gov/popest/states/states.html, accessed April 23, 2009.

[390] http://auto-loan.interest.com, 8/24/09 at 9:20AM.

[391] Consumer Reports, August 2008,"What That Car Really Costs to Own," http://www.consumerreports.org/cro/cars/pricing/what-that-car-really-costs-to-own-4-08/overview/what-that-car-really-costs-to-own-ov.htm , accessed April 23, 2009.

[392] Kleit A.N., 1990, "The Effect of Annual Changes in Automobile Fuel Economy Standards," Journal of Regulatory Economics 2: 151-172; McCarthy, Patrick S., 1996. "Market Price and Income Elasticities of New Vehicle Demands." Review of Economics and Statistics 78: 543-547; Goldberg, Pinelopi K., 1998. "The Effects of the Corporate Average Fuel Efficiency Standards in the US," Journal of Industrial Economics 46(1): 1-33; Greene, David L., "Feebates, Footprints and Highway Safety," Transportation Research Part D 14 (2009): 375-384.

[393] Goldberg, Pinelopi Koujianou, "Product Differentiation and Oligopoly in International Markets: The Case of the U.S. Automobile Industry," Econometrica 63(4) (July 1995): 891-951; Goldberg, Pinelopi Koujianou, "The Effects of the Corporate Average Fuel Efficiency Standards in the US," Journal of Industrial Economics 46(1) (March 1998): 1-33.

[394] Greene, David L., K.G. Duleep, Doug Elliott, and Sanjana Ahmad, "A Fuel Economy Regulatory Analysis Model (FERAM) For the Energy Information Administration," prepared by the Oak Ridge National Laboratory for the U.S. Department of Energy under contract No. DE-AC0500OR22725, 2005; Greene, David L., Philip D. Patterson, Margaret Singh, and Jia Li, "Feebates, Rebates, and Gas-Guzzler Taxes: A Study of Incentives for Increased Fuel Economy," Energy Policy 33 (2005): 757-775.

[395] McManus, Walter M., "Can Proactive Fuel Economy Strategies Help Automakers Mitigate Fuel-Price Risks?" University of Michigan Transportation Research Institute, September 14, 2006.

[396] Berry, Steven, James Levinsohn, and Ariel Pakes, "Automobile Prices in Market Equilibrium," Econometrica 63(4) (July 1995): 841-940; Berry, Steven, James Levinsohn, and Ariel Pakes, "Differentiated Products Demand Systems from a Combination of Micro and Macro Data: The New Car Market," Journal of Political Economy 112(1) (2004): 68-105.

---

[397] Bento, Antonio M., Lawrence H. Goulder, Emeric Henry, Mark R. Jacobsen, and Roger H. von Haefen, "Distributional and Efficiency Impacts of Gasoline Taxes: An Econometrically Based Multi-Market Study," American Economic Review 95(2) (May 2005): 282-287.

[398] Train, Kenneth E., and Clifford Winston, "Vehicle Choice Behavior and the Declining Market Share of U.S. Automakers," International Economic Review 48(4) (November 2007): 1469-1496.

[399] Kleit, Andrew N., "Impacts of Long-Range Increases in the Fuel Economy (CAFE) Standard," Economic Inquiry 42(2) (April 2004): 279-294.

[400] Austin, David, and Terry Dinan, "Clearing the Air: The Costs and Consequences of Higher CAFE Standards and Increased Gasoline Taxes," Journal of Environmental Economics and Management 50 (2005): 562-582.

[401] E.g., Bento, Antonio M., Lawrence H. Goulder, Emeric Henry, Mark R. Jacobsen, and Roger H. von Haefen, "Distributional and Efficiency Impacts of Gasoline Taxes: An Econometrically Based Multi-Market Study," American Economic Review 95(2) (May 2005): 282-287; Train, Kenneth E., and Clifford Winston, "Vehicle Choice Behavior and the Declining Market Share of U.S. Automakers," International Economic Review 48(4) (November 2007): 1469-1496.

[402] E.g., Berry, Steven, James Levinsohn, and Ariel Pakes, "Automobile Prices in Market Equilibrium," Econometrica 63(4) (July 1995): 841-940.

[403] Greene, David L., K.G. Duleep, Doug Elliott, and Sanjana Ahmad, "A Fuel Economy Regulatory Analysis Model (FERAM) For the Energy Information Administration," prepared by the Oak Ridge National Laboratory for the U.S. Department of Energy under contract No. DE-AC0500OR22725, 2005.

[404] NERA Economic Consulting, "Evaluation of NHTSA's Benefit-Cost Analysis of 2011-2015 CAFE Standards," 2008, available at http://www.heartland.org/policybot/results/23495/Evaluation_of_NHTSAs_BenefitCost_Analysis_Of_20112015_CAFE_Standards.html.

[405] E.g., Train, Kenneth E., and Clifford Winston, "Vehicle Choice Behavior and the Declining Market Share of U.S. Automakers," International Economic Review 48(4) (November 2007): 1469-1496.

[406] E.g., Berry, Steven, James Levinsohn, and Ariel Pakes, "Automobile Prices in Market Equilibrium," Econometrica 63(4) (July 1995): 841-940.

[407] E.g., Bento, Antonio M., Lawrence H. Goulder, Emeric Henry, Mark R. Jacobsen, and Roger H. von Haefen, "Distributional and Efficiency Impacts of Gasoline Taxes: An Econometrically Based Multi-Market Study," American Economic Review 95(2) (May 2005): 282-287.

[408] Bento, Antonio M., Lawrence H. Goulder, Emeric Henry, Mark R. Jacobsen, and Roger H. von Haefen, "Distributional and Efficiency Impacts of Gasoline Taxes: An Econometrically Based Multi-Market Study," American Economic Review 95(2) (May 2005): 282-287; Feng, Yi, Don Fullerton, and Li Gan, "Vehicle Choices, Miles Driven and Pollution Policies," National Bureau of Economic Analysis Working Paper 11553, available at http://econweb.tamu.edu/gan/w11553.pdf , accessed 5/12/09.

[409] NERA Economic Consulting, "Appendix B: New Vehicle Market Model," "Impacts of the California Greenhouse Gas Emission Standards on Motor Vehicle Sales," comments submitted to the U.S. Environmental Protection Agency at Regulations.gov, document number EPA-HQ-OAR-2006-0173-9053.1.

[410] Berry, Steven, James Levinsohn, and Ariel Pakes, "Automobile Prices in Market Equilibrium," Econometrica 63(4) (July 1995): 841-940.

---

[411] Goldberg, Pinelopi Koujianou, "Product Differentiation and Oligopoly in International Markets: The Case of the U.S. Automobile Industry," Econometrica 63(4) (July 1995): 891-951.

[412] Brownstone, David, and Kenneth Train, "Forecasting New Product Penetration with Flexible Substitution Patterns," Journal of Econometrics 89 (1999): 109-129; Brownstone, David, David S. Bunch, and Kenneth Train, "Joint Mixed Logit Models of Stated and Revealed Preferences for Alternative-Fuel Vehicles," Transportation Research Part B 34 (2000): 315-338; Greene David L., "TAFV Alternative Fuels and Vehicles Choice Model Documentation," prepared by the Oak Ridge National Laboratory for the U.S. Department of Energy, July 2001; Greene, David L., K. G. Duleep, and Walter McManus, "Future Potential of Hybrid and Diesel Powertrains in the U.S. Light-Duty Vehicle Market," prepared by the Oak Ridge National Laboratory for the U.S. Department of Energy, August 2004.

[413] Petrin, Amil, "Quantifying the Benefits of New Products: The Case of the Minivan," Journal of Political Economy 110 (2002): 705-729; Berry, Steven, James Levinsohn, and Ariel Pakes, "Differentiated Products Demand Systems from a Combination of Micro and Macro Data: The New Car Market," Journal of Political Economy 112 (2004): 68-105.

[414] Train, Kenneth E., and Clifford Winston, "Vehicle Choice Behavior and the Declining Market Share of U.S. Automakers," International Economic Review 48 (November 2007): 1469-1496.

[415] Bento, Antonio M., Lawrence H. Goulder, Emeric Henry, Mark R. Jacobsen, and Roger H. von Haefen, "Distributional and Efficiency Impacts of Gasoline Taxes: An Econometrically Based Multi-Market Study," American Economic Review 95(2) (May 2005): 282-287; Feng, Yi, Don Fullerton, and Li Gan, "Vehicle Choices, Miles Driven and Pollution Policies," National Bureau of Economic Analysis Working Paper 11553, available at http://econweb.tamu.edu/gan/w11553.pdf , accessed 5/12/09.

[416] Greene, David L., Philip D. Patterson, Margaret Singh, and Jia Li, "Feebates, Rebates, and Gas-Guzzler Taxes: A Study of Incentives for Increased Fuel Economy," Energy Policy 33 (2005): 757-775; Feng, Yi, Don Fullerton, and Li Gan, "Vehicle Choices, Miles Driven and Pollution Policies," National Bureau of Economic Analysis Working Paper 11553, available at http://econweb.tamu.edu/gan/w11553.pdf , accessed 5/12/09; Greene, David L., "Feebates, Footprints and Highway Safety," Transportation Research Part D (2009) (in press).

[417] E.g., Austin, David, and Terry Dinan, "Clearing the Air: The Costs and Consequences of Higher CAFE Standards and Increased Gasoline Taxes," Journal of Environmental Economics and Management 50 (2005): 562-582.

[418] Turrentine, Thomas S., and Kenneth S. Kurani, "Car Buyers and Fuel Economy?" Energy Policy 35 (2007): 1213-1223.

[419] E.g., Espey, Molly, and Santosh Nair, 2005. "Automobile Fuel Economy: What Is It Worth?" Contemporary Economic Policy 23: 317-323.

[420] Larrick, Richard P., and Jack B. Soll, 2008. "The MPG Illusion," Science 320(5883): 1593-1594.

[421] E.g., Goldberg, Pinelopi Koujianou, "Product Differentiation and Oligopoly in International Markets: The Case of the U.S. Automobile Industry," Econometrica 63(4) (July 1995): 891-951.

[422] E.g., Berry, Steven, James Levinsohn, and Ariel Pakes, "Automobile Prices in Market Equilibrium," Econometrica 63(4) (July 1995): 841-940.

[423] Busse, Meghan, Christopher R. Knittel, and Florian Zettelmeyer, 2009. "Pain at the Pump: How Gasoline Prices Affect Automobile Purchasing in New and Used Markets," working paper, http://www.econ.ucdavis.edu/faculty/knittel/papers/gaspaper_latest.pdf (accessed 6/16/09).

---

[424] Greene, David L., and Jin-Tan Liu, 1988. “Automotive Fuel Economy Improvements and Consumers’ Surplus,” Transportation Research Part A 22A (3): 203-218.

[425] Goldberg, Pinelopi Koujianou, “Product Differentiation and Oligopoly in International Markets: The Case of the U.S. Automobile Industry,” Econometrica 63(4) (July 1995): 891-951; Berry, Steven, James Levinsohn, and Ariel Pakes, “Automobile Prices in Market Equilibrium,” Econometrica 63(4) (July 1995): 841-940.

[426] Gramlich, Jacob, “Gas Prices and Endogenous Product Selection in the U.S. Automobile Industry,” http://www.econ.yale.edu/seminars/apmicro/am08/gramlich-081216.pdf , accessed 5/11/09.

[427] Gramlich, Jacob, “Gas Prices and Endogenous Product Selection in the U.S. Automobile Industry,” http://www.econ.yale.edu/seminars/apmicro/am08/gramlich-081216.pdf , accessed 5/11/09.

[428] Espey, Molly, and Santosh Nair, 2005. “Automobile Fuel Economy: What Is It Worth?” Contemporary Economic Policy 23: 317-323.

[429] McManus, Walter, “Can Proactive Fuel Economy Strategies Help Automakers Mitigate Fuel-Price Risks?” Ann Arbor, MI: University of Michigan Transportation Research Institute; Munich Personal RePEc Archive Paper No. 3460, September 14, 2006; http://mpra.ub.uni-muenchen.de/3460/1/MPRA_paper_3460.pdf, accessed 6/16/09.

[430] Gramlich, Jacob, “Gas Prices and Endogenous Product Selection in the U.S. Automobile Industry,” http://www.econ.yale.edu/seminars/apmicro/am08/gramlich-081216.pdf , accessed 5/11/09.

[431] Gramlich, Jacob, “Gas Prices and Endogenous Product Selection in the U.S. Automobile Industry,” http://www.econ.yale.edu/seminars/apmicro/am08/gramlich-081216.pdf , accessed 5/11/09; McManus, Walter, 2007. “The Impact of Attribute-Based Corporate Average Fuel Economy (CAFE) Standards: Preliminary Results.” Ann Arbor, MI: University of Michigan Transportation Research Institute, Report No. UMTRI-2007-31.

[432] For instance, Kleit, Andrew N., “Impacts of Long-Range Increases in the Fuel Economy (CAFE) Standard,” Economic Inquiry 42(2) (April 2004): 279-294; Austin, David, and Terry Dinan, “Clearing the Air: The Costs and Consequences of Higher CAFE Standards and Increased Gasoline Taxes,” Journal of Environmental Economics and Management 50 (2005): 562-582; Klier, Thomas, and Joshua Linn, 2008. “New Vehicle Characteristics and the Cost of the Corporate Average Fuel Economy Standard,” Federal Reserve Bank of Chicago WP 2008-13, at http://www.chicagofed.org/publications/workingpapers/wp2008_13.pdf (accessed 5/6/09); Jacobsen, Mark, 2008. “Evaluating U.S. Fuel Economy Standards in a Model with Producer and Household Heterogeneity,” working paper, at http://econ.ucsd.edu/~m3jacobs/Jacobsen_CAFE.pdf (accessed 5/6/09).

[433] Austin, David, and Terry Dinan, “Clearing the Air: The Costs and Consequences of Higher CAFE Standards and Increased Gasoline Taxes,” Journal of Environmental Economics and Management 50 (2005): 562-582.

[434] IEA. 2007. “Mind the Gap: Quantifying Principal-Agent Problems in Energy Efficiency.” Paris, France: International Energy Agency; Jaffe, Adam B., Richard G. Newell, and Robert N. Stavins (2001). "Energy Efficient Technologies and Climate Change Policies: Issues and Evidence." In *Climate Change Economics and Policy*, Toman, Michael A., ed., Washington, D.C.: Resources for the Future. p.171-181; Metcalf, Gilbert E., and Kevin A. Hassett (1999). "Measuring the Energy Savings From Home Improvement Investments: Evidence From Monthly Billing Data." *The Review of Economics and Statistics* 81(3): 516-528; Tietenberg, T. (2009). “Reflections – Energy Efficiency Policy: Pipe Dream or Pipeline to the Future?” Review of Environmental Economics and Policy. Vol.3, 2: 304-320.

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[435] Welch, David. "CAFE: A Prize for Making Gas-Guzzlers?" Business Week April 16, 2009, http://www.businessweek.com/magazine/content/09_17/b4128048030307.htm?chan=magazine+channel_what's+next , accessed 7/7/09.

[436] Berry, Steven, James Levinsohn, and Ariel Pakes (July 1995). "Automobile Prices in Market Equilibrium," Econometrica 63(4): 841-940.

[437] Greene, David L., Philip D. Patterson, Margaret Singh, and Jia Li, "Feebates, Rebates, and Gas-Guzzler Taxes: A Study of Incentives for Increased Fuel Economy," Energy Policy 33 (2005): 757-775.

[438] *Peer Review Report Summary: Estimating the Energy Security Benefits of Reduced U.S. Oil Imports*, ICF, Inc., September 2007.

[439] Estimated reductions in imports of finished petroleum products and crude oil are 95% of 108 MMB in 2015, 353MMB in 2020, 637MMB in 2030,and 740MMB in 2040.

[440] Preliminary Regulatory Impacts Analysis, April 2008. Based on a detailed analysis of differences in fuel consumption, petroleum imports, and imports of refined petroleum products among the Reference Case, High Economic Growth, and Low Economic Growth Scenarios presented in the Energy Information Administration's Annual Energy Outlook 2007, NHTSA estimated that approximately 50 percent of the reduction in fuel consumption is likely to be reflected in reduced U.S. imports of refined fuel, while the remaining 50 percent would be expected to be reflected in reduced domestic fuel refining. Of this latter figure, 90 percent is anticipated to reduce U.S. imports of crude petroleum for use as a refinery feedstock, while the remaining 10 percent is expected to reduce U.S. domestic production of crude petroleum. Thus on balance, each gallon of fuel saved is anticipated to reduc total U.S. imports of crude petroleum or refined fuel by 0.95 gallons..

[441] See http://ostpxweb.dot.gov/policy/Data/VOT97guid.pdf and http://ostpxweb.dot.gov/policy/Data/VOTrevision1_2-11-03.pdf

[442] California Environmental Protection Agency, Air Resources Board. Draft Assessment of the Real-World Impacts of Commingling California Phase 3 Reformulated Gasoline. August 2003

[443] The 19.3 gallon average tank size is from EPA calculations conducted on the Volpe Model Market Data file used in NHTSA's Model Year 2011 CAFE Standards Final Rule.

[444] These benefits are included in the value of fuel savings reported in Tables VIII-5 through VIII-9.

[445] These estimates were developed by FHWA for use in its 1997 *Federal Highway Cost Allocation Study*; *see* http://www.fhwa.dot.gov/policy/hcas/final/index.htm (last accessed July 29, 2009).

[446] *See* Federal Highway Administration, 1997 *Federal Highway Cost Allocation Study*, http://www.fhwa.dot.gov/policy/hcas/final/index.htm, Tables V-22, V-23, and V-24 (last accessed July 27, 2009).

[447] The Federal Highway Administration's estimates of these costs agree closely with some other recent estimates. For example, recent published research conducted by Resources for the Future (RFF) estimates marginal congestion and external accident costs for increased light-duty vehicle use in the U.S. to be 3.5 and 3.0 cents per vehicle-mile in year-2002 dollars. *See* Ian W.H. Parry and Kenneth A. Small, "Does Britain or the U.S. Have the Right Gasoline Tax?" Discussion Paper 02-12, Resources for the Future, 19 and Table 1 (March 2002). *Available at* http://www.rff.org/rff/Documents/RFF-DP-02-12.pdf (last accessed July 27, 2009).

CHAPTER 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, unless the agency certifies that the rule will not have a significant economic impact on a substantial number of small entities. As a part of this analysis, an agency is directed to convene a Small Business Advocacy Review Panel (SBAR Panel or 'the Panel'). During the Panel process, we would gather information and recommendations from Small Entity Representatives (SERs) on how to reduce the impact of the rule on small entities.

The following 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 proposed 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); (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 provides an overview of the primary SBA small business categories potentially affected by this proposed regulation.

Table 9-1: Primary Vehicle SBA Small Business Categories

	NAICS[a] Codes	Defined by SBA As a small business if less than or equal to :[b]
Light-duty vehicle manufacturers	336111	1,000 employees.
Vehicle importers	81111, 811112	$7 million annual sales.
Alternative fuel vehicle converters	811198	$7 million annual sales.

a. North American Industry Classification System

b. According to SBA's regulations (13 CFR 121), businesses with no more than the listed number of employees or dollars in annual receipts are considered "small entities" for RFA purposes.

We compiled a list of vehicle manufacturers, independent commercial importers (ICIs), and alternative fuel converters that would be potentially affected by the proposed rule from our 2008 model year certification databases. These companies are already certifying their vehicles for compliance with applicable EPA emissions standards (e.g., Tier 2). We then identified companies that appear to meet the definition of small business provided in the table above. We were able to identify companies based on certification information and previous rulemakings where we conducted Regulatory Flexibility Analyses.

Based on a preliminary assessment, EPA has identified a total of about 47 vehicle entities, 33 of which are vehicle manufacturers. Of a total of 33 manufacturers, 2 manufacturers fit the SBA definition of a small entity. These businesses produce vehicles for small niche markets, and all of these entities manufacture limited production, high performance cars. 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). There are currently eight ICIs, all of which are small entities. 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 small 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. We identified six alternative fuel converters in the light-duty vehicle market, and three of these would qualify as small entities under SBA's definition. Together, we estimate that small entities comprise less than 0.1 percent of total annual vehicle sales and deferring standards for them will have a negligible impact on the GHG emissions reductions from the proposed standards.

EPA has not conducted a Regulatory Flexibility Analysis or a SBREFA SBAR Panel for the proposed rule because we are proposing to certify that the rule would not have a significant economic impact on a substantial number of small entities. EPA is proposing to defer standards for manufacturers meeting SBA's definition of small business as described in 13 CFR 121.201. EPA would instead consider appropriate GHG standards for these entities as part of a future regulatory action. This includes small entities in three distinct categories of businesses for light-duty vehicles: small volume manufacturers, independent commercial importers (ICIs), and alternative fuel vehicle converters. EPA has identified about 13 entities that fit the Small Business Administration (SBA) criterion of a small business. EPA estimates that these small entities comprise less than 0.1 percent of the total light-duty vehicle sales in the U.S., and therefore the proposed deferment will have a negligible impact on the GHG emissions reductions from the proposed standards.

To ensure that EPA is aware of which companies would be deferred, EPA is proposing that such entities submit a declaration to EPA containing a detailed written description of how that manufacturer qualifies as a small entity under the provisions of 13 CFR 121.201. Small entities are currently covered by a number of EPA motor vehicle emission regulations, and they routinely submit information and data on an annual basis as part of their compliance responsibilities. Because such entities are not automatically exempted from other EPA regulations for light-duty vehicles and light-duty trucks, absent such a declaration, EPA would assume that the entity was subject to the greenhouse gas control requirements in this GHG proposal. The declaration would need to be submitted at time of vehicle emissions certification under the EPA Tier 2 program. EPA expects that the additional paperwork burden associated with completing and submitting a small entity declaration to gain deferral from the proposed GHG standards would be negligible and easily done in the context of other routine submittals to EPA. However, EPA has accounted for this cost with a nominal estimate included in the Information Collection Request completed under the Paperwork Reduction Act. Additional information can be found in the Paperwork Reduction Act discussion in section III.I.2. Based on this, EPA is proposing to certify that the rule would not have a significant economic impact on a substantial number of small entities.