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

Regulatory Impact Analysis

United States
Environmental Protection
Agency

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Assessment and Standards Division
Office of Transportation and Air Quality
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EPA-420-R-10-009
April 2010

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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

Executive Summary

The Environmental Protection Agency (EPA) and the National Highway Traffic Safety Administration (NHTSA) are issuing a joint final rulemaking to establish new standards for light-duty highway vehicles that will reduce greenhouse gas emissions (GHG) and improve fuel economy. The joint 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 finalizing greenhouse gas emissions standards under the Clean Air Act, and NHTSA is finalizing Corporate Average Fuel Economy standards under the Energy Policy and Conservation Act (EPCA), as amended. These standards apply to passenger cars, light-duty trucks, and medium-duty passenger vehicles, covering model years (MY) 2012 through 2016. The standards will 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 National Program will result in approximately 960 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.

Mobile sources are significant contributors to air pollutant emissions (both GHG and non-GHG) across the country, internationally, and into the future. The Agency has determined that these emissions cause or contribute to air pollution which may reasonably be anticipated to endanger public health or welfare, and is therefore establishing standards to control these emissions as required by section 202 (a) of the Clean Air Act.[1] The health- and environmentally-related effects associated with these emissions are a classic example of an externality-related market failure. An externality occurs when one party's actions impose uncompensated costs on another party. EPA's final rule will deliver additional environmental and energy benefits, as well as cost savings, on a nationwide basis that would likely not be available if the rule were not in place.

Table 1 shows EPA's estimated lifetime discounted cost, benefits and net benefits for all vehicles projected to be sold in model years 2012-2016. It is important to note that there is significant overlap in costs and benefits for NHTSA's CAFE program and EPA's GHG program and therefore combined program costs and benefits are not a sum of the individual programs.

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[1] "Technical Support Document for Endangerment and Cause or Contribute Findings for Greenhouse Gases Under Section 202(a) of the Clean Air Act" Docket: EPA-HQ-OAR-2009-0472-11292, http://epa.gov/climatechange/endangerment.html. See also State of Massachusetts v. EPA, 549 U.S. 497, 533 ("If EPA makes a finding of endangerment, the Clean Air Act requires the agency to regulate emissions of the deleterious pollutant from new motor vehicles").

Table 1 EPA's Estimated 2012-2016 Model Year Lifetime Discounted Costs, Benefits, and Net Benefits assuming the $21/ton SCC Value[a,b,c,d] (Millions of 2007 dollars)

3% Discount Rate	
Costs	$51,500
Benefits	$240,200
Net Benefits	$188,700
7% Discount Rate	
Costs	$51,500
Benefits	$191,700
Net Benefits	$140,200

[a] As noted in Section III.H, SCC increases over time. The $21/ton value applies to 2010 CO2 emissions and grows larger over time.
[b] Although EPA estimated the benefits associated with four different values of a one ton GHG reduction ($5, $21, $35, $65), for the purposes of this overview presentation of estimated costs and benefits EPA is showing the benefits associated with the marginal value deemed to be central by the interagency working group on this topic: $21 per ton of CO2e, in 2007 dollars and 2010 emissions. The $21/ton value applies to 2010 CO2 emissions and grows over time.
[c] Note that net present value of reduced GHG emissions is calculated differently than other benefits. The same discount rate used to discount the value of damages from future emissions (SCC at 5, 3, and 2.5 percent) is used to calculate net present value of SCC for internal consistency. Refer to Section III.H for more detail.
[d] Monetized GHG benefits exclude the value of reductions in non-CO2 GHG emissions (HFC, CH4 and N2O) expected under this final rule. Although EPA has not monetized the benefits of reductions in these non-CO2 emissions, the value of these reductions should not be interpreted as zero. Rather, the reductions in non-CO2 GHGs will contribute to this rule's climate benefits, as explained in Section III.F.2. The SCC TSD notes the difference between the social cost of non-CO2 emissions and CO2 emissions, and specifies a goal to develop methods to value non-CO2 emissions in future analyses.

This Regulatory Impact Analysis (RIA) contains supporting documentation to the EPA rulemaking. NHTSA has prepared their own RIA in support of their rulemaking (this can be found in NHTSA's docket for the rulemaking, NHTSA-2009-0059). While the two rulemakings are similar, there are also differences in the analyses that require separate discussion. This is largely because EPA and NHTSA act under different statutes. EPA's authority comes under the Clean Air Act, and NHTSA's authority comes under EPCA, and 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 joint Technical Support Document (joint TSD can be found in EPA's docket EPA-HQ-OAR-2009-0472). Therefore, this RIA should be viewed as a companion document to the Joint TSD and the two documents together provide the details of EPA's technical analysis in support of its rulemaking.

While NHTSA and EPA each modeled their respective regulatory programs under the National Program, the analyses were generally consistent and featured similar parameters. EPA did not conduct an overall uncertainty analysis of the impacts associated with its regulatory program, though it did conduct uncertainty and sensitivity analyses of individual components of the analysis (e.g., uncertainty ranges associated with quantified and monetized non-GHG health impacts). NHTSA, however, conducted a Monte Carlo simulation of the uncertainty associated with its regulatory program. The focus of the simulation model was variation around the chosen uncertainty parameters and their resulting impact on the key output parameters, fuel savings, and net benefits. Among other parameters, NHTSA varied technology costs, technology effectiveness, fuel prices, the values of oil consumption externalities and the rebound effect. Because of the similarities between the two analyses, EPA references NHTSA RIA Chapter XII as indicative of the relative magnitude, uncertainty and sensitivities of parameters of the cost/benefit analysis.

This document contains the following;

Chapter 1: Technology Packages, Cost and Effectiveness. The details of the vehicle technology packages used as inputs to EPA's Optimization Model for Emissions of Greenhouse gases from Automobiles (OMEGA) are presented. These vehicle packages represent potential ways of meeting the CO2 stringency established by this rule and are the basis of the technology costs and effectiveness analyses discussed in Chapter 3 of the Joint TSD. This chapter also contains details on the lumped parameter model, which is a major part of EPA's determination of the effectiveness of these packages.

Chapter 2: Air Conditioning. EPA's unique air conditioning (A/C) program is discussed. Details for this chapter include the A/C credit program and the related technology costs and effectiveness associated with new A/C systems. The A/C credit program allows manufacturers to earn credit for both direct and indirect CO2eq emissions. Direct emission credits are earned through reducing refrigerant leakage (as the current refrigerant, R-134a, has a very high global warming potential) from the A/C system. The amount of direct emission, or leakage, credit that a manufacturer can earn is determined by using a design-based method to calculate the yearly refrigerant leakage from a vehicle's A/C system. This leakage value is then used to calculate a "grams-per-mile" credit, with allowances made for the global warming potential of the refrigerant. Indirect emission credits are earned through improving the efficiency of the A/C system, which reduces the amount of power required to operate the A/C system as well as the amount of CO2 emitted by the vehicle. The amount of indirect emission credit is determined by using a menu-based approach, where the inclusion of specific efficiency-improving components or design elements into a vehicle's A/C system results in an assigned credit value.

Chapter 3: Technical Basis of the Standards. This chapter contains two subchapters. In the first, EPA evaluates 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 RIA. In the second subchapter, EPA discusses an analysis of the "footprint" approach EPA is using for establishing standards.

Chapter 4: Results of Final and Alternative Standards. A conceptual overview of EPA's OMEGA model and technology cost results for the program and alternative standards considered. For each manufacturer, EPA estimates the following achieved fleetwide CO2 levels and technology costs over the reference case, see Table 2.

Table 2 Fleetwide Costs in 2016

	Fleetwide Cost
BMW	$ 1,453
Chrysler	$ 1,329
Ford	$ 1,231
Subaru	$ 899
General Motors	$ 1,219
Honda	$ 575
Hyundai	$ 745
Tata	$ 984
Kia	$ 594
Mazda	$ 808
Daimler	$ 1,343
Mitsubishi	$ 978
Nissan	$ 810
Porsche	$ 1,257
Suzuki	$ 937
Toyota	$ 455
Volkswagen	$ 1,694
Total	$ 948

Key results of the alternative stringencies analyzed are presented in Table 3:

Table 3 Key Results Per Reduction Scenarios of 4% and 6% Per Year

Reduction Scenarios	Industry achieved CO2 level (g/mi)	Average industry cost per vehicle
4% per year	256.9	$883
6% per year	236.1	$1,343

Chapter 5: Emissions Impacts. This chapter contains the greenhouse gas and non-greenhouse gas emission impacts of this rule and includes the impact of credits.

Greenhouse Emission Impacts of EPA's Rulemaking

Table 4 shows reductions estimated from EPA's GHG standards. The analyses assume a pre-control case of MY 2011 CAFE standards continuing indefinitely beyond 2011, and a post-control case in which MY 2016 standards continue indefinitely beyond 2016.

Including the reductions from upstream emissions (fuel production and transport), total reductions are estimated to reach 307 MMTCO_2eq (million metric tons of CO_2 equivalent emissions) annually by 2030 (equivalent to a 21 percent reduction in U.S. car and light truck emissions as compared to the reference scenario), and grow to over 500 MMTCO_2eq in 2050 as cleaner vehicles continue to come into the fleet (equivalent to a 23 percent reduction in U.S. car and light truck emissions relative to the control case that year).

Table 4. Projected Net GHG Reductions (MMT CO_2 Equivalent per year)

Calendar Year:	**2020**	**2030**	**2040**	**2050**
Net Reduction*	**156.4**	**307.0**	**401.5**	**505.9**
Net CO_2	*139.1*	*273.3*	*360.4*	*458.7*
Net other GHG	*17.3*	*33.7*	*41.1*	*47.2*
Downstream Reduction	**125.2**	**245.7**	**320.7**	**403.0**
CO_2 (excluding A/C)	*101.2*	*199.5*	*263.2*	*335.1*
A/C – indirect CO_2	*10.6*	*20.2*	*26.5*	*33.8*
A/C – direct HFCs	*13.3*	*26.0*	*30.9*	*34.2*
CH_4 (rebound effect)	*0.0*	*0.0*	*0.0*	*0.0*
N_2O (rebound effect)	*0.0*	*-0.1*	*-0.1*	*-0.1*
Upstream Reduction	**31.2**	**61.3**	**80.8**	**102.9**
CO_2	*27.2*	*53.5*	*70.6*	*89.9*
CH_4	*3.9*	*7.6*	*10.0*	*12.7*
N_2O	*0.1*	*0.3*	*0.3*	*0.4*

* includes impacts of 10% VMT rebound rate

Impacts of EPA's Rulemaking on Emissions of Criteria and Toxic Pollutants

The results of EPA's analyses on the impacts of the program on annual criteria emissions are listed in Table 5. For all criteria pollutants the overall impact of the program will be relatively small compared to total U.S. inventories across all sectors. In 2030, EPA estimates the program will reduce total NO_X, PM and SO_X inventories by 0.1 to 0.8 percent and reduce the VOC inventory by 1.0 percent, while increasing the total national CO inventory by 0.6 percent.

EPA estimates that the GHG program will result in small changes for toxic emissions compared to total U.S. inventories across all sectors, as listed in Table 6. In 2030, EPA estimates the program will reduce total benzene and 1,3 butadiene emissions by 0.1 to 0.3 percent. Total acrolein and formaldehyde emissions will increase by 0.1 percent. Acetaldehyde emissions will increase by 2.2 percent.

Table 5 Annual Criteria Emission Impacts of Program (short tons)

	Total Impacts		*Upstream Impacts*		*Downstream Impacts*	
	2020	**2030**	*2020*	*2030*	*2020*	*2030*
VOC	**-60,187**	**-115,542**	*-64,506*	*-126,749*	*4,318*	*11,207*
% of total inventory	**-0.51%**	**-1.01%**	*-0.55%*	*-1.11%*	*0.04%*	*0.01%*
CO	**3,992**	**170,675**	*-6,165*	*-12,113*	*10,156*	*182,788*
% of total inventory	**0.01%**	**0.56%**	*-0.02%*	*-0.04%*	*0.01%*	*0.6%*
NO_X	**-5,881**	**-21,763**	*-19,291*	*-37,905*	*13,410*	*16,143*
% of total inventory	**-0.02**	**-0.07%**	*-0.06%*	*-0.12%*	*0.04%*	*0.05%*
PM2.5	**-2,398**	**-4,564**	*-2,629*	*-5,165*	*231.0*	*602.3*
% of total inventory	**-0.03%**	**-0.05%**	*-0.03%*	*-0.06%*	*0.00%*	*0.01%*
SO_X	**-13,832**	**-27,443**	*-11,804*	*-23,194*	*-2,027*	*-4,249*
% of total inventory	**-0.41%**	**-0.82%**	*-0.35%*	*-0.69%*	*-0.06%*	*-0.13%*

Table 6. Annual Air Toxic Emission Impacts of Program (short tons)

	Total Impacts		*Upstream Impacts*		*Downstream Impacts*	
	2020	**2030**	*2020*	*2030*	*2020*	*2030*
1,3-Butadiene	**-95**	**-21**	*-1.5*	*-3.0*	*-93.6*	*-18.1*
% of total inventory	**-0.38%**	**-0.10%**	*-0.01%*	*-0.01%*	*-0.37%*	*-0.09%*
Acetaldehyde	**760**	**668**	*-6.8*	*-13.4*	*766.9*	*681.5*
% of total inventory	**2.26%**	**2.18%**	*-0.02%*	*-0.04%*	*2.28%*	*2.22%*
Acrolein	**1**	**5**	*-0.9*	*-1.8*	*1.7*	*6.5*
% of total inventory	**0.01%**	**0.07%**	*-0.01%*	*-0.03%*	*0.03%*	*0.10%*
Benzene	**-890**	**-523**	*-139.6*	*-274.3*	*-750.0*	*-248.3*
% of total inventory	**-0.48%**	**-0.29%**	*-0.08%*	*-0.15%*	*-0.40%*	*-0.14%*
Formaldehyde	**-49**	**15**	*-51.4*	*-101.0*	*2.1*	*116.3*
% of total inventory	**-0.06%**	**0.02%**	*-0.06%*	*-0.12%*	*0.00%*	*0.14%*

Chapter 6: Vehicle Program Costs Including Fuel Consumption Impacts. The program costs and fuel savings associated with EPA's rulemaking. In Chapter 6, we present briefly some of the outputs of the OMEGA model (costs per vehicle) and how we use those outputs to estimate the annual costs (and fuel savings) of the program through 2050. We also present our cost per ton analysis showing the cost incurred for each ton of GHG reduced by the program.

Chapter 7: Environmental and Health Impacts. This Chapter provides details on the non-GHG health and environmental impacts associated with criteria pollutants and air toxics. We also present the results of our non-GHG air quality modeling analysis and the quantified and monetized estimates of $PM_{2.5}$- and ozone-related health impacts. Our air quality modeling indicates that the final standards have relatively little impact on ambient concentrations of modeled PM2.5, ozone, and air toxics (See Chapter 7.2.). The criteria pollutant-related benefits of the rule are associated with small reductions in PM2.5.

As described in Chapter 7.5, EPA used four new estimates of the dollar value of marginal reductions in CO2 emissions—known as the social cost of carbon—to calculate total monetized CO2 benefits. Specifically, total monetized benefits in each year are calculated by multiplying the SCC by the reductions in CO2 for that year. EPA used four different SCC values to generate different estimates of total CO2 benefits and capture some of the uncertainties involved in regulatory impact analysis. The central value is the average SCC across models at the 3 percent discount rate. For purposes of capturing the uncertainties involved in regulatory impact analysis, we emphasize the importance and value of considering the full range. Chapter 7 also presents an analysis of the CO2 benefits over the model year lifetimes of the 2012 through 2016 model year vehicles.

Chapter 7.6 also includes additional information about EPA's mass reduction and safety analysis.

Chapter 8: Other Economic and Social Impacts. This chapter provides a description of other economic and social impacts associated with the rule, including vehicle sales impacts, consumer vehicle choice, energy security, and other economic impacts associated with reduced refueling, the value of increased driving, and the cost associated with additional noise, congestion and accidents.

Vehicle Sales Impacts: Our analysis predicts vehicle sales increasing as a result of the rule. 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 at least five years of 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).

Consumer Choice Impacts: Consumer vehicle choice models could in principle be used to examine the effects of this rule on the mix of vehicles sold. In practice, however, EPA finds that the state of the art of these models is not yet settled. The models show great variation, and there has been very little comparative assessment of them. 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 rule.

Payback Period on New Vehicle Purchases: We also conducted what we call our "payback analysis" which looks at how quickly the improved fuel efficiency of new vehicles provides savings to buyers despite the vehicles having new technology (and new costs). The consumer payback analysis shows that fuel savings will outweigh up-front costs within three years for people purchasing new vehicles with cash. For those purchasing new vehicles with a typical five-year car note, the fuel savings will outweigh increased costs in the first month of ownership.

Energy Security Impacts: A reduction of U.S. petroleum imports reduces both financial and strategic risks associated with a potential disruption in supply or a spike in cost of a particular energy source. This reduction in risk is a measure of improved U.S. energy security. Based on these estimates of fuel savings, over the lifetimes of model years 2012-2016, we estimate the discounted energy security impacts at $10.1 billion dollars, in 2007 dollars, assuming a 3 percent discount rate, and $8.0 billion dollars, assuming a 7 percent discount rate.

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

Chapter 8 also presents a summary of the total costs, total benefits, and net benefits expected under the final rule. Table 7 presents these economics impacts.

Chapter 9: Small Business Flexibility Analysis. EPA’s analysis of the small business impacts due to EPA’s rulemaking.

Table 7 Economic Impacts of the Light-Duty GHG Rule

	2020	2030	2040	2050	NPV, 3%[a]	NPV, 7%[a]
Vehicle Costs	$15,600	$15,800	$17,400	$19,000	$345,900	$191,900
Fuel Savings[b]	-$35,700	-$79,800	-$119,300	-$171,200	-$1,545,600	-$672,600
Reduced Refueling	$2,400	$4,800	$6,300	$8,000	$87,900	$40,100
Value of Increased Driving[b]	$4,200	$8,800	$13,000	$18,400	$171,500	$75,500
Benefits from Reduced CO_2 Emissions at each assumed SCC value[c,d,e]						
Avg SCC at 5%	$900	$2,700	$4,600	$7,200	$34,500	$34,500
Avg SCC at 3%	$3,700	$8,900	$14,000	$21,000	$176,700	$176,700
Avg SCC at 2.5%	$5,800	$14,000	$21,000	$30,000	$299,600	$299,600
95[th] percentile SCC at 3%	$11,000	$27,000	$43,000	$62,000	$538,500	$538,500
Other Impacts						
Criteria Pollutant Benefits[f,g,h,i]	B	$1,200-$1,300	$1,200-$1,300	$1,200-$1,300	$21,000	$14,000
Energy Security Impacts (price shock)	$2,200	$4,500	$6,000	$7,600	$81,900	$36,900
Accidents, Noise, Congestion	-$2,300	-$4,600	-$6,100	-$7,800	-$84,800	-$38,600
Quantified Net Benefits at each assumed SCC value[c,d,e]						
Avg SCC at 5%	$27,500	$81,500	$127,000	$186,900	$1,511,700	$643,100
Avg SCC at 3%	$30,300	$87,700	$136,400	$200,700	$1,653,900	$785,300
Avg SCC at 2.5%	$32,400	$92,800	$143,400	$209,700	$1,776,800	$908,200
95[th] percentile SCC at 3%	$37,600	$105,800	$165,400	$241,700	$2,015,700	$1,147,100

[a] Note that net present value of reduced GHG emissions is calculated differently than other benefits. The same discount rate used to discount the value of damages from future emissions (SCC at 5, 3, 2.5 percent) is used to calculate net present value of SCC for internal consistency. Refer to Chapter 7 for more detail.

[b] Calculated using pre-tax fuel prices.

[c] Monetized GHG benefits exclude the value of reductions in non-CO2 GHG emissions (HFC, CH4 and N2O) expected under this final rule. Although EPA has not monetized the benefits of reductions in these non-CO2 emissions, the value of these reductions should not be interpreted as zero. Rather, the reductions in non-CO2 GHGs will contribute to this rule's climate benefits, as explained in Section III.F.2 of the preamble. The SCC Technical Support Document (TSD) notes the difference between the social cost of non-CO2 emissions and CO2 emissions, and specifies a goal to develop methods to value non-CO2 emissions in future analyses.

[d] Section III.H.6 notes that SCC increases over time. Corresponding to the years in this table, the SCC estimates range as follows: for Average SCC at 5%: $5-$16; for Average SCC at 3%: $21-$45; for Average SCC at 2.5%: $35-$65; and for 95th percentile SCC at 3%: $65-$136. Section III.H.6 also presents these SCC estimates.

[e] Note that net present value of reduced GHG emissions is calculated differently than other benefits. The same discount rate used to discount the value of damages from future emissions (SCC at 5, 3, 2.5 percent) is used to calculate net present value of SCC for internal consistency. Refer to SCC TSD for more detail.

[f] Note that "B" indicates unquantified criteria pollutant benefits in the year 2020. For the final rule, we only modeled the rule's PM2.5- and ozone-related impacts in the calendar year 2030. For the purposes of estimating a stream of future-year criteria pollutant benefits, we assume that the benefits out to 2050 are equal to, and no less than, those modeled in 2030 as reflected by the stream of estimated future emission reductions. The NPV of criteria pollutant-related benefits should therefore be considered a conservative estimate of the potential benefits associated with the final rule.

[g] The benefits presented in this table include an estimate of PM-related premature mortality derived from Laden et al., 2006, and the ozone-related premature mortality estimate derived from Bell et al., 2004. If the benefit estimates were based on the ACS study of PM-related premature mortality (Pope et al., 2002) and the Levy et al., 2005 study of ozone-related premature mortality, the values would be as much as 70% smaller.

[h] The calendar year benefits presented in this table assume either a 3% discount rate in the valuation of PM-related premature mortality ($1,300 million) or a 7% discount rate ($1,200 million) to account for a twenty-year segmented cessation lag. Note that the benefits estimated using a 3% discount rate were used to calculate the

NPV using a 3% discount rate and the benefits estimated using a 7% discount rate were used to calculate the NPV using a 7% discount rate. For benefits totals presented at each calendar year, we used the mid-point of the criteria pollutant benefits range ($1,250).

[i] Note that the co-pollutant impacts presented here do not include the full complement of endpoints that, if quantified and monetized, would change the total monetized estimate of impacts. The full complement of human health and welfare effects associated with PM and ozone remain unquantified because of current limitations in methods or available data. We have not quantified a number of known or suspected health effects linked with ozone and PM for which appropriate health impact functions are not available or which do not provide easily interpretable outcomes (e.g., changes in heart rate variability). Additionally, we are unable to quantify a number of known welfare effects, including reduced acid and particulate deposition damage to cultural monuments and other materials, and environmental benefits due to reductions of impacts of eutrophication in coastal areas.

CHAPTER 1: Technology Packages, Cost and Effectiveness

1.1 Overview of Technology

The final 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 CO_2 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 by reducing the energy needed to perform either of these functions.

This focus on efficiency involves a major change in focus and calls for looking at the vehicle as an entire system. In addition to fuel delivery, combustion, and aftertreatment technology, any aspect of the vehicle that affects the need to produce energy must also be considered. For example, the efficiency of the transmission system, which takes the energy produced by the engine and transmits it to the wheels, and the resistance of the tires to rolling both have major impacts on the amount of fuel that is combusted while operating the vehicle. 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 final standards. Vehicle manufacturers typically develop their many different models by basing them on a limited number of vehicle platforms. Several different models of vehicles are produced using a common platform, allowing for efficient use of design and manufacturing resources. The platform typically consists of common vehicle architecture and structural components. Given the very large investment put into designing and producing each vehicle model, manufacturers cannot reasonably redesign any given vehicle every year or even every other year, let alone redesign all of their vehicles every year or every other year. At the redesign stage, the manufacturer will upgrade or add all of the technology and make all of the other changes needed so the vehicle model will meet the manufacturer's plans for the next several years. This includes meeting all of the emissions and other requirements that would apply during the years before the next major redesign of the vehicle.

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

Given that the regulatory timeframe of the GHG program is five years (2012 through 2016), and given EPA's belief that full line manufacturers (i.e., those making small cars through large cars, minivans, small trucks and large trucks) cannot redesign, on average, their entire product line more than once during that timeframe, a five year redesign cycle has been used in our final rule. This same redesign cycle was used in the proposal. This means that the analysis assumes that each vehicle platform in the US fleet can undergo at least one full redesign during our regulatory timeframe. While some may undergo more than one, the analysis assumes that the extra redesign comes at the expense of another vehicle that would, in effect, undergo no redesign during the regulatory timeframe.

Commenters were generally supportive of the use of a five year redesign cycle. However, at least one commenter argued that shorter redesign cycles are possible and that the final GHG standards are too low in light of the ability of manufacturers to conduct redesigns at a faster pace. EPA's response on both sides of this issue can be found in the Response to Comments document (see issue 3.1).

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

As described below, the vast majority of technology required by the GHG rule is commercially available and already being employed to a limited extent across the fleet, although far greater penetration of these technologies into the fleet is projected as a result of the final rule. The vast majority of the emission reductions which will result from the rule would result from the increased use of these technologies. EPA also believes the rule would encourage the development and limited use of more advanced technologies, such as PHEVs and EVs, and is structuring the rule to encourage these technologies' use.

In section 1.2 below, a summary of technology costs and effectiveness is presented. In section 1.3, the process of combining technologies into packages is described along with package costs and effectiveness. Sections 1.4 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 CO_2 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.

Since publication of the 2011 CAFE FRM and EPA's 2008 Staff Technical Report, EPA began a contracted study 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. Also, cost and effectiveness estimates were adjusted 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 CO_2 emission control, such as papers published by the Society of Automotive Engineers and the American Society of Mechanical Engineers. The results of these efforts and early results of the FEV contracted study were used in the proposal for this rule.

Since the proposal, EPA has carefully examined all information on technology cost and effectiveness received during the comment period. Importantly, the FEV contracted study has progressed and provides many more new cost estimates that have been incorporated in the final analysis. As a result, while some FEV teardown costs were used in the proposal, we have expanded our use of FEV costs for the final rule using new information available to us shortly after the proposal. For more detail on our technology cost estimates and how they have changed since the proposal refer to Chapter 3 of the joint TSD and, specifically, section 3.3.2.2 of the joint TSD for how costs have changed.

EPA reviewed all this information in order to develop the best estimates of the cost and effectiveness of CO_2 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 CO_2 reducing technologies can be found in Chapter 3 of the joint TSD, along with a more detailed description of the comprehensive technical evaluation underlying the estimates.

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 I4	Base I4	$209	209	$209	209	209
	GDI – stoichiometric V6	Base V6	n/a	$301	$301	$301	$301
	GDI – stoichiometric V8	Base V8	n/a	$346	$346	n/a	$346
	GDI – lean burn	GDI - stoich	$623	$623	$623	$623	$623
Turbo w/o downsize Downsize w/o turbo	Turbocharge (single)	Base I4	$397	n/a	$397	n/a	n/a
	Turbocharge (single)	Base V6	n/a	$420	$420	$420	$420
	Turbocharge (twin)	Base engine	$666	$666	$666	$666	$666
	Downsize to I4 DOHC	V6 DOHC	n/a	-$384	-$384	-$384	-$384
	Downsize to I4 DOHC	V6 SOHC	n/a	-$177	-$177	-$177	-$177
	Downsize to I4 DOHC	V6 OHV	n/a	$265	$265	$265	$265
	Downsize to I4 DOHC	I4 DOHC (larger)	-$67	-$67	-$67	-$67	-$67
	Downsize to I3 DOHC	I4 DOHC	-$116	n/a	n/a	n/a	n/a
	Downsize to V6 DOHC	V8 DOHC	n/a	-$188	-$188	-$188	-$188
	Downsize to V6 DOHC	V8 SOHC 2V	n/a	$59	$59	$59	$59
	Downsize to V6 DOHC	V8 SOHC 3V	n/a	-$17	-$17	-$17	-$17
	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	n/a	$149	$149	$149	$149
	Downsize to I4 DOHC & add turbo	V6 SOHC w/o turbo	n/a	$323	$323	$323	$323
	Downsize to I4 DOHC & add turbo	V6 OHV w/o turbo	$771	$771	$771	$771	$771
	Downsize to I4 DOHC & add turbo	I4 DOHC (larger) w/o turbo	$391	n/a	$391	n/a	n/a
	Downsize to I3 DOHC & add turbo	I4 DOHC w/o turbo	$349	n/a	n/a	n/a	n/a
	Downsize to V6 DOHC & add twin turbo	V8 DOHC w/o turbo	n/a	$592	$592	$592	$592
	Downsize to V6 DOHC & add twin turbo	V8 SOHC 2V w/o turbo	n/a	$816	$816	$816	$816

	Downsize to V6 DOHC & add twin turbo	V8 SOHC 3V w/o turbo	n/a	$736	$736	$736	$736
	Downsize to V6 DOHC & add twin turbo	V8 OHV w/o turbo	n/a	$1,099	$1,099	$1,099	$1,099
	Convert to V6 DOHC	V6 SOHC	n/a	$258	$258	$258	$258
	Convert to V6 DOHC	V6 OHV	n/a	$464	$464	$464	$464
	Convert to V8 DOHC	V8 SOHC 2V	n/a	$292	$292	$292	$292
	Convert to V8 DOHC	V8 SOHC 3V	n/a	$213	$213	$213	$213
	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	$1,877				
	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	$99	$99	$99	$99	$99
6-speed DCT – dry clutch	6-speed auto trans	-$52	-$52	-$52	-$52	-$52
6-speed DCT – wet clutch	6-speed auto trans	-$7	-$7	-$7	-$7	-$7
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
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 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

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 CO_2reductions. 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 CO_2reductions 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. No commenter took issue with this concept.

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 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. No commenter took issue with this concept or the list of packages that were developed.

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 CO_2than gasoline. As this rule is based on the reduction of CO_2emissions 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.

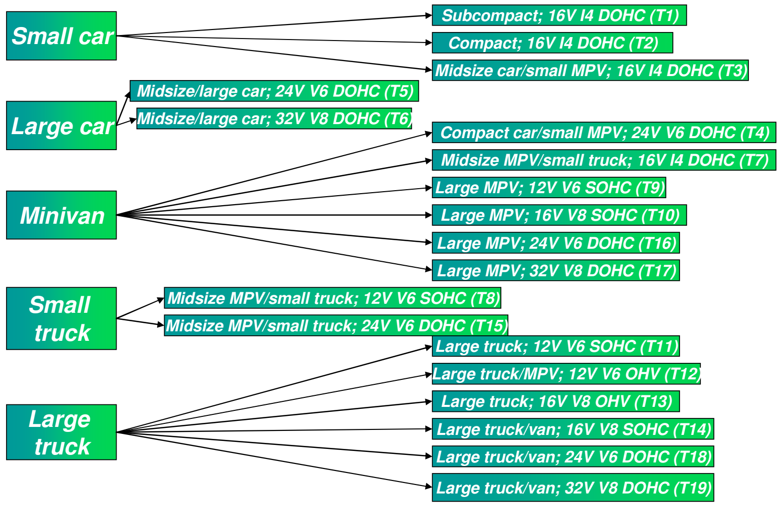

Figure 1-1 Scaling classes to Vehicle Type Mapping

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 provides superior cost effectiveness). Table 1-12 shows the package costs for the packages that were actually used as inputs to 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 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 in 2012 are, on average, 118% 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 109% of those for 2016 as learning has occurred between 2012 and 2014. The costs for 2022 are 94% 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 GHG 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). No commenter took issue with this concept.

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 (not used for downsized engines)	Lubes	Friction Rdxn	Fuel system	Downsize	Aftertreatment	Aggressive shift	Early torque lock	Alternator & electrification	Power steering	Aero	Low RR tires	Low drag brakes	Axle disconnect	Weight rdxn	2016 MY Cost
Subcompact Car I4 (Type 1)	**100**	**1.5L 4V DOHC I4**	**AT 4 spd**	**12V**																
	101	1.5L 4V I4	AT 4 spd	12V		LUB	EFR				ASL	TORQ	IACC 12V			LRR				$189
	102	1.5L 4V I4 + CCP	DCT 6 spd	12V		LUB	EFR						IACC 12V	EPS	AERO 1	LRR			3%	$518
	103	1.2L 4V I3 + CCP + DVVL + GDI	dry DCT 6 spd	42V S-S		LUB	EFR	GDI-I4>I3	I4 to I3				IACC 42V	EPS	AERO 1	LRR			5%	$1,205
	104	1.0L 4V I3 (small) Turbo + DCP + GDI	dry DCT 6 spd	42V S-S		LUB	EFR	GDI-I4>I3	I4 to I3				IACC 42V	EPS	AERO 1	LRR			10%	$1,770
	105	29KWH (FTP 150 miles @160 WH/mi)	N/A	EV											AERO 1	LRR			20%	$28,537
Compact Car I4 (Type 2)	**200**	**2.4L 4V DOHC I4**	**AT 4 spd**	**12V**																
	201	2.4L 4V I4	AT 4 spd	12V		LUB	EFR				ASL	TORQ	IACC 12V			LRR				$189
	202	2.0L 4V I4 + CCP + GDI	AT 6 spd	12V		LUB	EFR	GDI-I4	I4 to I4		ASL	TORQ	IACC 12V	EPS	AERO 1	LRR			3%	$730
	203	2.0L 4V I4 + CCP + GDI	DCT 6 spd	12V		LUB	EFR	GDI-I4	I4 to I4				IACC 12V	EPS	AERO 1	LRR			3%	$669
	204	2.0L 4V I4 + CCP + DVVL + GDI	dry DCT 6 spd	42V S-S		LUB	EFR	GDI-I4	I4 to I4				IACC 42V	EPS	AERO 1	LRR			10%	$1,475
	205	1.5L 4V I4 Turbo + DCP + GDI	dry DCT 6 spd	42V S-S		LUB	EFR	GDI-I4	I4 to I4				IACC 42V	EPS	AERO 1	LRR			10%	$1,841
	206	1.2L 4V I4 HEV (IMA) + GDI	dry DCT 6 spd	HEV		LUB	EFR	GDI-I4	I4 to I4						AERO 1	LRR				$3,144
	207	1.2L 4V I4 Plug-in HEV (IMA) + GDI (50% UF)	dry DCT 6 spd	HEV		LUB	EFR	GDI-I4	I4 to I4						AERO 1	LRR				$10,066
Midsize Car/Small MPV (unibody) I4 (Type 3)	**300**	**2.4L 4V DOHC I4**	**AT 4 spd**	**12V**																
	301	2.4L 4V I4	AT 4 spd	12V		LUB	EFR				ASL	TORQ	IACC 12V			LRR				$189
	302	2.2L 4V I4 + CCP + GDI	AT 6 spd	12V		LUB	EFR	GDI-I4	I4 to I4		ASL	TORQ	IACC 12V	EPS	AERO 1	LRR			3%	$749
	303	2.2L 4V I4 + CCP + DVVL + GDI	DCT 6 spd	12V		LUB	EFR	GDI-I4	I4 to I4				IACC 12V	EPS	AERO 1	LRR			5%	$908
	304	2.2L 4V I4 + CCP + DVVL + GDI	dry DCT 6 spd	42V S-S		LUB	EFR	GDI-I4	I4 to I4				IACC 42V	EPS	AERO 1	LRR			10%	$1,538
	305	1.6L 4V I4 Turbo + DCP + GDI	dry DCT 6 spd	42V S-S		LUB	EFR	GDI-I4	I4 to I4				IACC 42V	EPS	AERO 1	LRR			10%	$1,904
	307	1.4L 4V I4 Turbo HEV (IMA) + GDI	dry DCT 6 spd	HEV		LUB	EFR	GDI-I4	I4 to I4						AERO 1	LRR				$3,602
	308	1.8L 4V I4 HEV (Power Split) + GDI	N/A	HEV		LUB	EFR	GDI-I4	I4 to I4						AERO 1	LRR				$4,211
	309	1.8L 4V I4 Plug-in HEV (Power Split) + GDI (50% UF)	N/A	HEV		LUB	EFR	GDI-I4	I4 to I4						AERO 1	LRR				$9,634
Compact Car/Small MPV (unibody) V6 (Type 4)	**400**	**3.0L 4V DOHC V6**	**AT 4 spd**	**12V**																
	401	3.0L 4V V6	AT 4 spd	12V		LUB	EFR				ASL	TORQ	IACC 12V			LRR				$214
	402	2.0L 4V I4 Turbo + DCP + GDI	AT 6 spd	12V		LUB	EFR	GDI-V6>I4	V6 DOHC to I4		ASL	TORQ	IACC 12V	EPS	AERO 1	LRR			3%	$1,111
	403	2.0L 4V I4 Turbo + DCP + GDI	DCT 6 spd	12V		LUB	EFR	GDI-V6>I4	V6 DOHC to I4				IACC 12V	EPS	AERO 1	LRR			3%	$1,051
	404	2.0L 4V I4 Turbo + DCP + GDI	DCT 6 spd	42V S-S		LUB	EFR	GDI-V6>I4	V6 DOHC to I4				IACC 42V	EPS	AERO 1	LRR			5%	$1,633
	406	2.4L I4 Turbo Diesel	DCT 6 spd	12V		LUB	EFR	Diesel		Diesel-SCR				EPS	AERO 1	LRR			5%	$2,722
	407	1.5L 4V I4 Turbo HEV (IMA) + GDI	DCT 6 spd	HEV		LUB	EFR	GDI-V6>I4	V6 DOHC to I4						AERO 1	LRR				$4,188
	408	2.8L 4V V6 HEV (2-mode) + CCP + Deac + GDI	N/A	HEV		LUB	EFR	GDI-V6							AERO 1	LRR				$6,109

Table 1-11 Continued

Vehicle	Technology Package #	Engine	Transmission	System Voltage	Camshaft changes (not used for downsized engines)	Lubes	Friction Rdxn	Fuel system	Downsize	Aftertreatment	Aggressive shift	Early torque lock	Alternator & electrification	Power steering	Aero	Low RR tires	Low drag brakes	Axle disconnect	Weight rdxn	2016 MY Cost
Midsize/Large Car V6 (Type 5)	**500**	**3.3L 4V DOHC V6**	**AT 4 spd**	**12V**																
	501	3.3L 4V V6	AT 4 spd	12V		LUB	EFR				ASL	TORQ	IACC 12V			LRR				$214
	502	3.0L 4V V6 + CCP +GDI	AT 6 spd	12V		LUB	EFR	GDI-V6			ASL	TORQ	IACC 12V	EPS	AERO 1	LRR			3%	$985
	503	3.0L 4V V6 + CCP + Deac + GDI	AT 6 spd	12V		LUB	EFR	GDI-V6			ASL	TORQ	IACC 12V	EPS	AERO 1	LRR			5%	$1,238
	504	3.0L 4V V6 + CCP + Deac + GDI	DCT 6 spd	42V S-S		LUB	EFR	GDI-V6					IACC 42V	EPS	AERO 1	LRR			10%	$1,919
	505	2.2L 4V I4 Turbo + DCP + GDI	DCT 6 spd	42V S-S		LUB	EFR	GDI-V6>I4	V6 DOHC to I4				IACC 42V	EPS	AERO 1	LRR			10%	$1,903
	508	2.5L 4V I4 HEV (Power Split) + GDI	N/A	HEV		LUB	EFR	GDI-V6>I4	V6 DOHC to I4						AERO 1	LRR				$5,329
Midsize Car/Large Car V8 (Type 6)	**600**	**4.5L 4V DOHC V8**	**AT 4 spd**	**12V**																
	601	4.5L 4V V8	AT 4 spd	12V		LUB	EFR				ASL	TORQ	IACC 12V			LRR				$214
	602	4.0L 4V V6 + CCP+ GDI	AT 6 spd	12V		LUB	EFR	GDI-V8>V6	V8 DOHC to V6 DOHC		ASL	TORQ	IACC 12V	EPS	AERO 1	LRR			3%	$817
	603	4.0L 4V V6 + CCP + Deac + GDI	AT 6 spd	42V S-S		LUB	EFR	GDI-V8>V6	V8 DOHC to V6 DOHC		ASL	TORQ	IACC 42V	EPS	AERO 1	LRR			5%	$1,567
	604	4.0L 4V V6 + CCP+ Deac + GDI	DCT 6 spd	42V S-S		LUB	EFR	GDI-V8>V6	V8 DOHC to V6 DOHC				IACC 42V	EPS	AERO 1	LRR			5%	$1,506
	605	3.0L 4V V6 Turbo + DCP + GDI	AT 6 spd	42V S-S		LUB	EFR	GDI-V8>V6	V8 DOHC to V6 DOHC		ASL	TORQ	IACC 42V	EPS	AERO 1	LRR			5%	$2,274
	606	3.0L 4V V6 Turbo + DCP + GDI	DCT 6 spd	42V S-S		LUB	EFR	GDI-V8>V6	V8 DOHC to V6 DOHC				IACC 42V	EPS	AERO 1	LRR			5%	$2,214
	608	3.0L 4V V6 Turbo Diesel	DCT 6 spd	12V		LUB	EFR	Diesel		Diesel-SCR				EPS	AERO 1	LRR			5%	$3,258
	609	3.0L 4V V6 HEV (2-mode) + CCP + Deac + GDI	N/A	HEV		LUB	EFR	GDI-V8>V6	V8 DOHC to V6 DOHC						AERO 1	LRR				$5,939
Mid-sized MPV (unibody)/Small Truck I4 (Type 7)	**700**	**2.6L 4V DOHC I4 (I5)**	**AT 4 spd**	**12V**																
	701	2.6L 4V I4	AT 4 spd	12V		LUB	EFR				ASL	TORQ	IACC 12V			LRR				$214
	702	2.4L 4V I4 + CCP + GDI	AT 6 spd	12V		LUB	EFR	GDI-I4	I4 to I4		ASL	TORQ	IACC 12V	EPS	AERO 1	LRR			3%	$838
	703	2.4L 4V I4 + CCP + DVVL + GDI	DCT 6 spd	12V		LUB	EFR	GDI-I4	I4 to I4				IACC 12V	EPS	AERO 1	LRR			3%	$959
	704	2.4L 4V I4 + CCP + DVVL + GDI	dry DCT 6 spd	42V S-S		LUB	EFR	GDI-I4	I4 to I4				IACC 42V	EPS	AERO 1	LRR			10%	$1,788
	705	2.0L 4V I4 Turbo + DCP + GDI	dry DCT 6 spd	42V S-S		LUB	EFR	GDI-I4	I4 to I4				IACC 42V	EPS	AERO 1	LRR			10%	$2,141
	707	1.8L 4V I4 Turbo HEV (IMA) + GDI	dry DCT 6 spd	HEV		LUB	EFR	GDI-I4	I4 to I4						AERO 1	LRR				$4,401
	708	1.8L 4V I4 Turbo HEV (Power Split) + GDI	N/A	HEV		LUB	EFR	GDI-I4	I4 to I4						AERO 1	LRR				$6,104
	709	1.8L 4V I4 Turbo Plug-in HEV (IMA) + GDI (50% UF)	dry DCT 6 spd	HEV		LUB	EFR	GDI-I4	I4 to I4						AERO 1	LRR				$13,999
Midsize MPV (unibody)/Small Truck V6/V8 (Type 8)	**800**	**3.7L 2V SOHC V6**	**AT 4 spd**	**12V**																
	801	3.7L 2V SOHC V6	AT 4 spd	12V		LUB	EFR				ASL	TORQ	IACC 12V			LRR				$214
	802	3.2L 2V SOHC V6 + CCP + GDI	AT 6 spd	12V		LUB	EFR	GDI-V6			ASL	TORQ	IACC 12V	EPS	AERO 1	LRR			3%	$1,006
	803	3.2L 2V SOHC V6 + CCP + Deac + GDI	AT 6 spd	12V		LUB	EFR	GDI-V6			ASL	TORQ	IACC 12V	EPS	AERO 1	LRR			3%	$1,156
	804	2.8L 4V V6 + CCP + GDI	AT 6 spd	12V	V6 SOHC to V6 DOHC	LUB	EFR	GDI-V6			ASL	TORQ	IACC 12V	EPS	AERO 1	LRR			3%	$1,264
	805	2.8L 4V V6 + CCP + DVVL + GDI	AT 6 spd	12V	V6 SOHC to V6 DOHC	LUB	EFR	GDI-V6			ASL	TORQ	IACC 12V	EPS	AERO 1	LRR			5%	$1,563
	806	2.8L 4V V6 + CCP + Deac + GDI	AT 6 spd	12V	V6 SOHC to V6 DOHC	LUB	EFR	GDI-V6			ASL	TORQ	IACC 12V	EPS	AERO 1	LRR			5%	$1,531
	807	2.8L 4V V6 + CCP + Deac + GDI	DCT 6 spd	42V S-S	V6 SOHC to V6 DOHC	LUB	EFR	GDI-V6					IACC 42V	EPS	AERO 1	LRR			10%	$2,248
	808	2.4L 4V I4 Turbo + DCP + GDI	DCT 6 spd	42V S-S		LUB	EFR	GDI-V6>I4	V6 SOHC to I4				IACC 42V	EPS	AERO 1	LRR			10%	$2,149
	811	2.8L I4 Turbo Diesel	DCT 6 spd	12V		LUB	EFR	Diesel		Diesel-SCR				EPS	AERO 1	LRR			5%	$2,770
	812	3.0L 4V V6 HEV (IMA) + CCP + Deac + GDI	DCT 6 spd	HEV	V6 SOHC to V6 DOHC	LUB	EFR	GDI-V6							AERO 1	LRR				$4,430
	813	3.0L 4V V6 HEV (2-mode) + CCP + Deac + GDI	N/A	HEV	V6 SOHC to V6 DOHC	LUB	EFR	GDI-V6							AERO 1	LRR				$5,858

Table 1-11 Continued

Vehicle	Technology Package #	Engine	Transmission	System Voltage	Camshaft changes (not used for downsized engines)	Lubes	Friction Rdxn	Fuel system	Downsize	Aftertreatment	Aggressive shift	Early torque lock	Alternator & electrification	Power steering	Aero	Low RR tires	Low drag brakes	Axle disconnect	Weight rdxn	2016 MY Cost
Large MPV (unibody) V6 (Type 9)	**900**	**4.0L 2V SOHC V6**	**AT 4 spd**	**12V**																
	901	4.0L 2V SOHC V6	AT 4 spd	12V		LUB	EFR				ASL	TORQ	IACC 12V			LRR				$214
	902	3.6L 2V SOHC V6 + CCP + GDI	AT 6 spd	12V		LUB	EFR	GDI-V6			ASL	TORQ	IACC 12V	EPS	AERO 1	LRR			3%	$1,027
	903	3.6L 2V SOHC V6 + CCP + Deac + GDI	AT 6 spd	12V		LUB	EFR	GDI-V6			ASL	TORQ	IACC 12V	EPS	AERO 1	LRR			3%	$1,176
	904	3.2L 4V V6 + CCP + GDI	AT 6 spd	12V	V6 SOHC to V6 DOHC	LUB	EFR	GDI-V6			ASL	TORQ	IACC 12V	EPS	AERO 1	LRR			3%	$1,285
	905	3.2L 4V V6 + CCP + Deac + GDI	AT 6 spd	12V	V6 SOHC to V6 DOHC	LUB	EFR	GDI-V6			ASL	TORQ	IACC 12V	EPS	AERO 1	LRR			5%	$1,565
	906	3.2L 4V V6 + CCP + Deac + GDI	DCT 6 spd	42V S-S	V6 SOHC to V6 DOHC	LUB	EFR	GDI-V6					IACC 42V	EPS	AERO 1	LRR			10%	$2,316
	907	2.4L 4V I4 Turbo + DCP + GDI	DCT 6 spd	42V S-S		LUB	EFR	GDI-V6>I4	V6 SOHC to I4				IACC 42V	EPS	AERO 1	LRR			10%	$2,217
	910	2.0L 4V I4 Turbo HEV (IMA) + GDI	DCT 6 spd	HEV		LUB	EFR	GDI-V6>I4	V6 SOHC to I4						AERO 1	LRR				$4,512
	911	3.2L 4V V6 HEV (2-mode) + CCP + Deac + GDI	N/A	HEV	V6 SOHC to V6 DOHC	LUB	EFR	GDI-V6							AERO 1	LRR				$6,367
Large MPV (unibody) V8 (Type 10)	**1000**	**4.7L 2V SOHC V8**	**AT 4 spd**	**12V**																
	1001	4.7L 2V SOHC V8	AT 4 spd	12V		LUB	EFR				ASL	TORQ	IACC 12V			LRR				$214
	1002	4.4L 2V SOHC V8 + CCP + GDI	AT 6 spd	12V		LUB	EFR	GDI-V8			ASL	TORQ	IACC 12V	EPS	AERO 1	LRR			3%	$1,092
	1003	4.4L 2V SOHC V8 + CCP + Deac + GDI	AT 6 spd	12V		LUB	EFR	GDI-V8			ASL	TORQ	IACC 12V	EPS	AERO 1	LRR			3%	$1,242
	1004	4.2L 4V V6 + CCP + GDI	AT 6 spd	12V		LUB	EFR	GDI-V8>V6	V8 SOHC to V6 DOHC		ASL	TORQ	IACC 12V	EPS	AERO 1	LRR			3%	$1,106
	1005	4.2L 4V V6 + CCP + Deac + GDI	AT 6 spd	12V		LUB	EFR	GDI-V8>V6	V8 SOHC to V6 DOHC		ASL	TORQ	IACC 12V	EPS	AERO 1	LRR			5%	$1,401
	1006	4.2L 4V V6 + CCP + Deac + GDI	DCT 6 spd	42V S-S		LUB	EFR	GDI-V8>V6	V8 SOHC to V6 DOHC				IACC 42V	EPS	AERO 1	LRR			10%	$2,187
	1007	2.8L 4V V6 Turbo + DCP + GDI	DCT 6 spd	42V S-S		LUB	EFR	GDI-V8>V6	V8 SOHC to V6 DOHC				IACC 42V	EPS	AERO 1	LRR			10%	$2,872
	1010	3.0L V6 Turbo Diesel	DCT 6 spd	12V		LUB	EFR	Diesel		Diesel-SCR				EPS	AERO 1	LRR			5%	$2,839
	1011	4.2L 4V V6 HEV (2-mode) + CCP + Deac + GDI	N/A	HEV		LUB	EFR	GDI-V8>V6	V8 SOHC to V6 DOHC						AERO 1	LRR				$6,167
Large Truck (+ Van) V6 (Type 11)	**1100**	**4.2L 2V SOHC V6**	**AT 4 spd**	**12V**																
	1101	4.2L 2V SOHC V6	AT 4 spd	12V		LUB	EFR				ASL	TORQ	IACC 12V			LRR				$239
	1102	3.9L 2V SOHC V6 + CCP + GDI	AT 6 spd	12V		LUB	EFR	GDI-V6			ASL	TORQ	IACC 12V		AERO 1	LRR			3%	$948
	1103	3.9L 2V SOHC V6 + CCP + Deac + GDI	AT 6 spd	12V		LUB	EFR	GDI-V6			ASL	TORQ	IACC 12V		AERO 1	LRR			3%	$1,117
	1104	3.6L 4V V6 + CCP + GDI	AT 6 spd	12V	V6 SOHC to V6 DOHC	LUB	EFR	GDI-V6			ASL	TORQ	IACC 12V		AERO 1	LRR			3%	$1,206
	1105	3.6L 4V V6 + CCP + DVVL + GDI	AT 6 spd	12V	V6 SOHC to V6 DOHC	LUB	EFR	GDI-V6			ASL	TORQ	IACC 12V		AERO 1	LRR			5%	$1,590
	1106	3.6L 4V V6 + CCP + Deac + GDI	AT 6 spd	12V	V6 SOHC to V6 DOHC	LUB	EFR	GDI-V6			ASL	TORQ	IACC 12V		AERO 1	LRR			5%	$1,500
	1107	3.6L 4V V6 + CCP + Deac + GDI	DCT 6 spd	42V S-S	V6 SOHC to V6 DOHC	LUB	EFR	GDI-V6					IACC 42V	EPS	AERO 1	LRR	LDB		10%	$2,430
	1108	2.5L 4V I4 Turbo + DCP + GDI	DCT 6 spd	42V S-S		LUB	EFR	GDI-V6>I4	V6 SOHC to I4				IACC 42V	EPS	AERO 1	LRR	LDB		10%	$2,312
	1111	2.8L I4 Turbo Diesel	DCT 6 spd	12v		LUB	EFR	Diesel		Diesel-SCR					AERO 1	LRR	LDB		5%	$3,579
	1112	3.6L 4V V6 HEV (IMA) + CCP + Deac + GDI	DCT 6 spd	HEV	V6 SOHC to V6 DOHC	LUB	EFR	GDI-V6							AERO 1	LRR	LDB			$5,545
	1113	3.6L 4V V6 HEV (2-mode)+ CCP + Deac + GDI	N/A	HEV	V6 SOHC to V6 DOHC	LUB	EFR	GDI-V6							AERO 1	LRR	LDB			$8,257
Large Truck + Large MPV V6 (T12)	**1200**	**3.8L 2V OHV V6**	**AT 4 spd**	**12V**																
	1201	3.8L 2V OHV V6	AT 4 spd	12V		LUB	EFR				ASL	TORQ	IACC 12V			LRR				$239
	1202	3.2L 4V DOHC V6 + CCP + GDI	AT 6 spd	12V	V6 OHV to V6 DOHC	LUB	EFR	GDI-V6			ASL	TORQ	IACC 12V		AERO 1	LRR			3%	$1,413
	1203	3.2L 4V DOHC V6 + CCP + Deac + GDI	AT 6 spd	12V	V6 OHV to V6 DOHC	LUB	EFR	GDI-V6			ASL	TORQ	IACC 12V		AERO 1	LRR			3%	$1,581
	1204	3.2L 4V DOHC V6 + CCP + Deac + GDI	DCT 6 spd	42V S-S	V6 OHV to V6 DOHC	LUB	EFR	GDI-V6					IACC 42V	EPS	AERO 1	LRR	LDB		10%	$2,637
	1205	2.5L 4V I4 Turbo + DCP + GDI	DCT 6 spd	42V S-S		LUB	EFR	GDI-V6>I4	V6 OHV to I4 DOHC				IACC 42V	EPS	AERO 1	LRR	LDB		10%	$2,760

Table 1-11 Continued

Vehicle	Technology Package #	Engine	Transmission	System Voltage	Camshaft changes (not used for downsized engines)	Lubes	Friction Rdxn	Fuel system	Downsize	Aftertreatment	Aggressive shift	Early torque lock	Alternator & electrification	Power steering	Aero	Low RR tires	Low drag brakes	Axle disconnect	Weight rdxn	2016 MY Cost
Large Truck (+ Van) V8 (Type 13)	**1300**	**5.7L 2V OHV V8**	**AT 4 spd**	**12V**																
	1301	5.7L 2V OHV V8	AT 4 spd	12V		LUB	EFR				ASL	TORQ	IACC 12V			LRR				$239
	1302	5.2L 2V OHV V8 + CCP + GDI	AT 6 spd	12V		LUB	EFR	GDI-V8			ASL	TORQ	IACC 12V		AERO 1	LRR			3%	$993
	1303	5.2L 2V OHV V8 + CCP + Deac + GDI	AT 6 spd	12V		LUB	EFR	GDI-V8			ASL	TORQ	IACC 12V		AERO 1	LRR			3%	$1,162
	1304	4.6L 4V V8 + CCP + GDI	AT 6 spd	12V	V8 OHV to V8 DOHC	LUB	EFR	GDI-V8			ASL	TORQ	IACC 12V		AERO 1	LRR			3%	$1,541
	1305	4.6L 4V V8 + CCP + Deac + GDI	AT 6 spd	12V	V8 OHV to V8 DOHC	LUB	EFR	GDI-V8			ASL	TORQ	IACC 12V		AERO 1	LRR			5%	$1,862
	1306	4.6L 4V V8 + CCP + Deac + GDI	DCT 6 spd	42V S-S	V8 OHV to V8 DOHC	LUB	EFR	GDI-V8					IACC 42V	EPS	AERO 1	LRR	LDB		10%	$2,859
	1307	3.5L 4V V6 Turbo + DCP + GDI	DCT 6 spd	42V S-S		LUB	EFR	GDI-V8>V6	V8 OHV to V6 DOHC				IACC 42V	EPS	AERO 1	LRR	LDB		10%	$3,314
	1310	3.5L V6 Turbo Diesel	DCT 6 spd	12V		LUB	EFR	Diesel		Diesel-SCR					AERO 1	LRR	LDB		5%	$3,646
	1311	4.6L 4V V8 HEV (2-mode) + CCP + Deac + GDI	N/A	HEV	V8 OHV to V8 DOHC	LUB	EFR	GDI-V8							AERO 1	LRR	LDB			$8,552
Large Truck (+Van) V8 (Type 14)	**1400**	**5.4L 3V SOHC V8**	**AT 4 spd**	**12V**																
	1401	5.4L 3V SOHC V8	AT 4 spd	12V		LUB	EFR				ASL	TORQ	IACC 12V			LRR				$239
	1402	4.6L 4V DOHC V8 + CCP + GDI	AT 6 spd	12V	V8 SOHC 3V to V8 DOHC	LUB	EFR	GDI-V8			ASL	TORQ	IACC 12V		AERO 1	LRR			3%	$1,246
	1403	4.6L 4V DOHC V8 + CCP + Deac + GDI	AT 6 spd	12V	V8 SOHC 3V to V8 DOHC	LUB	EFR	GDI-V8			ASL	TORQ	IACC 12V		AERO 1	LRR			5%	$1,566
	1404	4.6L 4V DOHC V8 + CCP + Deac + GDI	DCT 6 spd	42V S-S	V8 SOHC 3V to V8 DOHC	LUB	EFR	GDI-V8					IACC 42V	EPS	AERO 1	LRR	LDB		10%	$2,564
	1405	3.5L 4V V6 Turbo + DCP + GDI	DCT 6 spd	42V S-S		LUB	EFR	GDI-V8>V6	V8 SOHC 3V to V6 DOHC				IACC 42V	EPS	AERO 1	LRR	LDB		10%	$2,952
Midsize MPV (unibody)/Small Truck V6/V8 (Type 15)	**1500**	**3.2L 4V DOHC V6**	**AT 4 spd**	**12V**																
	1501	3.2L 4V V6	AT 4 spd	12V		LUB	EFR				ASL	TORQ	IACC 12V			LRR				$214
	1502	2.8L 4V V6 + CCP + GDI	AT 6 spd	12V		LUB	EFR	GDI-V6			ASL	TORQ	IACC 12V	EPS	AERO 1	LRR			3%	$1,006
	1503	2.8L 4V V6 + CCP + DVVL + GDI	AT 6 spd	12V		LUB	EFR	GDI-V6			ASL	TORQ	IACC 12V	EPS	AERO 1	LRR			5%	$1,305
	1504	2.8L 4V V6 + CCP + Deac + GDI	AT 6 spd	12V		LUB	EFR	GDI-V6			ASL	TORQ	IACC 12V	EPS	AERO 1	LRR			5%	$1,273
	1505	2.8L 4V V6 + CCP + Deac + GDI	DCT 6 spd	42V S-S		LUB	EFR	GDI-V6					IACC 42V	EPS	AERO 1	LRR			5%	$1,697
	1506	2.4L 4V I4 Turbo + DCP + GDI	DCT 6 spd	42V S-S		LUB	EFR	GDI-V6>I4	V6 DOHC to I4				IACC 42V	EPS	AERO 1	LRR			5%	$1,681
	1509	2.8L I4 Turbo Diesel	DCT 6 spd	12V		LUB	EFR	Diesel		Diesel-SCR				EPS	AERO 1	LRR			5%	$2,770
	1510	3.0L 4V V6 HEV (IMA) + CCP + Deac + GDI	DCT 6 spd	HEV		LUB	EFR	GDI-V6							AERO 1	LRR				$4,172
	1511	3.0L 4V V6 HEV (2-mode) + CCP + Deac + GDI	N/A	HEV		LUB	EFR	GDI-V6							AERO 1	LRR				$5,600
Large MPV (unibody) V6 (Type 16)	**1600**	**3.5L 4V DOHC V6**	**AT 4 spd**	**12V**																
	1601	3.5L 4V V6	AT 4 spd	12V		LUB	EFR				ASL	TORQ	IACC 12V			LRR				$214
	1602	3.2L 4V V6 + CCP + GDI	AT 6 spd	12V		LUB	EFR	GDI-V6			ASL	TORQ	IACC 12V	EPS	AERO 1	LRR			3%	$1,027
	1603	3.2L 4V V6 + CCP + Deac + GDI	AT 6 spd	12V		LUB	EFR	GDI-V6			ASL	TORQ	IACC 12V	EPS	AERO 1	LRR			5%	$1,307
	1604	3.2L 4V V6 + CCP + Deac + GDI	DCT 6 spd	42V S-S		LUB	EFR	GDI-V6					IACC 42V	EPS	AERO 1	LRR			10%	$2,058
	1605	2.4L 4V I4 Turbo + DCP + GDI	DCT 6 spd	42V S-S		LUB	EFR	GDI-V6>I4	V6 DOHC to I4				IACC 42V	EPS	AERO 1	LRR			5%	$1,715
	1608	2.0L 4V I4 Turbo HEV (IMA) + GDI	DCT 6 spd	HEV		LUB	EFR	GDI-V6>I4	V6 DOHC to I4						AERO 1	LRR				$4,188
	1609	3.2L 4V V6 HEV (2-mode) + CCP + Deac + GDI	N/A	HEV		LUB	EFR	GDI-V6							AERO 1	LRR				$6,109

Table 1-11 Continued

Vehicle	Technology Package #	Engine	Transmission	System Voltage	Camshaft changes (not used for downsized engines)	Lubes	Friction Rdxn	Fuel system	Downsize	Aftertreatment	Aggressive shift	Early torque lock	Alternator & electrification	Power steering	Aero	Low RR tires	Low drag brakes	Axle disconnect	Weight rdxn	2016 MY Cost
Large MPV (unibody) V8 (Type 17)	**1700**	**4.6L 4V DOHC V8**	**AT 4 spd**	**12V**																
	1701	4.6L 4V V8	AT 4 spd	12V		LUB	EFR				ASL	TORQ	IACC 12V			LRR				$214
	1702	4.2L 4V V6 + CCP + GDI	AT 8 spd	12V		LUB	EFR	GDI-V8>V6	V8 DOHC to V6 DOHC		ASL	TORQ	IACC 12V	EPS	AERO 1	LRR			3%	$860
	1703	4.2L 4V V6 + CCP + Deac + GDI	AT 8 spd	12V		LUB	EFR	GDI-V8>V6	V8 DOHC to V6 DOHC		ASL	TORQ	IACC 12V	EPS	AERO 1	LRR			5%	$1,155
	1704	4.2L 4V V6 + CCP + Deac + GDI	DCT 6 spd	42V S-S		LUB	EFR	GDI-V8>V6	V8 DOHC to V6 DOHC				IACC 42V	EPS	AERO 1	LRR			10%	$1,941
	1705	2.8L 4V V6 Turbo + DCP + GDI	DCT 6 spd	42V S-S		LUB	EFR	GDI-V8>V6	V8 DOHC to V6 DOHC				IACC 42V	EPS	AERO 1	LRR			10%	$2,648
	1708	3.0L V6 Turbo Diesel	DCT 6 spd	12V		LUB	EFR	Diesel		Diesel-SCR				EPS	AERO 1	LRR			5%	$2,839
	1709	4.2L 4V V6 HEV (2-mode) + CCP + Deac + GDI	N/A	HEV		LUB	EFR	GDI-V8>V6	V8 DOHC to V6 DOHC						AERO 1	LRR				$5,921
Large Truck (+ Van) V6 (Type 18)	**1800**	**4.0L 4V DOHC V6**	**AT 4 spd**	**12V**																
	1801	4.0L 4V V6	AT 4 spd	12V		LUB	EFR				ASL	TORQ	IACC 12V			LRR				$239
	1802	3.6L 4V V6 + CCP + GDI	AT 6 spd	12V		LUB	EFR	GDI-V6			ASL	TORQ	IACC 12V		AERO 1	LRR			3%	$948
	1803	3.6L 4V V6 + CCP + DVVL + GDI	AT 6 spd	12V		LUB	EFR	GDI-V6			ASL	TORQ	IACC 12V		AERO 1	LRR			5%	$1,332
	1804	3.6L 4V V6 + CCP + Deac + GDI	AT 6 spd	12V		LUB	EFR	GDI-V6			ASL	TORQ	IACC 12V		AERO 1	LRR			5%	$1,242
	1805	3.6L 4V V6 + CCP + Deac + GDI	DCT 6 spd	42V S-S		LUB	EFR	GDI-V6					IACC 42V	EPS	AERO 1	LRR	LDB		10%	$2,172
	1806	2.5L 4V I4 Turbo + DCP + GDI	DCT 6 spd	42V S-S		LUB	EFR	GDI-V6>I4	V6 DOHC to I4				IACC 42V	EPS	AERO 1	LRR	LDB		10%	$2,138
	1809	2.8L I4 Turbo Diesel	DCT 6 spd	12V		LUB	EFR	Diesel		Diesel-SCR					AERO 1	LRR	LDB		5%	$3,579
	1810	3.6L 4V V6 HEV (IMA) + CCP + Deac + GDI	DCT 6 spd	HEV		LUB	EFR	GDI-V6							AERO 1	LRR	LDB			$5,287
	1811	3.6L 4V V6 HEV (2-mode) + CCP + Deac + GDI	N/A	HEV		LUB	EFR	GDI-V6							AERO 1	LRR	LDB			$8,000
Large Truck (+ Van) V8 (Type 19)	**1900**	**5.6L 4V DOHC V8**	**AT 4 spd**	**12V**																
	1901	5.6L 4V V8	AT 4 spd	12V		LUB	EFR				ASL	TORQ	IACC 12V			LRR				$239
	1902	4.6L 4V V8 + CCP + GDI	AT 6 spd	12V		LUB	EFR	GDI-V8			ASL	TORQ	IACC 12V		AERO 1	LRR			3%	$1,033
	1903	4.6L 4V V8 + CCP + Deac + GDI	AT 6 spd	12V		LUB	EFR	GDI-V8			ASL	TORQ	IACC 12V		AERO 1	LRR			5%	$1,353
	1904	4.6L 4V V8 + CCP + Deac + GDI	DCT 6 spd	42V S-S		LUB	EFR	GDI-V8					IACC 42V	EPS	AERO 1	LRR	LDB		10%	$2,351
	1905	3.5L 4V V6 Turbo + DCP + GDI	DCT 6 spd	42V S-S		LUB	EFR	GDI-V8>V6	V8 DOHC to V6 DOHC				IACC 42V	EPS	AERO 1	LRR	LDB		10%	$2,807
	1908	3.5L V6 Turbo Diesel	DCT 6 spd	12V		LUB	EFR	Diesel		Diesel-SCR					AERO 1	LRR	LDB		5%	$3,646
	1909	4.6L 4V V8 HEV (2-mode) + CCP + Deac + GDI	N/A	HEV		LUB	EFR	GDI-V8							AERO 1	LRR	LDB			$8,044

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

Technology Package	Engine	Transmission	System Voltage	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	CO2 % Reduction
100	**1.5L 4V DOHC I4**	**AT 4 spd**	**12V**												
101	1.5L 4V I4	AT 4 spd	12V	$206	$202	$197	$193	$189	$189	$189	$189	$189	$189	$182	7.6%
102	1.5L 4V I4 + CCP	DCT 6 spd	12V	$578	$562	$547	$532	$518	$518	$518	$518	$518	$518	$498	18.9%
103	1.2L 4V I3 + CCP + DVVL + GDI	dry DCT 6 spd	42V S-S	$1,506	$1,479	$1,343	$1,230	$1,205	$1,205	$1,205	$1,205	$1,205	$1,205	$1,116	33.2%
104	1.0L 4V I3 (small) Turbo + DCP + GDI	dry DCT 6 spd	42V S-S	$2,144	$2,098	$1,943	$1,812	$1,770	$1,770	$1,770	$1,770	$1,770	$1,770	$1,624	36.4%
200	**2.4L 4V DOHC I4**	**AT 4 spd**	**12V**												
201	2.4L 4V I4	AT 4 spd	12V	$206	$202	$197	$193	$189	$189	$189	$189	$189	$189	$182	7.6%
203	2.0L 4V I4 + CCP + GDI	DCT 6 spd	12V	$748	$728	$708	$688	$669	$669	$669	$669	$669	$669	$638	20.0%
204	2.0L 4V I4 + CCP + DVVL + GDI	dry DCT 6 spd	42V S-S	$1,810	$1,774	$1,629	$1,508	$1,475	$1,475	$1,475	$1,475	$1,475	$1,475	$1,380	35.4%
207	1.2L 4V I4 Plug-in HEV (IMA) + GDI (50% UF)	dry DCT 6 spd	HEV	$15,595	$15,587	$12,525	$10,074	$10,066	$10,066	$10,066	$10,066	$10,066	$10,066	$8,611	64.5%
300	**2.4L 4V DOHC I4**	**AT 4 spd**	**12V**												
301	2.4L 4V I4	AT 4 spd	12V	$206	$202	$197	$193	$189	$189	$189	$189	$189	$189	$182	7.6%
303	2.2L 4V I4 + CCP + DVVL + GDI	DCT 6 spd	12V	$1,018	$989	$961	$934	$908	$908	$908	$908	$908	$908	$869	23.2%
304	2.2L 4V I4 + CCP + DVVL + GDI	dry DCT 6 spd	42V S-S	$1,882	$1,843	$1,697	$1,573	$1,538	$1,538	$1,538	$1,538	$1,538	$1,538	$1,441	35.4%
309	1.8L 4V I4 Plug-in HEV (Power Split) + GDI (50% UF)	N/A	HEV	$13,222	$13,081	$11,250	$9,762	$9,634	$9,634	$9,634	$9,634	$9,634	$9,634	$8,273	68.0%
400	**3.0L 4V DOHC V6**	**AT 4 spd**	**12V**												
401	3.0L 4V V6	AT 4 spd	12V	$231	$227	$222	$218	$214	$214	$214	$214	$214	$214	$207	7.6%
403	2.0L 4V I4 Turbo + DCP + GDI	DCT 6 spd	12V	$1,176	$1,143	$1,111	$1,081	$1,051	$1,051	$1,051	$1,051	$1,051	$1,051	$920	23.4%
404	2.0L 4V I4 Turbo + DCP + GDI	DCT 6 spd	42V S-S	$2,006	$1,967	$1,804	$1,668	$1,633	$1,633	$1,633	$1,633	$1,633	$1,633	$1,452	31.6%
406	2.4L I4 Turbo Diesel	DCT 6 spd	12V	$3,063	$2,974	$2,887	$2,803	$2,722	$2,722	$2,722	$2,722	$2,722	$2,722	$2,492	32.9%
408	2.8L 4V V6 HEV (2-mode) + CCP + Deac + GDI	N/A	HEV	$9,249	$9,230	$7,508	$6,127	$6,109	$6,109	$6,109	$6,109	$6,109	$6,109	$5,371	36.5%
500	**3.3L 4V DOHC V6**	**AT 4 spd**	**12V**												
501	3.3L 4V V6	AT 4 spd	12V	$231	$227	$222	$218	$214	$214	$214	$214	$214	$214	$207	7.6%
502	3.0L 4V V6 + CCP +GDI	AT 6 spd	12V	$1,102	$1,071	$1,041	$1,013	$985	$985	$985	$985	$985	$985	$949	17.9%
503	3.0L 4V V6 + CCP + Deac + GDI	AT 6 spd	12V	$1,387	$1,348	$1,310	$1,274	$1,238	$1,238	$1,238	$1,238	$1,238	$1,238	$1,193	20.6%
505	2.2L 4V I4 Turbo + DCP + GDI	DCT 6 spd	42V S-S	$2,311	$2,263	$2,092	$1,947	$1,903	$1,903	$1,903	$1,903	$1,903	$1,903	$1,713	34.3%
508	2.5L 4V I4 HEV (Power Split) + GDI	N/A	HEV	$6,008	$5,831	$5,658	$5,491	$5,329	$5,329	$5,329	$5,329	$5,329	$5,329	$4,595	37.5%
600	**4.5L 4V DOHC V8**	**AT 4 spd**	**12V**												
601	4.5L 4V V8	AT 4 spd	12V	$231	$227	$222	$218	$214	$214	$214	$214	$214	$214	$207	7.6%
602	4.0L 4V V6 + CCP+ GDI	AT 6 spd	12V	$912	$887	$863	$839	$817	$817	$817	$817	$817	$817	$772	17.9%
604	4.0L 4V V6 + CCP+ Deac + GDI	DCT 6 spd	42V S-S	$1,863	$1,828	$1,670	$1,538	$1,506	$1,506	$1,506	$1,506	$1,506	$1,506	$1,406	31.9%
609	3.0L 4V V6 HEV (2-mode) + CCP + Deac + GDI	N/A	HEV	$9,065	$9,052	$7,330	$5,951	$5,939	$5,939	$5,939	$5,939	$5,939	$5,939	$5,190	44.4%

Table 1-12 Continued

Technology Package	Engine	Transmission	System Voltage	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	CO2 % Reduction
700	**2.6L 4V DOHC I4 (I5)**	**AT 4 spd**	**12V**												
701	2.6L 4V I4	AT 4 spd	12V	$231	$227	$222	$218	$214	$214	$214	$214	$214	$214	$207	7.6%
703	2.4L 4V I4 + CCP + DVVL + GDI	DCT 6 spd	12V	$1,072	$1,042	$1,014	$986	$959	$959	$959	$959	$959	$959	$917	21.4%
704	2.4L 4V I4 + CCP + DVVL + GDI	dry DCT 6 spd	42V S-S	$2,181	$2,136	$1,969	$1,828	$1,788	$1,788	$1,788	$1,788	$1,788	$1,788	$1,679	34.7%
708	1.8L 4V I4 Turbo HEV (Power Split) + GDI	N/A	HEV	$6,884	$6,680	$6,482	$6,290	$6,104	$6,104	$6,104	$6,104	$6,104	$6,104	$5,336	39.6%
709	1.8L 4V I4 Turbo Plug-in HEV (IMA) + GDI (50% UF)	dry DCT 6 spd	HEV	$21,528	$21,504	$17,349	$14,020	$13,999	$13,999	$13,999	$13,999	$13,999	$13,999	$11,985	62.2%
800	**3.7L 2V SOHC V6**	**AT 4 spd**	**12V**												
801	3.7L 2V SOHC V6	AT 4 spd	12V	$231	$227	$222	$218	$214	$214	$214	$214	$214	$214	$207	7.6%
802	3.2L 2V SOHC V6 + CCP + GDI	AT 6 spd	12V	$1,126	$1,094	$1,064	$1,035	$1,006	$1,006	$1,006	$1,006	$1,006	$1,006	$970	17.8%
803	3.2L 2V SOHC V6 + CCP + Deac + GDI	AT 6 spd	12V	$1,295	$1,259	$1,223	$1,189	$1,156	$1,156	$1,156	$1,156	$1,156	$1,156	$1,114	19.6%
808	2.4L 4V I4 Turbo + DCP + GDI	DCT 6 spd	42V S-S	$2,588	$2,532	$2,353	$2,200	$2,149	$2,149	$2,149	$2,149	$2,149	$2,149	$1,983	32.3%
813	3.0L 4V V6 HEV (2-mode) + CCP + Deac + GDI	N/A	HEV	$8,746	$8,718	$7,146	$5,884	$5,858	$5,858	$5,858	$5,858	$5,858	$5,858	$5,177	36.3%
900	**4.0L 2V SOHC V6**	**AT 4 spd**	**12V**												
901	4.0L 2V SOHC V6	AT 4 spd	12V	$231	$227	$222	$218	$214	$214	$214	$214	$214	$214	$207	7.6%
902	3.6L 2V SOHC V6 + CCP + GDI	AT 6 spd	12V	$1,149	$1,117	$1,086	$1,056	$1,027	$1,027	$1,027	$1,027	$1,027	$1,027	$990	17.4%
903	3.6L 2V SOHC V6 + CCP + Deac + GDI	AT 6 spd	12V	$1,318	$1,281	$1,245	$1,210	$1,176	$1,176	$1,176	$1,176	$1,176	$1,176	$1,134	19.4%
907	2.4L 4V I4 Turbo + DCP + GDI	DCT 6 spd	42V S-S	$2,665	$2,607	$2,425	$2,270	$2,217	$2,217	$2,217	$2,217	$2,217	$2,217	$2,049	32.3%
911	3.2L 4V V6 HEV (2-mode) + CCP + Deac + GDI	N/A	HEV	$9,541	$9,513	$7,782	$6,392	$6,367	$6,367	$6,367	$6,367	$6,367	$6,367	$5,619	36.5%
1000	**4.7L 2V SOHC V8**	**AT 4 spd**	**12V**												
1001	4.7L 2V SOHC V8	AT 4 spd	12V	$231	$227	$222	$218	$214	$214	$214	$214	$214	$214	$207	7.6%
1004	4.2L 4V V6 + CCP + GDI	AT 6 spd	12V	$1,239	$1,204	$1,170	$1,138	$1,106	$1,106	$1,106	$1,106	$1,106	$1,106	$1,066	18.3%
1006	4.2L 4V V6 + CCP + Deac + GDI	DCT 6 spd	42V S-S	$2,632	$2,574	$2,394	$2,240	$2,187	$2,187	$2,187	$2,187	$2,187	$2,187	$2,078	34.3%
1011	4.2L 4V V6 HEV (2-mode) + CCP + Deac + GDI	N/A	HEV	$9,316	$9,294	$7,570	$6,187	$6,167	$6,167	$6,167	$6,167	$6,167	$6,167	$5,427	36.5%
1100	**4.2L 2V SOHC V6**	**AT 4 spd**	**12V**												
1101	4.2L 2V SOHC V6	AT 4 spd	12V	$256	$252	$247	$243	$239	$239	$239	$239	$239	$239	$231	7.6%
1102	3.9L 2V SOHC V6 + CCP + GDI	AT 6 spd	12V	$1,057	$1,029	$1,001	$974	$948	$948	$948	$948	$948	$948	$914	18.3%
1103	3.9L 2V SOHC V6 + CCP + Deac + GDI	AT 6 spd	12V	$1,248	$1,213	$1,180	$1,148	$1,117	$1,117	$1,117	$1,117	$1,117	$1,117	$1,077	19.9%
1108	2.5L 4V I4 Turbo + DCP + GDI	DCT 6 spd	42V S-S	$2,778	$2,721	$2,528	$2,365	$2,312	$2,312	$2,312	$2,312	$2,312	$2,312	$2,138	35.1%
1200	**3.8L 2V OHV V6**	**AT 4 spd**	**12V**												
1201	3.8L 2V OHV V6	AT 4 spd	12V	$256	$252	$247	$243	$239	$239	$239	$239	$239	$239	$231	7.6%
1202	3.2L 4V DOHC V6 + CCP + GDI	AT 6 spd	12V	$1,582	$1,537	$1,495	$1,453	$1,413	$1,413	$1,413	$1,413	$1,413	$1,413	$1,362	18.9%
1204	3.2L 4V DOHC V6 + CCP + Deac + GDI	DCT 6 spd	42V S-S	$3,145	$3,076	$2,873	$2,700	$2,637	$2,637	$2,637	$2,637	$2,637	$2,637	$2,509	34.9%
1205	2.5L 4V I4 Turbo + DCP + GDI	DCT 6 spd	42V S-S	$3,285	$3,212	$3,005	$2,827	$2,760	$2,760	$2,760	$2,760	$2,760	$2,760	$2,582	35.1%

Table 1-12 Continued

Technology Package	Engine	Transmission	System Voltage	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	CO2 % Reduction
1300	**5.7L 2V OHV V8**	**AT 4 spd**	**12V**												
1301	5.7L 2V OHV V8	AT 4 spd	12V	$256	$252	$247	$243	$239	$239	$239	$239	$239	$239	$231	7.6%
1302	5.2L 2V OHV V8 + CCP + GDI	AT 6 spd	12V	$1,107	$1,077	$1,048	$1,020	$993	$993	$993	$993	$993	$993	$957	18.3%
1303	5.2L 2V OHV V8 + CCP + Deac + GDI	AT 6 spd	12V	$1,298	$1,262	$1,228	$1,194	$1,162	$1,162	$1,162	$1,162	$1,162	$1,162	$1,120	19.9%
1306	4.6L 4V V8 + CCP + Deac + GDI	DCT 6 spd	42V S-S	$3,397	$3,320	$3,110	$2,929	$2,859	$2,859	$2,859	$2,859	$2,859	$2,859	$2,724	34.9%
1307	3.5L 4V V6 Turbo + DCP + GDI	DCT 6 spd	42V S-S	$3,910	$3,819	$3,593	$3,398	$3,314	$3,314	$3,314	$3,314	$3,314	$3,314	$3,096	35.1%
1400	**5.4L 3V SOHC V8**	**AT 4 spd**	**12V**												
1401	5.4L 3V SOHC V8	AT 4 spd	12V	$256	$252	$247	$243	$239	$239	$239	$239	$239	$239	$231	7.6%
1402	4.6L 4V DOHC V8 + CCP + GDI	AT 6 spd	12V	$1,393	$1,355	$1,317	$1,281	$1,246	$1,246	$1,246	$1,246	$1,246	$1,246	$1,201	18.9%
1404	4.6L 4V DOHC V8 + CCP + Deac + GDI	DCT 6 spd	42V S-S	$3,063	$2,996	$2,796	$2,624	$2,564	$2,564	$2,564	$2,564	$2,564	$2,564	$2,439	34.9%
1405	3.5L 4V V6 Turbo + DCP + GDI	DCT 6 spd	42V S-S	$3,501	$3,421	$3,208	$3,024	$2,952	$2,952	$2,952	$2,952	$2,952	$2,952	$2,765	35.1%
1500	**3.2L 4V DOHC V6**	**AT 4 spd**	**12V**												
1501	3.2L 4V V6	AT 4 spd	12V	$231	$227	$222	$218	$214	$214	$214	$214	$214	$214	$207	7.6%
1502	2.8L 4V V6 + CCP + GDI	AT 6 spd	12V	$1,126	$1,094	$1,064	$1,035	$1,006	$1,006	$1,006	$1,006	$1,006	$1,006	$970	17.8%
1505	2.8L 4V V6 + CCP + Deac + GDI	DCT 6 spd	42V S-S	$2,078	$2,037	$1,873	$1,734	$1,697	$1,697	$1,697	$1,697	$1,697	$1,697	$1,605	31.8%
1511	3.0L 4V V6 HEV (2-mode) + CCP + Deac + GDI	N/A	HEV	$8,454	$8,435	$6,872	$5,618	$5,600	$5,600	$5,600	$5,600	$5,600	$5,600	$4,929	35.8%
1600	**3.5L 4V DOHC V6**	**AT 4 spd**	**12V**												
1601	3.5L 4V V6	AT 4 spd	12V	$231	$227	$222	$218	$214	$214	$214	$214	$214	$214	$207	7.6%
1602	3.2L 4V V6 + CCP + GDI	AT 6 spd	12V	$1,149	$1,117	$1,086	$1,056	$1,027	$1,027	$1,027	$1,027	$1,027	$1,027	$990	17.4%
1605	2.4L 4V I4 Turbo + DCP + GDI	DCT 6 spd	42V S-S	$2,099	$2,057	$1,892	$1,753	$1,715	$1,715	$1,715	$1,715	$1,715	$1,715	$1,531	31.6%
1609	3.2L 4V V6 HEV (2-mode) + CCP + Deac + GDI	N/A	HEV	$9,249	$9,230	$7,508	$6,127	$6,109	$6,109	$6,109	$6,109	$6,109	$6,109	$5,371	36.5%
1700	**4.6L 4V DOHC V8**	**AT 4 spd**	**12V**												
1701	4.6L 4V V8	AT 4 spd	12V	$231	$227	$222	$218	$214	$214	$214	$214	$214	$214	$207	7.6%
1702	4.2L 4V V6 + CCP + GDI	AT 8 spd	12V	$960	$934	$908	$884	$860	$860	$860	$860	$860	$860	$814	17.4%
1704	4.2L 4V V6 + CCP + Deac + GDI	DCT 6 spd	42V S-S	$2,354	$2,304	$2,132	$1,986	$1,941	$1,941	$1,941	$1,941	$1,941	$1,941	$1,825	33.7%
1709	4.2L 4V V6 HEV (2-mode) + CCP + Deac + GDI	N/A	HEV	$9,037	$9,024	$7,308	$5,933	$5,921	$5,921	$5,921	$5,921	$5,921	$5,921	$5,174	36.5%
1800	**4.0L 4V DOHC V6**	**AT 4 spd**	**12V**												
1801	4.0L 4V V6	AT 4 spd	12V	$256	$252	$247	$243	$239	$239	$239	$239	$239	$239	$231	7.6%
1802	3.6L 4V V6 + CCP + GDI	AT 6 spd	12V	$1,057	$1,029	$1,001	$974	$948	$948	$948	$948	$948	$948	$914	18.3%
1806	2.5L 4V I4 Turbo + DCP + GDI	DCT 6 spd	42V S-S	$2,582	$2,530	$2,343	$2,185	$2,138	$2,138	$2,138	$2,138	$2,138	$2,138	$1,936	34.5%
1900	**5.6L 4V DOHC V8**	**AT 4 spd**	**12V**												
1901	5.6L 4V V8	AT 4 spd	12V	$256	$252	$247	$243	$239	$239	$239	$239	$239	$239	$231	7.6%
1902	4.6L 4V V8 + CCP + GDI	AT 6 spd	12V	$1,152	$1,121	$1,091	$1,061	$1,033	$1,033	$1,033	$1,033	$1,033	$1,033	$996	18.3%
1904	4.6L 4V V8 + CCP + Deac + GDI	DCT 6 spd	42V S-S	$2,822	$2,763	$2,569	$2,405	$2,351	$2,351	$2,351	$2,351	$2,351	$2,351	$2,233	34.4%
1905	3.5L 4V V6 Turbo + DCP + GDI	DCT 6 spd	42V S-S	$3,338	$3,263	$3,055	$2,875	$2,807	$2,807	$2,807	$2,807	$2,807	$2,807	$2,597	34.5%

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

YEAR	PACKAGE COSTS RELATIVE TO 2016
2012	119%
2013	117%
2014	109%
2015	102%
2016	100%
2017	100%
2018	100%
2019	100%
2020	100%
2021	100%
2022+	94%

A number of the packages shown in Table 1-11 are not shown in Table 1-12 because it was determined that those 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 RIA, 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 information listed in the first seven columns is taken from Table 1-11 and/or Table 1-12. The values in the eighth 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

Technology Package	Engine	Transmission	System Voltage	Weight Reduc-tion	Total CO_2 Reduction	Total 2016 Cost	$/delta CO_2%
601	4.5L DOHC 4-Valve V8	AT 4 spd	12V	0%	7.6%	$214	$28
602	4.0L V6 GDI + CCP	AT 6 spd	12V	3%	17.9%	$817	$59
603	4.0L V6 w/ Deac GDI + CCP	AT 6 spd	42 S-S	5%	28.2%	$1567	$73
605	3.0L V6 Turbo DCP + GDI	AT 6 spd	42 S-S	5%	28.5%	$2274	$288
604	4.0L V6 w/ Deac GDI + CCP	DCT 6 spd	42 S-S	5%	31.9%	$1506	$(220)
606	3.0L V6 Turbo DCP + GDI	DCT 6spd	42 S-S	5%	32.1%	$2214	$4,568
608	3.0L V6 Turbo Diesel	DCT 6 spd	12V	5%	32.3%	$3258	$4,128
609	3.0L V6 w/ Deac GDI+CCP HEV	2-mode	HEV	0%	44.4%	$5939	$223
Remove Package 605							
601	4.5L DOHC 4-Valve V8	AT 4 spd	12V	0%	7.6%	$214	$28
602	4.0L V6 GDI + CCP	AT 6 spd	12V	3%	17.9%	$817	$59
603	4.0L V6 w/ Deac GDI + CCP	AT 6 spd	42 S-S	5%	28.2%	$1567	$73
604	4.0L V6 w/ Deac GDI + CCP	DCT 6 spd	42 S-S	5%	31.9%	$1506	($16)
606	3.0L V6 Turbo DCP + GDI	DCT 6spd	42 S-S	5%	32.1%	$2214	$4,568
608	3.0L V6 Turbo Diesel	DCT 6 spd	12V	5%	32.3%	$3258	$4,128
609	3.0L V6 w/ Deac GDI + CCP HEV	2-mode	HEV	0%	44.4%	$5939	$223
Remove Package 603							
601	4.5L DOHC 4-Valve V8	AT 4 spd	12V	0%	7.6%	$214	$28
602	4.0L V6 GDI + CCP	AT 6 spd	12V	3%	17.9%	$817	$59
604	4.0L V6 w/ Deac GDI + CCP	DCT 6 spd	42 S-S	5%	31.9%	$1506	$49
606	3.0L V6 Turbo DCP + GDI	DCT 6spd	42 S-S	5%	32.1%	$2214	$4,568
608	3.0L V6 Turbo Diesel	DCT 6 spd	12V	5%	32.3%	$3258	$4,128
609	3.0L V6 w/ Deac GDI + CCP HEV	2-mode	HEV	0%	44.4%	$5939	$223
Remove Package 606							
601	4.5L DOHC 4-Valve V8	AT 4 spd	12V	0%	7.6%	$214	$28
602	4.0L V6 GDI + CCP	AT 6 spd	12V	3%	17.9%	$817	$59
604	4.0L V6 w/ Deac GDI + CCP	DCT 6 spd	42 S-S	5%	31.9%	$1506	$49
608	3.0L V6 Turbo Diesel	DCT 6 spd	12V	5%	32.3%	$3258	$4,295
609	3.0L V6 w/ Deac GDI + CCP HEV	2-mode	HEV	0%	44.4%	$5939	$223
Remove Package 608							
601	4.5L DOHC 4-Valve V8	AT 4 spd	12V	0%	7.6%	$214	$28
602	4.0L V6 GDI + CCP	AT 6 spd	12V	3%	17.9%	$817	$59
604	4.0L V6 w/ Deac GDI + CCP	DCT 6 spd	42 S-S	5%	31.9%	$1506	$49
609	3.0L V6 w/ Deac GDI + CCP HEV	2-mode	HEV	0%	44.4%	$5939	$356

The eighth, 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 CO_2emissions. Here, however, the arithmetic difference in the effectiveness of two technology packages provides the best comparison across packages, since the base CO_2emissions 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 CO_2emission 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. The order of the packages has been rearranged slightly from that in Table 1-11 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 (package 605) is very high, while that for the engine with cylinder deactivation with a dual clutch transmission (package 604) is negative. The cause of this is that the cost of package 604 is lower than that for package 605. If package 604 can achieve a 31.9% reduction in CO_2emissions at a cost of $1,506, then there is no point in considering a package which only achieves a 28.5% reduction in CO_2emissions for a cost of $2,274. Therefore, package 605 was removed and the calculations were repeated. (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 after removing package 605.

The second set of packages now shows one obvious anomaly. Again, the ratio of incremental cost to incremental effectiveness for package 604 is negative. This occurs because package 604 achieves a higher CO2 reduction for less cost than package 603. As done above, package 603 was eliminated and the calculations were repeated using the revised set of packages shown in the third section of Table 1-14.

The third set of packages shows another anomaly. Package 606 is roughly a factor of 10 higher than any of the prior packages. This occurs because package 606 reduces CO2 emissions by only 0.2% over package 604 for an incremental cost of around $700. A manufacturer would be better off skipping package 606 and moving straight to package 608 (the diesel) since package 608 has a more attractive (although not much) ratio than does package 606. Therefore, package 606 was eliminated and the calculations were repeated using the revised set of packages shown in the fourth section of Table 1-14.

The greatest anomaly in the fourth set of ratios is that for the diesel package 608. It is considerably less attractive than package 609 (the 2-mode hybrid). Therefore, package 608 is removed and results in the list of packages shown in the fifth and last section of Table 1-14. If EPA believed that manufacturers would prefer to implement diesel technology over strong hybridization for some reason, both packages could have been left in the modeling. However, absent such a reason, the diesel engine package was removed from vehicle type #6. The revised set of technology packages is shown in the fourth section of Table 1-14.

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

EPA Staff Deliberative Materials--Do Not Quote or Cite

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%*	
DCP	3.0%	total VVT	Pumping	18.5% pumping, 38.2% IE, -2% fric	0	*0.0%*	Pick one
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
CVT	6.0%		Trans, pumping	46% pumping, -5% trans	0	*0.0%*	6-spd
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%*	
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%*	Pick one
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 CO_2 REDUCTION	CUMULATIVE CO_2REDUCTION
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. No commenter took issue with this concept.

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. No commenter took issue that the Ricardo work was a legitimate way to validate the lumped parameter methodology, and that it did in fact confirm that methodology's reasonable use in this rule

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 <u>major attributes and technology characteristics that are near the average of its class,</u> including engine type and displacement, transmission type, body type, weight rating, footprint size and fuel economy rating.
- <u>It should be among the sales volume leaders in its class</u>, or where there is not a clearly-established volume leader, the model should share attributes consistent with major sellers.
- <u>The vehicle should have undergone a recent update or redesign</u>, such that the technology in the baseline model could be considered representative of vehicles sold at the beginning of the 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
CO_2 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, Turbo	DCP	DCT6	EPS, EACC, HEA
	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 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. No commenter took issue with this concept.

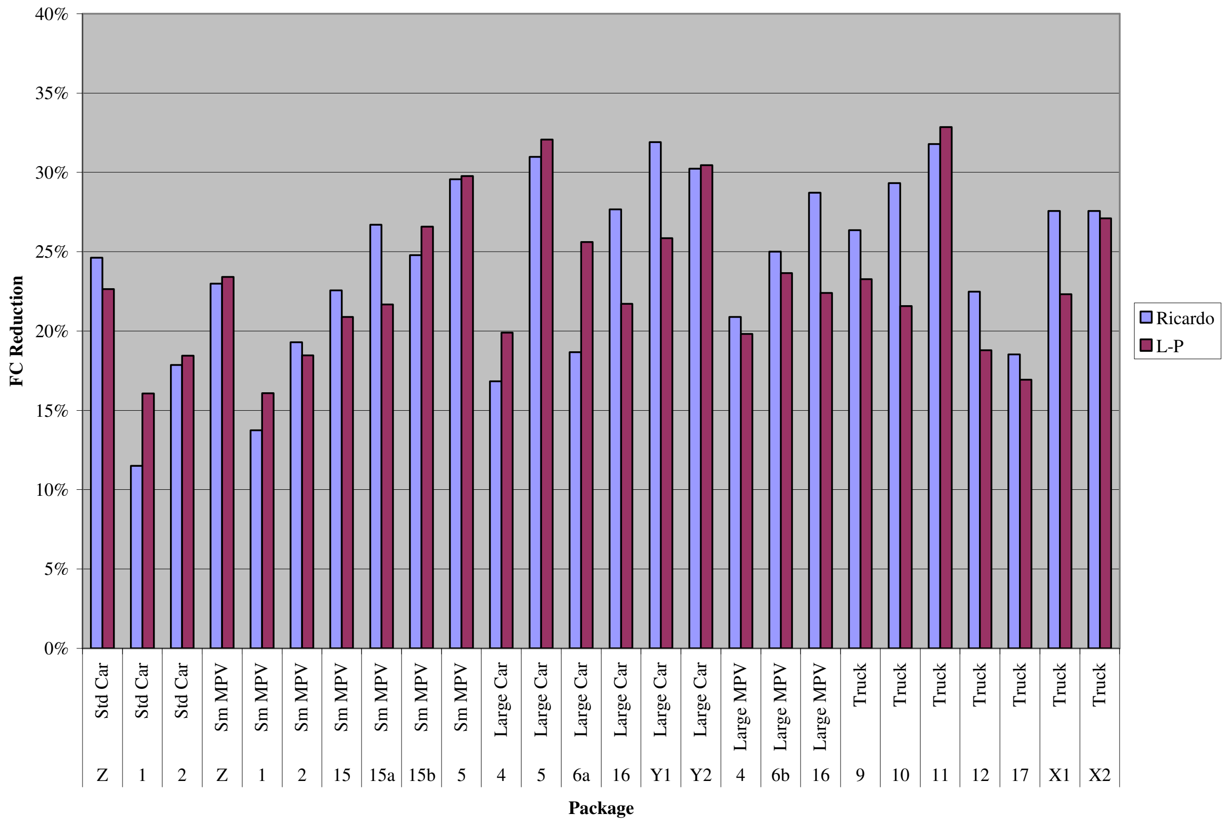

Figure 1-2 Comparison of Ricardo package results to equivalent lumped parameter package results

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.

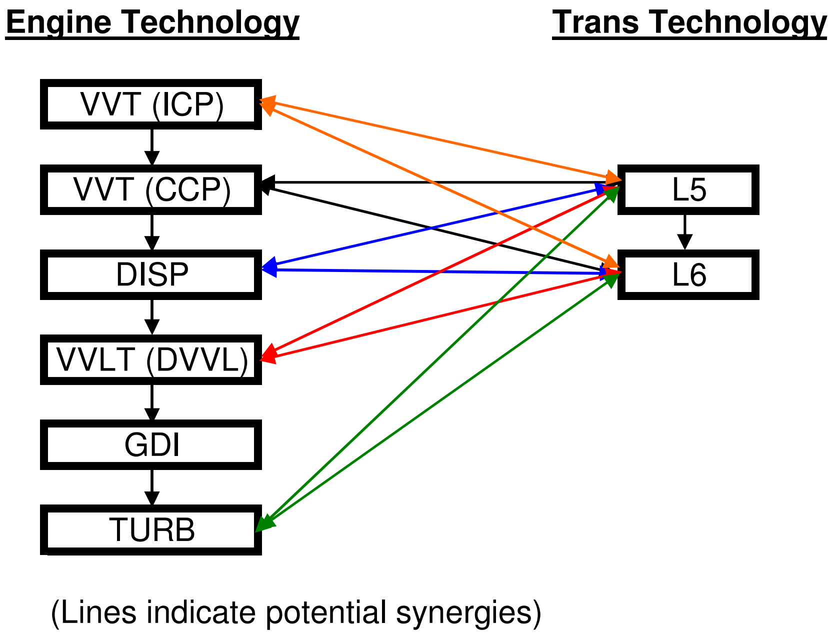

Figure 1-3 Illustration of technology pairings for a specific technology application path

References

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

[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. Docket Number: EPA-HQ-OAR-2009-0472-0162

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 mobile air conditioning (A/C) systems. In the 1970's and 1980's, A/C systems were an optional (luxury) feature, but these systems are now standard on almost all new vehicle models. The 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 (GHG) directly into the air - even when the vehicle is not in operation. No other vehicle system has associated GHG leakage. 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 (HFC) 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.[A] This means that 1 gram of R134a has the equivalent global warming potential of

[A] 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.

1,430 grams of CO_2 (which has a GWP of 1).[1] In order for the A/C system to take advantage of the refrigerant's thermodynamic properties and to exchange heat properly, the system must 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/designs 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

No substantive public comments were received during the public comment period on the size of the HFC credit or the HFC inventories presented here. Consequently, the NPRM analysis is presented here unchanged. The NPRM inventories differ slightly from the updated emission inventory analysis provided in the FRM (RIA Chapter 5) due to slight changes in sales and VMT. The global warming potentials used in this analysis are discussed in RIA chapter 5.

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.[2] 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.[3] 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.[4,B]

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 CO_2 emissions are from EPA and the National Renewable Energy Laboratory (NREL) as described below.

Table 2-1 CO_2 Equivalent Emissions from Light Duty Vehicles Broken Up by Source or Process

Emissions source or process	Tg CO_2 (equivalent)	Percentage of total
Tailpipe CO_2 (w/o A/C)	1,076	88.6%
CO_2 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 Multiplied by 1430 GWP to Convert to CO_2 Equivalent

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

[B] 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.

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.[5,6]

2.2.2.1 Why Is EPA Relying on a Design-Based Approach to Quantify Leakage?

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. In addition, at time of certification, manufacturers are required to attest that the components used in these systems are durable. 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.

As discussed in the preamble and Response to Comments document, 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 will rely on the best available design metrics to quantify system performance. A few commenters suggested that we allow manufacturers, as an option, to use an industry-developed "mini-shed" test procedure (SAE J2763 – Test Procedure for Determining Refrigerant Emissions from Mobile Air Conditioning Systems) to measure and report annual refrigerant leakage.[C] However, while EPA generally prefers performance testing, for an individual vehicle A/C

[C] Honeywell and Volvo supported this view; most other commenters did not.

system or component, there is not a strong inherent correlation between a performance test using SAE J2763 and the design-based approach we are adopting (based on SAE J2727, as discussed below).[D] Establishing such a correlation would require testing of a fairly broad range of current-technology systems in order to establish the effects of such factors as production variability and assembly practices (which are included in J2727 scores, but not in J2763 measurements). To EPA's knowledge, such a correlation study has not been done. At the same time, as discussed below, there are indications that much of the industry will eventually be moving toward alternative refrigerants with very low GWPs. EPA believes such a transition would diminish the value of any correlation studies that might be done to confirm the appropriateness of the SAE J2763 procedure as an option in this rule. For these reasons, EPA is therefore not adopting such an optional direct measurement approach to addressing refrigerant leakage at this time. 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 rule (expressed 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[E]) * (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

[D] However, there is a correlation in the fleet between J2763 measurements and J2727 scores.

[E] Section 86.166-12 sets out the individual component leakage values based on the SAE value.

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		Lowest-GWP Refrigerant (GWP=1)	
	Cars	Trucks	Cars	Trucks
MaxCredit equation input (grams /mile CO_2 EQ)	12.6	15.6	13.8	17.2
A/C credit maximum (grams /mile CO_2 EQ)[a]	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

[a] IWith electric compressor, value increases to 9.5 and 11.7 for cars and trucks, respectively.

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 (VMT).[F] 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 RIA 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.[4,7] 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),

[F] 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.

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 §86.112), as a design based test, decreases as the amount of expected leakage diminishes. 50% of the base rate is therefore 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 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).

- <u>Max Credit with Alternative Refrigerant</u>
  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.

AIAM commented that EPA should not set a lower limit on the leakage score, even for non-electric compressors. EPA has determined not to do so. First, although there do exist vehicles in the Minnesota data with lower scores than our proposed (and now final) minimum scores, there are very few car models that have scores less than 8.3, and these range from 7.0 to about 8.0 and the difference are small compared to our minimum score.[G] More important, lowering the leakage limit would necessarily increase credit opportunities for equipment design changes, and EPA believes that these changes could discourage the environmentally optimal result of using low GWP refrigerants. Introduction of low GWP refrigerants could be discouraged because it may be less costly to reduce leakage than to replace many of the A/C system components. Moreover, due to the likelihood of in-use factors, even a leak-less (according to J2727) R134a system will have some emissions due to manufacturing variability, accidents, deterioration, maintenance, and end of life emissions, a further reason to cap the amount of credits available through equipment design. The only way to guarantee a near zero emission system in-use is to use a low GWP refrigerant. The EPA has therefore decided for the purposes of this final rule to not change the minimum score for belt driven compressors due to the reason cited above and to the otherwise overwhelming support for the program as proposed from commenters.

In addition, as discussed above, EPA recognizes that substituting a refrigerant with a significantly lower GWP will be a very effective way to reduce the impact of all forms of refrigerant emissions, including maintenance, accidents, and vehicle scrappage. To address future GHG regulations in Europe and California, systems using alternative refrigerants -- including HFO1234yf, with a GWP of 4 and CO_2 with a GWP of 1 -- are under serious development and have been demonstrated in prototypes by A/C component suppliers. The European Union has enacted regulations phasing in alternative refrigerants with GWP less than 150 starting this year, and the State of California proposed providing credits for alternative refrigerant use in its GHG rule. Within the timeframe of MYs 2012-2016, EPA is not expecting widespread use of low-GWP refrigerants. However, EPA believes that these developments are promising, and, as proposed, has included in the A/C Leakage Credit formula above a factor to account for the effective GHG reductions that could be expected from refrigerant substitution. The A/C Leakage Credits that will be available will be a function of the GWP of the alternative refrigerant, with the largest credits being available for refrigerants with GWPs at or approaching a value of 1. For a hypothetical alternative refrigerant with a GWP of 1 (e.g., CO_2 as a refrigerant), effectively eliminating leakage as a GHG concern, our credit calculation method could result in maximum credits equal to total average emissions, or credits of 13.8 and 17.2 g/mi CO_2eq for cars and trucks, respectively, as incorporated into the A/C Leakage Credit formula above as the "MaxCredit" term.

[G] The Minnesota refrigerant leakage data can be found at http://www.pca.state.mn.us/climatechange/mobileair.html#leakdata

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.[8] 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 CO_2 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 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.[9] 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.[10] 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 Minimum 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. However, several commenters noted that electric A/C compressors are an enabler to lower leakage rates – beyond the minimum levels we specified - and when this technology is used in conjunction with other leakage-reducing technologies, the resulting system leakage can be lower than the minimum levels we proposed (8.3 g/yr for cars and 10.4 g/yr for trucks). We agree with the commenters that it is feasible for A/C systems with electric compressors to achieve lower leak rates than belt-driven compressors. Since compressor leakage can be responsible for more than 50% of the refrigerant leakage from a system, we are lowering the minimum leakage score for cars and trucks with electric compressors by 50%, to 4.1 and 5.2 g/yr respectively. The effect of this change will be that vehicles with electric compressors will be able to qualify for credit, on a grams-per-mile basis, than would have been possible with the limitations of the original minimum leakage score. For vehicles which do use an electric compressor, the 8.3 and 10.4 g/yr minimum leakage scores for cars and trucks are retained.

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.[4c] 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 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.[11] 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.[12] 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.[13] 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.[14] 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 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 leakage that are modeled: the "normal" leakage that results in annual refrigerant loss, and the "avoidable" leakage which results in total refrigerant loss due to failure of the A/C components (e.g. evaporator, condenser, or compressor). This model is developed to help us estimate the costs of the A/C leakage reductions. It is especially needed to determine the period over which the discounted cost savings should be applied.[H]

Normal refrigerant leakage 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 leakage rates decrease (proportionally) as the base leakage rates are decreased with the use of improved parts and components. The base leakage rate is modeled as a linear function,

[H] Air conditioning leakage controls are the only technology in this rule that have 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 CO_2 (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.

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[2] study and lower than CARB's study,[3] and thus is within the range of results in the literature.

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.

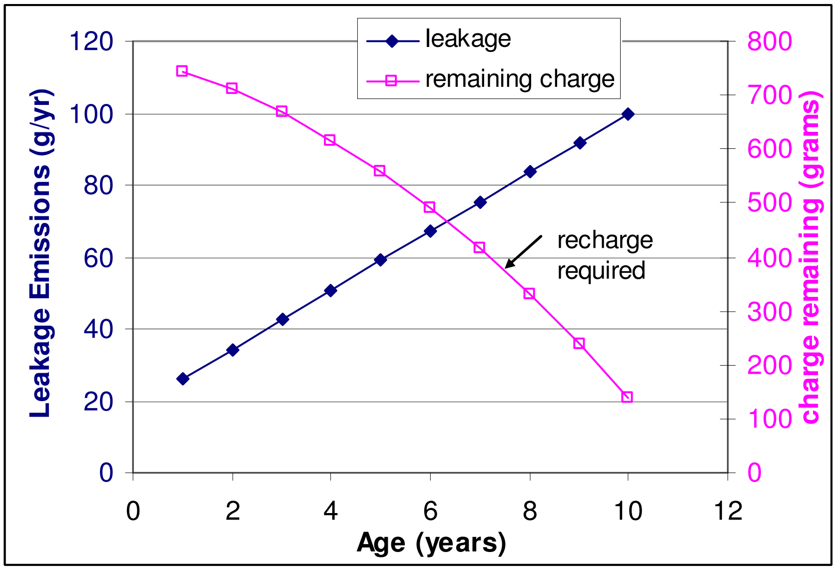

Figure 2-1 Deterioration Rate of Refrigerant Leakage

Figure 2-2 shows how the leakage rates vary with age as the initial leakage rates are decreased to meet new 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.

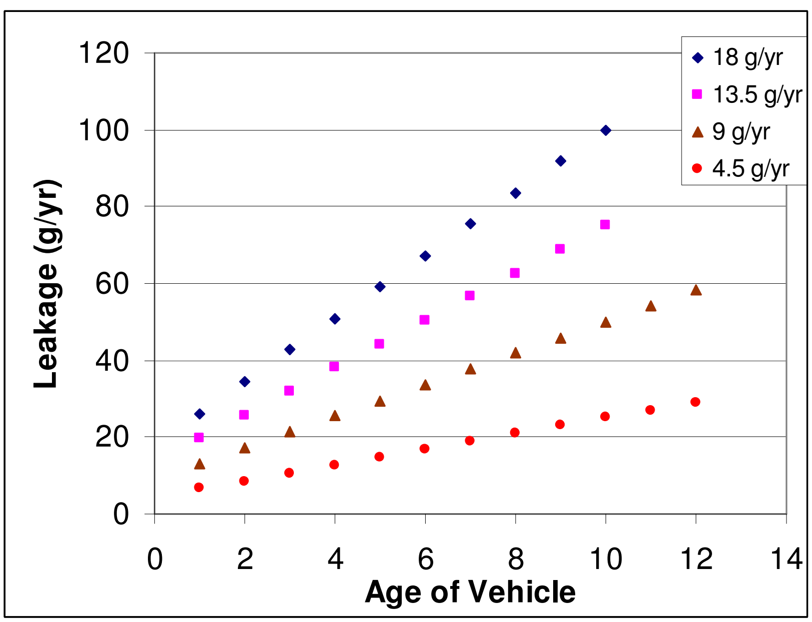

Figure 2-2 A/C Refrigerant Leakage Rate for Different Technologies as Vehicles Age

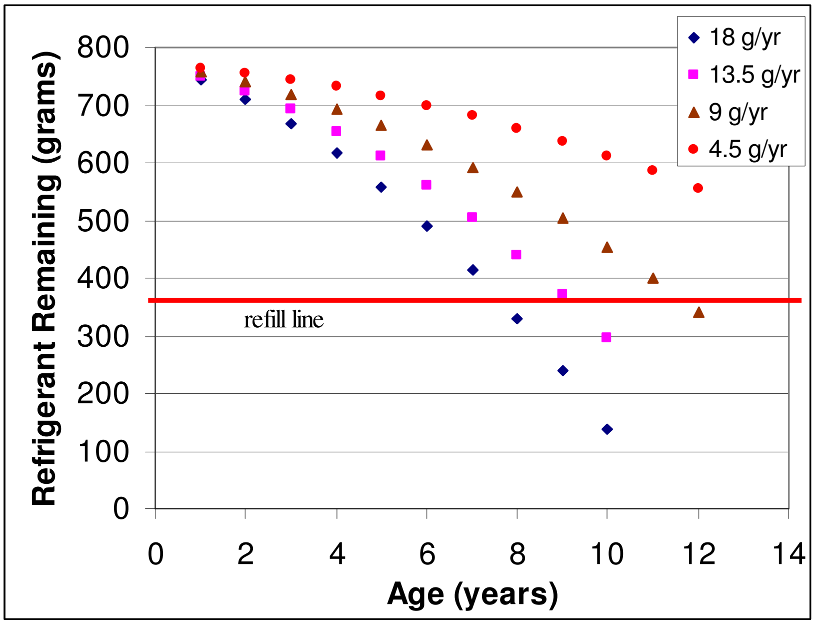

Figure 2-3 A/C Refrigerant Remaining in a Typical System as Vehicles Age and Deteriorate

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.[15] 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.[16] 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).[16]

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 CO_2 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.[17,18] 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.[19] 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.[20]

Table 2-7 CO_2 **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 CO_2 emissions were determined using a 55%/45% weighting of CO_2 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 CO_2 emissions and fuel use are equivalent, since the type of fuel being used is always gasoline.[I]

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.[20] 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.[J] 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.

[I] 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.

[J] 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.

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.[21] 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 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.[8] 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.[22] Resulting in 14.3 g/mi per vehicle CO_2 -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).[K]

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 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

[K] 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.)

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.[23] 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).[8]

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 CO_2 emissions over the FTP/HFET shown above in Table 2-7 are multiplied by a factor of 1.25 to represent onroad CO_2 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 CO_2 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 CO_2 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 CO_2 per mile. These figures were taken from Tables B-20 through B-23 of the NESCCAF report.[24] 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 CO_2 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 CO_2 per minute for the HFET cycle to that over the FTP.

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

	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 CO_2 emissions over the HFET to that over the FTP is greater than 1.0 for each of the five vehicles. VMT weighting the CO_2 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 finalizing a program that will 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 finalizing will encourage the reduction of A/C CO_2 emissions from cars and trucks by up to 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.[25] 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 its supply air from the cooler air inside the vehicle (also known as recirculated air, or ‘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 of 35-to-40% improvement is possible under the conditions of this test. 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 specifying 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 control the air supply in a ‘closed-loop’ manner, equipping their A/C systems with humidity sensors or fog sensors (which detect condensation on the inside glass), allowing them to adjust the blend of fresh-to-recirculated air and optimize the controls for maximum efficiency. In response to comments concerning the allowance of additional credit for humidity sensors (i.e. closed-loop control), we are redefining the credit available for recirculated cabin air based on how the air supply is controlled. Vehicles with closed-loop control of the air supply (i.e. sensor feedback is used to control the interior air quality) will qualify for a 1.7 g/mi CO_2 credit and vehicles with open-loop control (sensor feeback is not used to control interior air quality) will qualify for a 1.1 g/mi CO_2 credit. We believe that the closed-loop control system will be inherently more efficient than the open-loop control system because the former can maximize the amount to recirculation to achieve a desired air quality, whereas the latter will use a fixed ‘default’ amount of recirculated air which provides the desired air quality under worst case conditions (e.g. maximum number of passengers in the vehicle).

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) controller on the 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 either the blower or fan motors, an overall improvement in A/C system efficiency of 15% is possible.[26] We changed the definition for this credit from requiring waste heat reducing control on both the blower and fan motors to requiring it 'only' on the blower motor - whether or not similar control is used on the fan motor. This change was made because commenters noted the majority of the efficiency gain due to waste-heat-reducing control technology is realized on the blower motor, and not the fan motor. Since the blower motor is consuming energy almost 100% of the time (whether for heating, cooling, or ventilation, the motor is usually running at some speed whenever the vehicle is being driven), the efficiency to be gained from improved control technology is greatest on this motor, and thus credit for waste heat reducing technology will apply only when it is used on the blower motor.

2.3.2.5 Internal Heat Exchanger

An internal heat exchanger (IHX), which is alternatively described as a suction line heat exchanger, transfers heat from the high pressure liquid entering the evaporator to the gas exiting the evaporator, which reduces compressor power consumption and improves the efficiency of the A/C system. Previously, we considered that IHX technology would be required with the changeover to an alternative refrigerant such as HFO-1234yf, as the different expansion characteristics of that refrigerant (compared to R-134a) would necessitate an IHX. However, several commenters noted that an IHX can be used on R-134a systems as well, and that a significant efficiency improvement can be realized in doing so. It is estimated that use of an IHX can improve the coefficient of performance (COP) for the system can be improved by 7%, resulting in a fuel consumption reduction of 1-to-2%.[27] EPA believes that a 20% improvement in efficiency relative to the baseline configuration can be realized if the system includes an IHX, and a 1.1 g/mi credit for an IHX will be added to the list of efficiency improving technologies.

2.3.2.6 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 estimated that when fully developed, calibrated, and optimized to the requirements of particular system design, use of EXV technology could result in a 20% efficiency improvement over the baseline TXV system. However, many commenters stated that the EPA estimate for EXV efficiency was over-stated, that no manufacturers were developing this technology within the timeframe of this rulemaking, and that it should not be included on the list of efficiency-improving technologies. These commenters noted that the SAE IMAC report (from which we referenced the expected efficiency improvement) utilized an EXV in conjunction with a more efficient compressor – and not as a standalone technology. Given the uncertainty in the effectiveness of EXV technology, and the statements that no manufacturers plan on utilizing it, we are removing this technology from the list of efficiency improving technologies and credits.

2.3.2.7 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.[28] We solicited comments as to how we should define the "baseline" evaporator and condenser designs which are compared to the "improved" design. The bench test based engineering analysis that a manufacturer will submit at time of certification. We will consider the baseline component to be the version which a manufacturer most recently had in production on the same vehicle or a vehicle in a similar EPA vehicle classification. The design characteristics of the baseline component (e.g. tube configuration/thickness/spacing and fin density) are to be documented in an engineering analysis and compared to the improved components, along with data demonstrating the

COP improvement. This same engineering analysis can be applied to evaporators and condensers on other vehicles and models (even if the overall size of the heat exchanger is different), as long as the design characteristics of the baseline and improved components are the same. 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.

2.3.2.8 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.[29] 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.[11] 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. Whether the oil separator is a standalone component or is integral to the compressor design, manufacturers can submit an engineering analysis to demonstrate the effectiveness of the oil separation technology.

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 CO_2 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. In particular, EPA is specifying that the range of allowable ambient temperature for a valid A/C Idle Test be limited to 75 $\pm$ 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 $\pm$ 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 has modified 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 has revised 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 CO_2 rate for the A/C systems in todays vehicles, the EPA conducted laboratory tests to measure the amount of additional CO_2 a vehicle generated due to A/C use on the Idle Test. [30] 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 CO_2 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 CO_2 (g/min)	21.3
Standard Deviation of Test Results ($\pm$ 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 2-13). The individual test results from this testing are shown in Figure 2-4. EPA attempted to find a correlation between the A/C CO_2 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 CO_2 result.

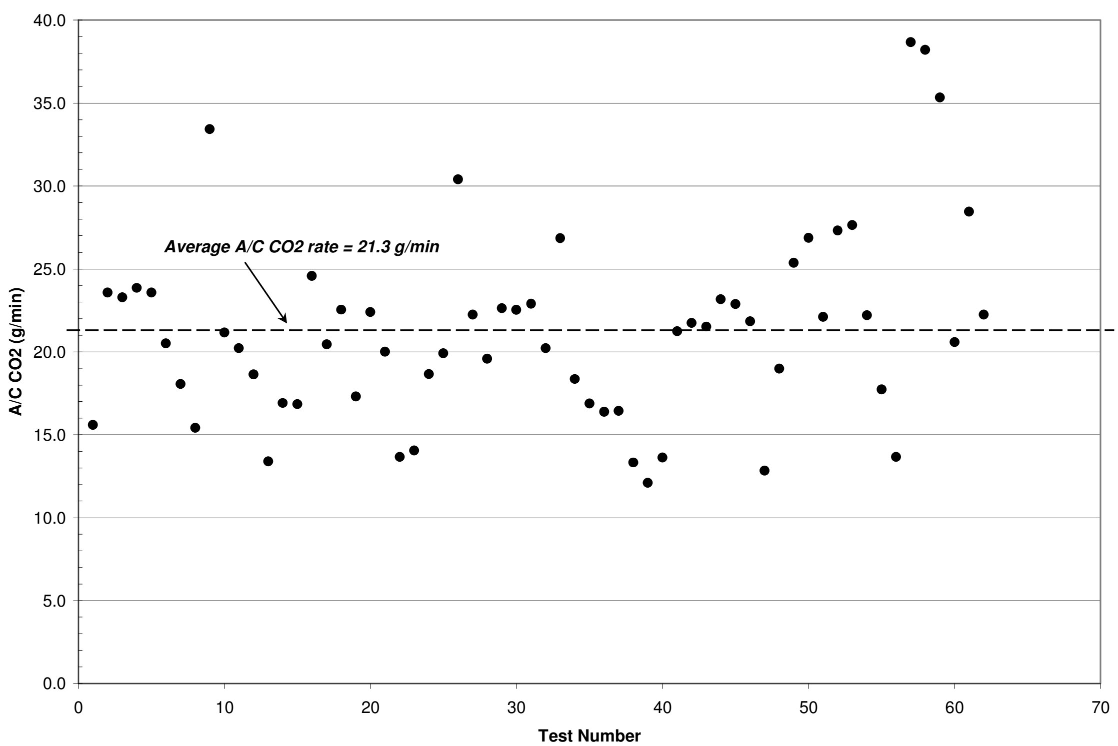

Figure 2-4 EPA A/C Idle Test Results from Various Vehicle Model Types

Part of this variation in the 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 CO_2 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. Many commenters questioned the ability of the A/C Idle Test to measure the effect of certain A/C technologies (e.g. technologies which improve performance under higher cooling load conditions), and stated that the test was not representative of real-world driving conditions. While we acknowledge that there are limitations to the Idle Test, we have determined that it is still a valid tool evaluating the efficiency of a vehicle's A/C system under conditions encountered in daily driving. Moreover, we believe that a performance test is necessary to assure that efficiency-improving technologies are implemented properly and that the vehicle's A/C system operates in an efficient manner under idle conditions. In the future, EPA will continue to work with industry groups, manufacturers, component suppliers, and other government organizations to develop a procedure for determining A/C system efficiency which incorporates the appropriate test-bench, modeling, and drive cycle tools. The goal of this exercise is the development of a reliable, accurate, and verifiable assessment and testing method which minimizes a manufacturers testing burden. This effort could include component-level assessment of A/C technologies, modeling of system control strategies, and development of a vehicle-based test procedure for validating the findings of component-level and system modeling analyses.

The average A/C CO_2 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 the full credit, it will be necessary for each model to achieve an A/C CO_2 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. Several commenters disagreed with the EPA's threshold for full credit, arguing that the 30% improvement was too aggressive. However, EPA test results on three vehicle size classes (large car, SUV, and pickup truck) indicate that significant reductions in fuel consumption can be achieved by simply switching A/C control from outside air (OSA) to recirculated cabin air. As shown in , the percentage reduction in the CO2 due to A/C use was greater than 30% in all three cases.

Table 2-12 Effect of Outside Air and Recirculated Cabin Air on A/C Idle Test Results (EPA Testing)

Vehicle Type	A/C CO2 Result (g/min)		Change in A/C CO2 w/Recirc (%)
	w/Outside Air	*w/Recirc Cabin Air*	
Large Car	25.9	14.0	-45.9
SUV	17.4	11.4	-34.5
Pickup Truck	14.1	9.0	-36.2

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. However, to avoid having an all-or-nothing threshold of 14.9 g/min on the Idle Test to qualify for credits, EPA will allow amount of credit to be scaled to Idle Test result, with vehicles achieving 14.9 g/min or better receiving full credit, and vehicles achieving 21.3 g/min or higher receiving no credit, as shown in Figure 2-5.

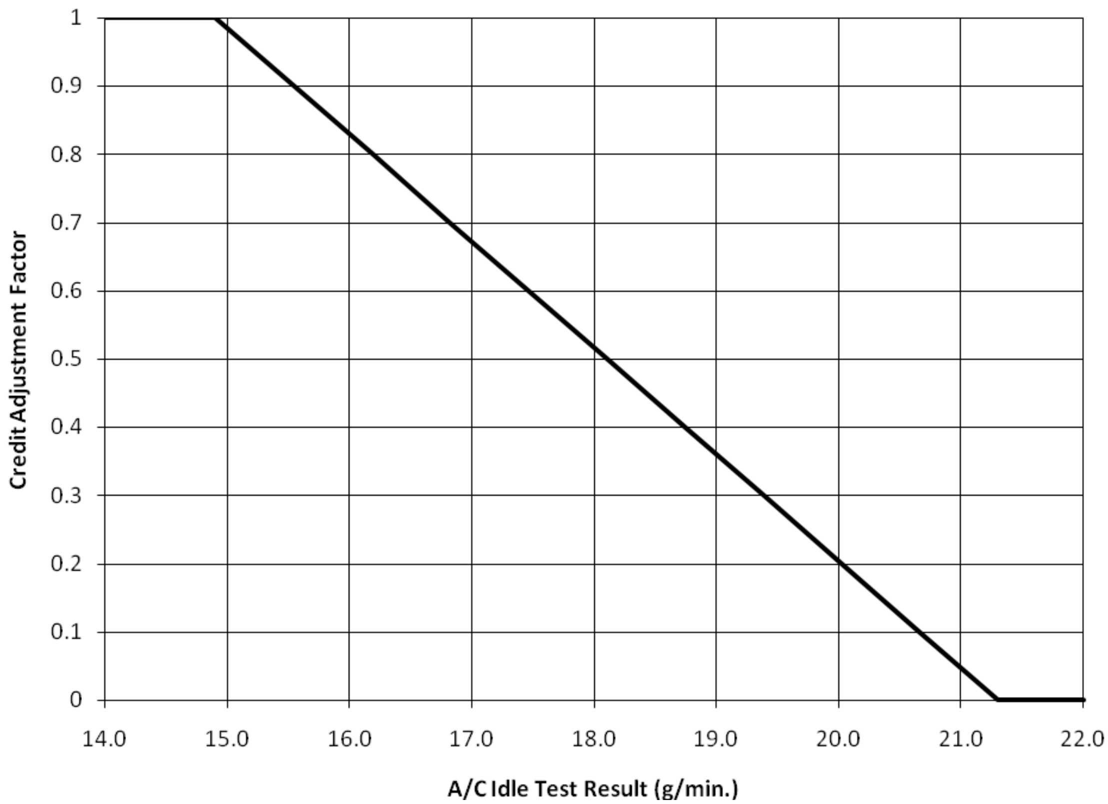

Figure 2-5 A/C Credit Adjustment Factor.

Once manufacturers begin using the technologies described in Table 2-13 – 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 CO_2 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 CO_2 '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 2-13. 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 CO_2 -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.[31] 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 2-13 Efficiency-Improving A/C Technologies and Credits

Technology Description	Estimated Reduction in A/C CO_2 Emissions	A/C Credit (g/mi CO_2)
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 with closed-loop control of the air supply (sensor feedback to control interior air quality) whenever the outside ambient temperature is 75 °F or higher (although deviations from this temperature are allowed if accompanied by an engineering analysis)	30%	1.7
Default to recirculated air with open-loop control of the air supply (no sensor feedback) whenever the outside ambient temperature is 75 °F or higher (although deviations from this temperature are allowed if accompanied by an engineering analysis)	20%	1.1
Blower motor control which limit wasted electrical energy (e.g. pulsewidth modulated power controller)	15%	0.9
Internal heat exchanger (or suction line heat exchanger)	20%	1.1
Improved evaporators and condensers (with engineering analysis on each component indicating a COP improvement greater than 10%, when compared to previous design)	20%	1.1
Oil Separator (internal or external to compressor)	10%	0.6

The estimates for the percent reduction in A/C CO_2 for each technology are 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 CO_2 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 CO_2 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.[L] 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 2-14 shows how these costs may be distributed on a year by year basis as the 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.[32] 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

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

these potential maintenance savings are not included in the cost and benefit analysis presented in Chapters 6 and 8 of this RIA. 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.

For indirect CO_2 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.[M] The IMAC Efficiency Improvement team of the Society of Automotive Engineers realized an efficiency improvement of 36.4% based on existing technologies and processes.[25] 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 RIA, the indirect AC fuel savings has been included in the total fuel savings resulting from this rulemaking.

Table 2-14 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.

[M] 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.

Table 2-14 Estimated Costs in Each Model Year for New AC Technology, 2007 Dollars

	2012	2013	2014	2015	2016
Penetration	28%	40%	60%	80%	85%
AC Leakage (Direct)	$5	$7	$11	$14	$15
AC Indirect	$15	$21	$32	$42	$45
Total	$20	$28	$42	$56	$60

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 RIA 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 2-15).

Table 2-15 Credit Summary with Estimated Penetration Rates

	Model Year				
	2012	**2013**	**2014**	**2015**	**2016**
Estimated Penetration	28%	40%	60%	80%	85%
Car Sales Fraction	61.1%	61.9%	63.2%	64.6%	65.6%
Truck Sales Fraction	38.9%	38.1%	36.8%	35.4%	34.4%
Car Direct Credit	1.8	2.5	3.8	5.0	5.4
Car Indirect Credit	1.6	2.3	3.4	4.6	4.8
Total Car Credit	3.4	4.8	7.2	9.6	10.2
Truck Direct Credit	2.2	3.1	4.7	6.2	6.6
Truck Indirect Credit	1.4	2.3	3.4	4.6	4.8
Total Truck credit	3.8	5.4	8.1	10.8	11.5
Fleet average credits	***3.5***	***5.0***	***7.5***	***10.0***	***10.6***

References `

[1] IPCC, Chapter 2, "Changes in Atmospheric Constituents and in Radiative Forcing," September, 2007. This document is available in Docket EPA-HQ-OAR-2009-0472-0117.

[2] 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. This document is available in Docket EPA-HQ-OAR-2009-0472-0157.

[3] Vincent, R., Cleary, K., Ayala, A., Corey, R., "Emissions of HFC-134a from Light-Duty Vehicles in California," SAE 2004-01-2256, 2004. This document is available in Docket EPA-HQ-OAR-2009-0472-0186.

[4] EPA, 2009, "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2007," http://www.epa.gov/climatechange/emissions/usinventoryreport.html. This document is available in Docket EPA-HQ-OAR-2009-0472.

[5] 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. This document is available in Docket EPA-HQ-OAR-2009-0175.

[6] State of Minnesota, "Reporting Leakage Rates of HFC-134a from Mobile Air Conditioners," http://www.pca.state.mn.us/climatechange/mac-letter-082908.pdf. This document is available in Docket EPA-HQ-OAR-2009-0472-0178.

[7] Office of Energy Efficiency and Renewable Energy, U.S. Department of Energy, "Transportation Energy Data Book: Edition 27," 2008. This document is available in Docket EPA-HQ-OAR-2009-0472

[8] 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. This document is available in Docket EPA-HQ-OAR-2009-0472.

[9] Ikegama, T., Kikuchi, K., "Field Test Results and Correlation with SAEJ2727," Proceedings of the SAE 7th Alternative Refrigerant Systems Symposium, 2006. This document is available in Docket EPA-HQ-OAR-2009-0472.

[10] Atkinson, W., Baker, J., Ikegami, T., Nickels, P., "Revised SAEJ2727: SAE Interior Climate Control Standards Committee Presentation to the European Commission," 2006. This document is available in Docket EPA-HQ-OAR-2009-0472.

[11] Society of Automotive Engineers, "IMAC Team 1 – Refrigerant Leakage Reduction, Final Report to Sponsors," 2006. This document is available in Docket EPA-HQ-OAR-2009-0472-0188.

[12] Society of Automotive Engineers Surface Vehicle Standard J2727, issued August, 2008, http://www.sae.org. This document is available in Docket EPA-HQ-OAR-2009-0472-0160.

[13] Minnesota Pollution Control Agency, "Model Year 2009 Leakage Rate List," http://www.pca.state.mn.us/climatechange/mobileair.html. This document is available in Docket EPA-HQ-OAR-2009-0472-0161.

[14] Society of Automotive Engineers, "IMAC Team 4 – Reducing Refrigerant Emissions at Service and Vehicle End of Life," June, 2007. This document is available in Docket EPA-HQ-OAR-2009-0472.

[15] Schwarz, W., "Emission of Refrigerant R-134a from Mobile Air-Conditioning Systems," Study conducted for the German Federal Environmental Office, September, 2001. This document is available in Docket EPA-HQ-OAR-2009-0472.

[16] "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. This document is available in Docket EPA-HQ-OAR-2009-0472-0167. This document is available in Docket EPA-HQ-OAR-2009-0472-0167.

[17] Johnson, V., "Fuel Used for Vehicle Air Conditioning: A State-by-State Thermal Comfort-Based Approach," SAE 2002-01-1957, 2002. This document is available in Docket EPA-HQ-OAR-2009-0472-0179.

[18] Rugh, J., Johnson, V., Andersen, S., "Significant Fuel Savings and Emission Reductions by Improving Vehicle Air Conditioning," Mobile Air Conditioning Summit, Washington DC., April 14-15, 2004. This document is available in Docket EPA-HQ-OAR-2009-0472-0179.

[19] 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. This document is available in Docket EPA-HQ-OAR-2009-0472.

[20] "Reducing Greenhouse Gas Emissions from Light-Duty Motor Vehicles," Northeast States Center for a Clean Air Future, September, 2004. This document is available in Docket EPA-HQ-OAR-2009-0472.

[21] Fuel Economy Labeling of Motor Vehicles: Revision to Improve Calculation of Fuel Economy Estimates; Final Rule, 71 FR 77872, December 27, 2006. This document is available in Docket EPA-HQ-OAR-2009-0472.

[22] EPA Technical Support Document for Fuel Economy Label Regulations, November, 2006. This document is available in Docket EPA-HQ-OAR-2009-0472.

[23] Nam, E.K., "Understanding and Modeling NOx Emissions from Automobiles During Hot Operation," PhD Thesis, University of Michigan, 1999. This document is available in Docket EPA-HQ-OAR-2009-0472.

[24] "Reducing Greenhouse Gas Emissions from Light-Duty Motor Vehicles," Northeast States Center for a Clean Air Future, September, 2004. This document is available in Docket EPA-HQ-OAR-2009-0472-0182.

[25] Society of Automotive Engineers, "IMAC Team 2 – Improved Efficiency, Final Report," April, 2006. This document is available in Docket EPA-HQ-OAR-2009-0472-0156.

[26] Memo to docket, "Meeting with Delphi and Presentation to EPA," March, 2009. This document is available in Docket EPA-HQ-OAR-2009-0472-0196.

[27] Mathur, G., "Experimental Investigation with Cross Fluted Double-Pipe Suction Line Heat Exchanger to Enhance AC System Performance," SAE 2009-01-0970, 2009. This document is available in Docket EPA-HQ-OAR-2009-0472.

[28] Society of Automotive Engineers Surface Vehicle Standard J2765, issued October, 2008, http://www.sae.org. This document is available in Docket EPA-HQ-OAR-2009-0472-0171.

[29] Barbat, T. et. Al., "CFD Study of Phase Separators in A/C Automotive Systems," SAE 2003-01-0736, 2003. This document is available in Docket EPA-HQ-OAR-2009-0472-0187.

[30] EPA, "AC Idle Test Results_Summary for docket," August, 2009. This document is available in Docket EPA-HQ-OAR-2009-0472-0183.

[31] "2009 Ward's Automotive Yearbook," Ward's Automotive Group, 2009. ISBN Number 978-0-9105-89-26-0. This document is available in Docket EPA-HQ-OAR-2009-0472-0248.

[32] 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. This document is available in Docket EPA-HQ-OAR-2009-0472.

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 rule, in developing the 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 RIA.

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 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 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.[1] 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.[2] 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 Final Rule

To determine the MY 2015 and MY 2016 fleetwide targets under the EPA final rule, 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.[3] 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.

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 3.1.2.1, 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%

One commenter, Yuli Chew, stated that he thought that the 6% per year alternative was more representative of Pavley I levels. As this analysis shows, the national GHG standard would provide 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 In their comments on the proposal, the California Air Resources Board agreed that the standards presented in this rulemaking align with California's Pavley greenhouse gas emissions standards, and ultimately arrive at the same stringency as California's standards in MY 2016.

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. [4]

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 CO_2 g/mile is essentially inversely proportional to vehicle fuel economy, expressed as miles per gallon. As part of the CAFE program, EPA measures vehicle CO_2 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 finalizing footprint-based CO_2 standards for cars and light trucks. EPA believes that this program design has the potential to promote CO_2 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 CO_2 emission targets, across all manufacturers.

In 2007, EPA evaluated several vehicle attributes on which to base CO_2 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 CO_2 emissions. Since emissions of CO_2 are controlled, there must be a reasonable degree of correlation from a technical perspective between an attribute and vehicle CO_2 emissions performance. 2) The relationship between the attribute and potential CO_2 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 CO_2 control strategies. 3) How much the attribute would encourage compliance strategies that tend to circumvent the goal of CO_2 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 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 basing the individual manufacturers fleetwide CO_2 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.

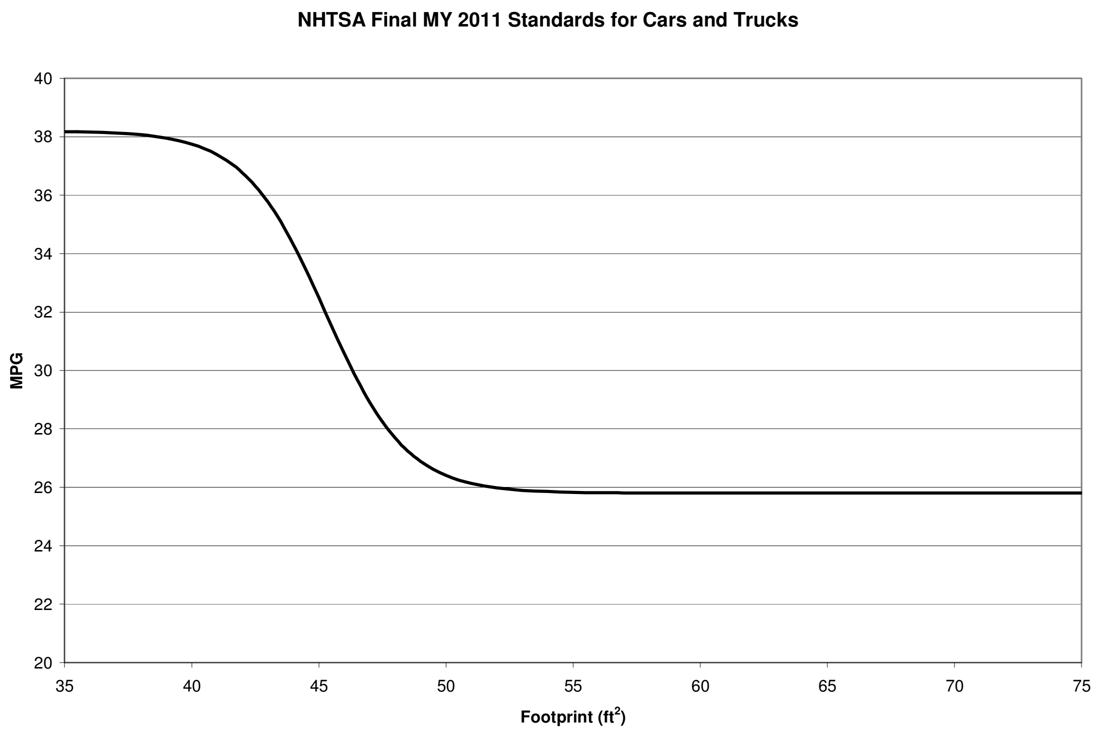

Figure 3-1 NHTSA Reformed CAFE Curve for MY 2011 Cars

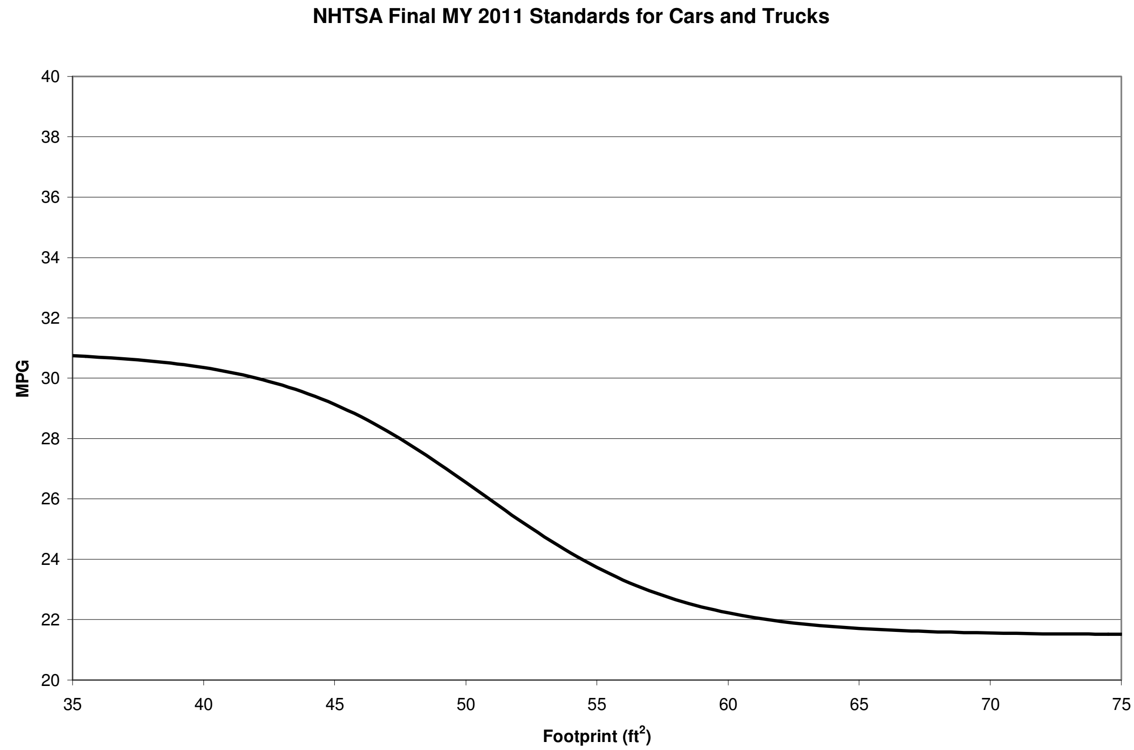

Figure 3-2 NHTSA Reformed CAFE Curve for MY 2011 Trucks

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.[5]

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 manufacturers' 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 do not appear 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 fuel economy and CO2 emission standards. The preamble of this final rule discusses the reasons for use of non-sales-weighted MAD regressions for this purpose.

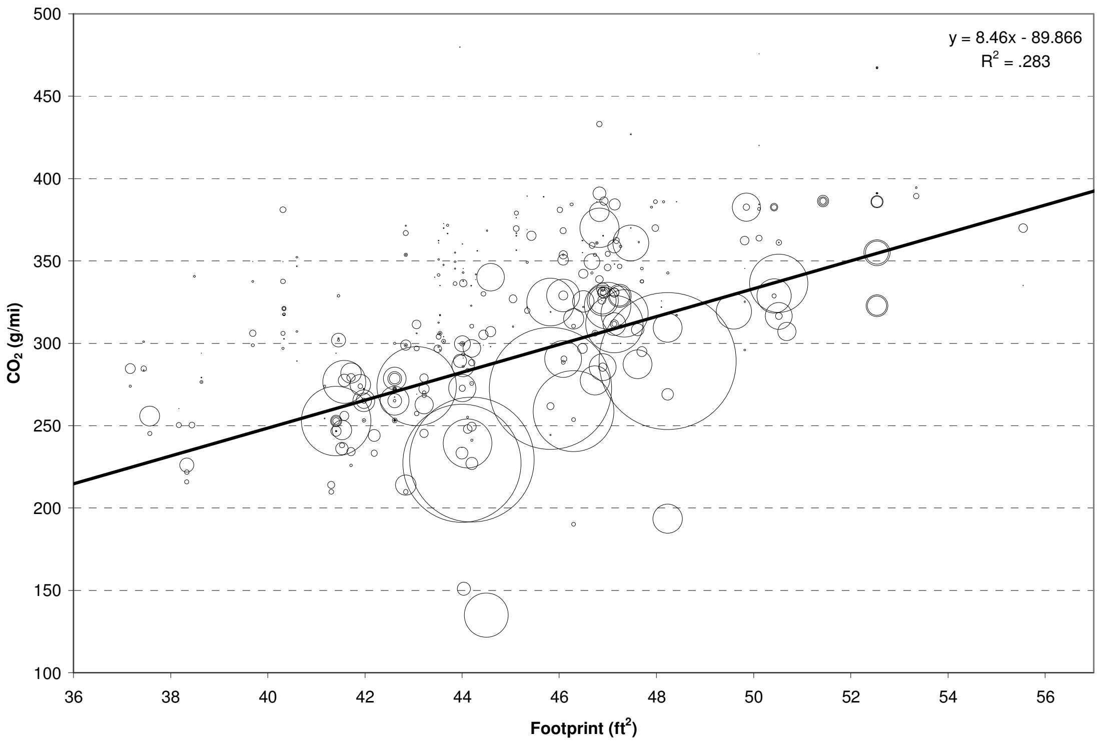

Figure 3-3 Model Year 2007 Cars; Sales-weighted Linear Regression of CO2 Tailpipe Emissions and Footprint

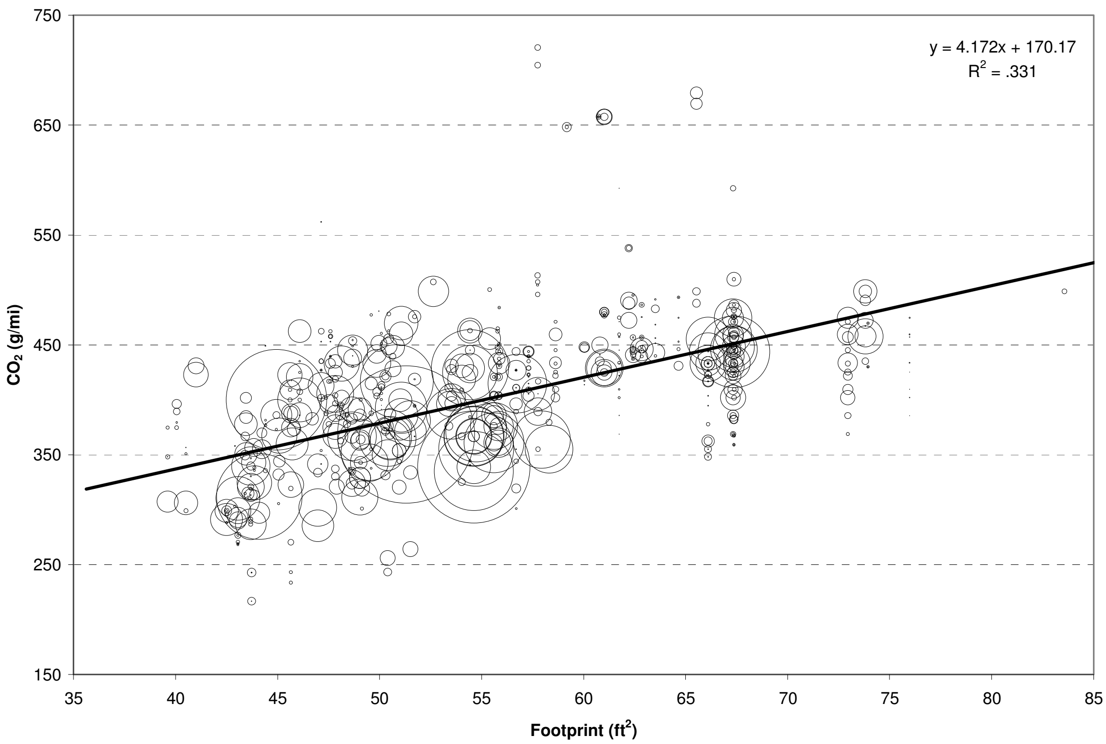

Figure 3-4 Model Year 2007 Trucks; Sales-weighted Linear Regression of CO2 Tailpipe Emissions and Footprint

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.[6] 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.[7] EPA is assuming that manufacturers can and will lightweight their vehicles at a given footprint level as a potential compliance strategy. EPA discusses the relationship of vehicle weight and safety in section 7.6 of this RIA .

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. 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 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 finalizing this metric in today's final rule, 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. See Section 3.1. 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 section III.C.1 of the preamble and Chapter 2 of the RIA, which offer an additional layer of consistency.

3.2.2 Alternative Attributes

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.

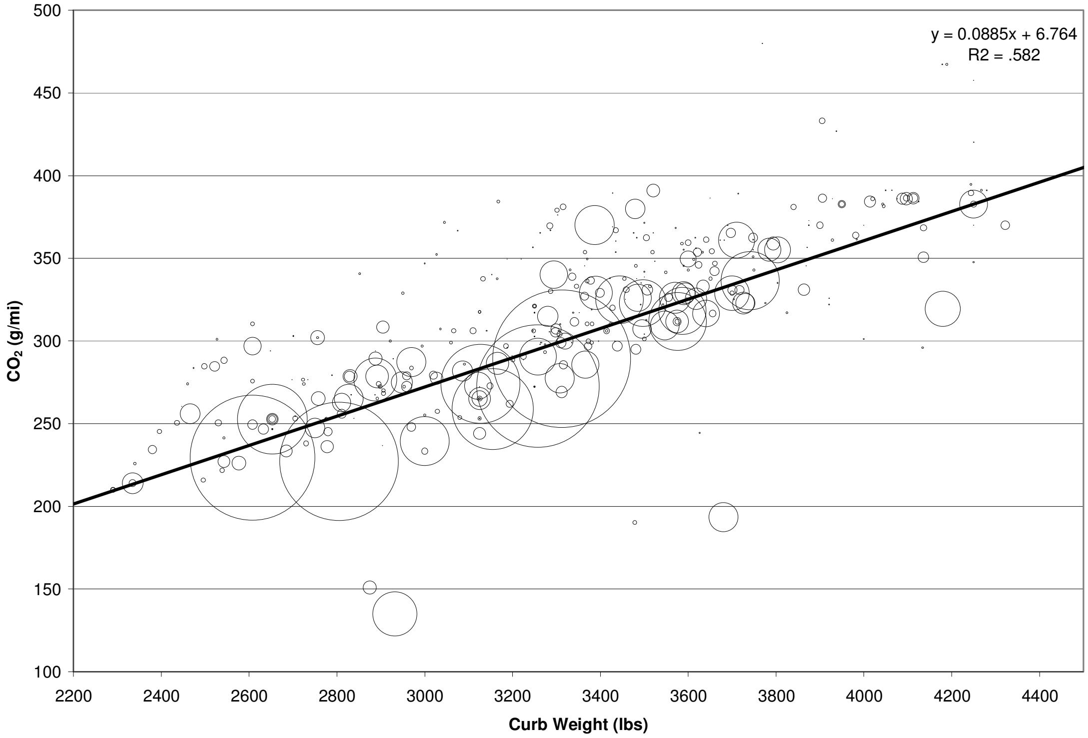

Figure 3-5 Model Year 2007 Cars; Sales-weighted Linear Regression of CO2 Tailpipe Emissions and Curb Weight

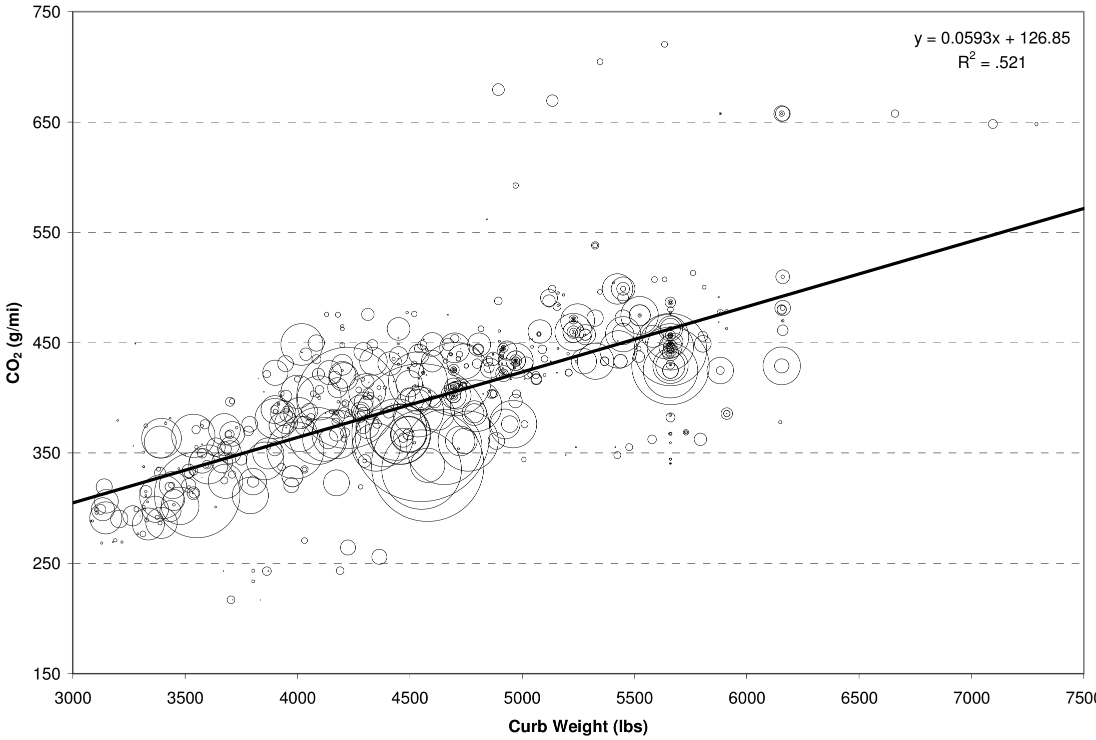

Figure 3-6 Model Year 2007 Trucks; Sales-weighted Linear Regression of CO2 Tailpipe Emissions and Curb Weight

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.[8] In fact, these studies have shown that a vehicle's size is a more important factor than weight in its effect on occupant safety. Section 7.6 of this RIA discusses in greater detail EPA's perspective on vehicle weight and 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.[9] 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.

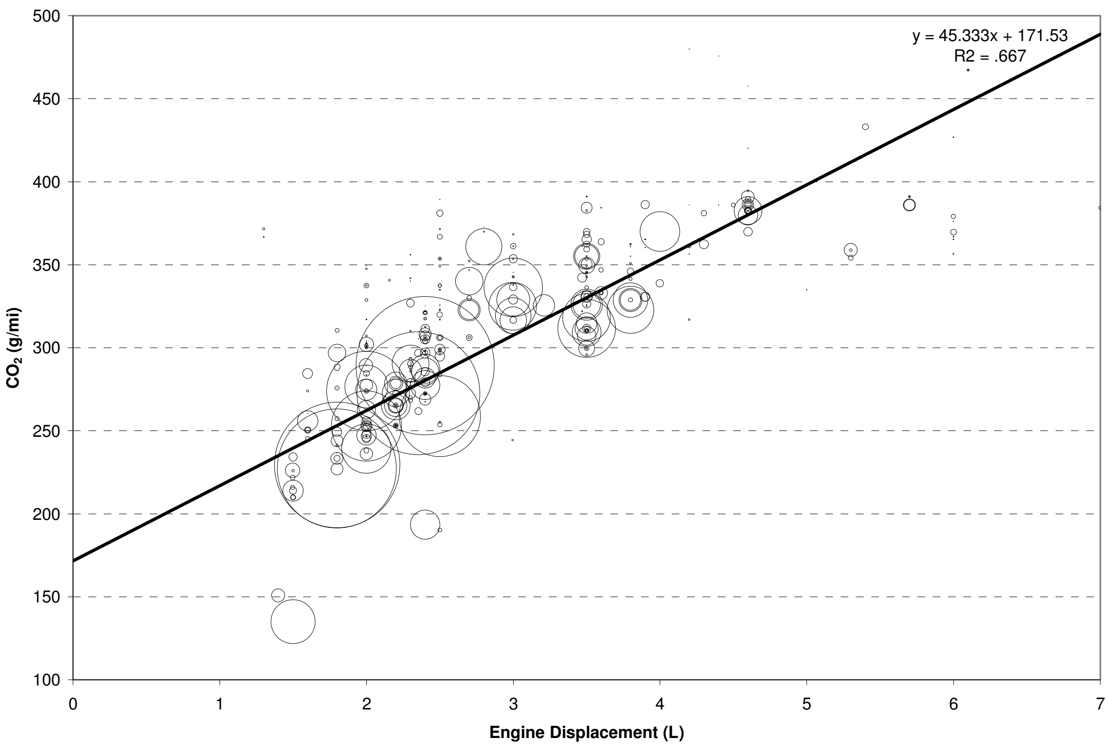

Figure 3-7 Model Year 2007 Cars; Sales-weighted Linear Regression of CO2 Tailpipe Emissions and Engine Displacement.

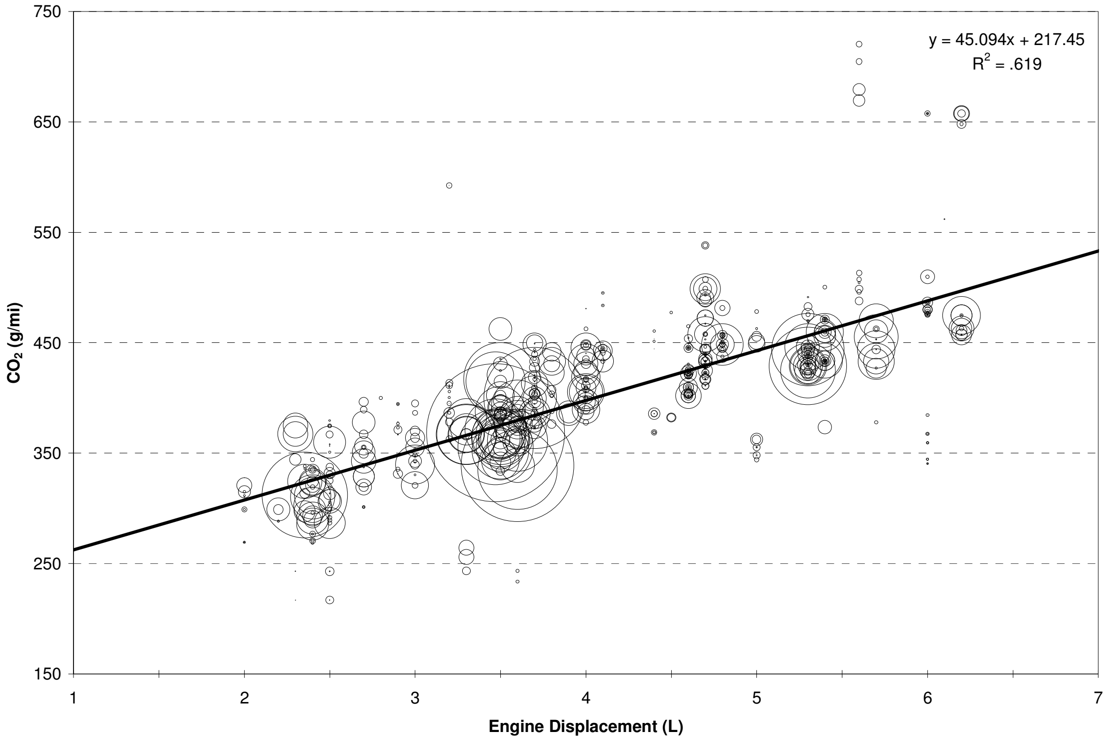

Figure 3-8 Model Year 2007 Trucks; Sales-weighted Linear Regression of CO2 Tailpipe Emissions and Engine Displacement

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 Chapter 1 of the RIA) 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.

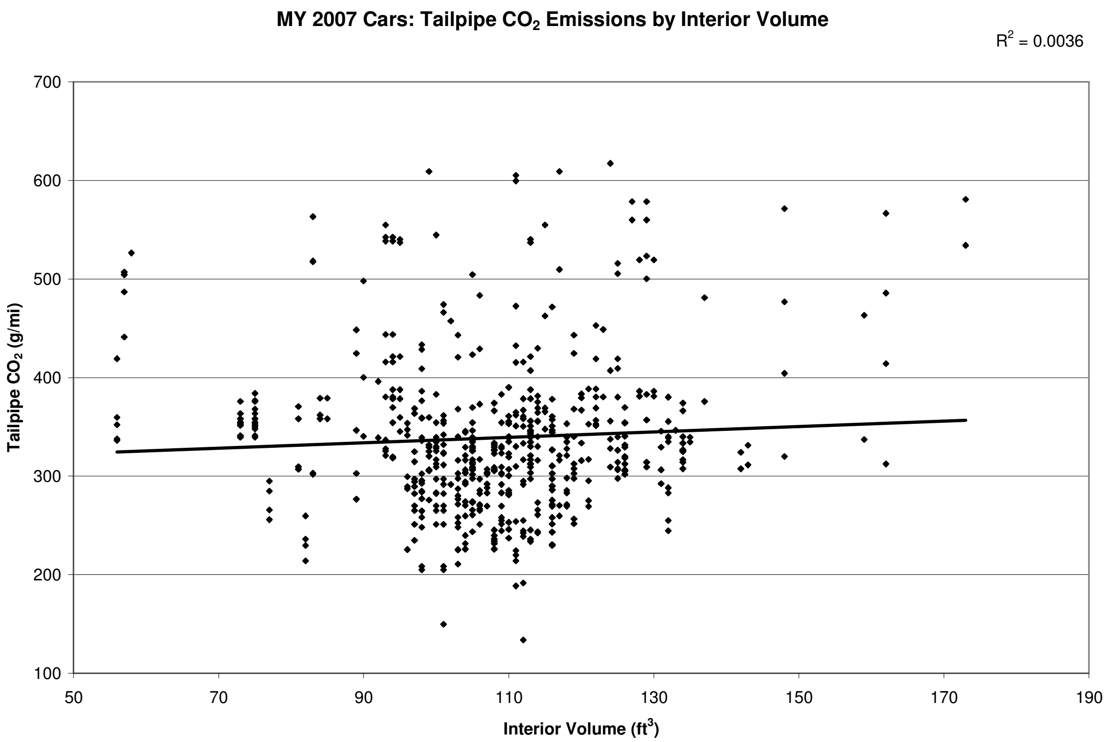

Figure 3-9 Model Year 2007 Cars; Linear Trend of CO2 Tailpipe Emissions and Engine Displacement

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 finalizing 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.

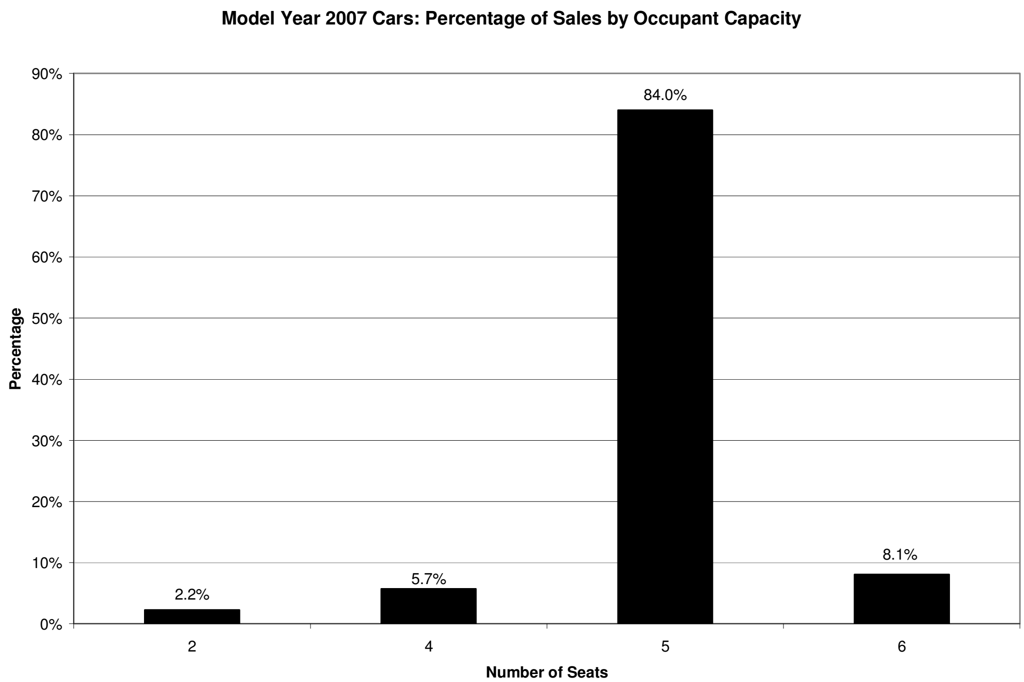

Figure 3-10 Model Year 2007 Cars; Percentage of Sales by Occupant Capacity

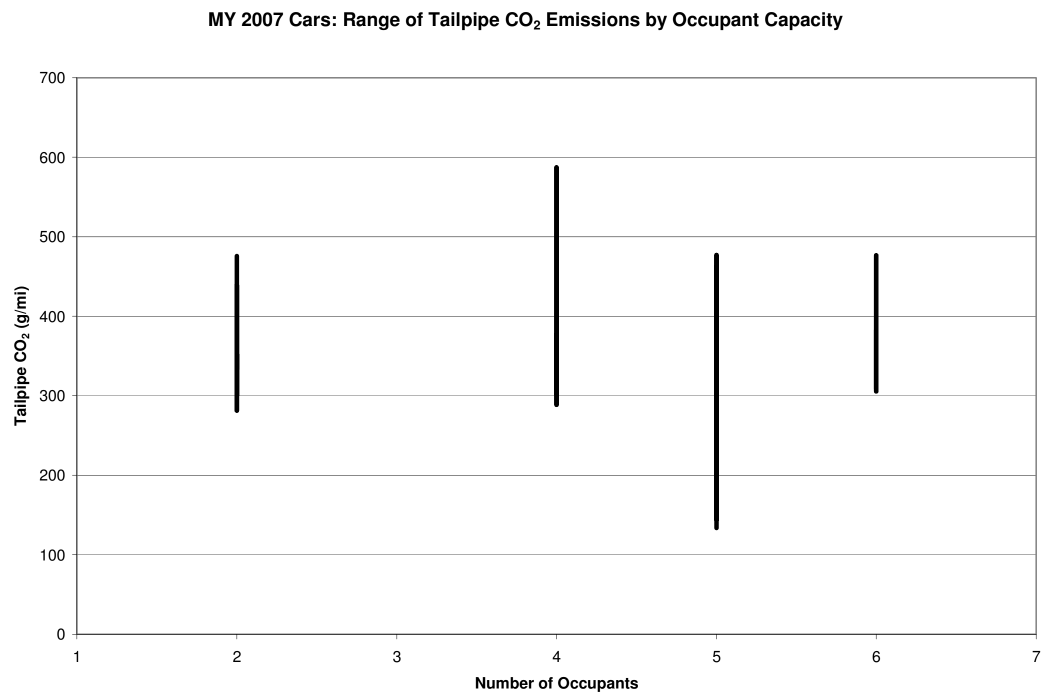

Figure 3-11 Model Year 2007 Cars; Range of Tailpipe CO2 Emissions by Occupant Capacity

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 finalizing 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[10,11] 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.

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

EPA is implementing the footprint attribute in this CO2 control program via a piecewise linear function. As mentioned above, this is the equivalent to the shape finalized by NHTSA for its CAFE standards for model years 2012-2016. The shape of this function with respect to CO2 is reflected in Figures I.B.3-3 and I.B.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.

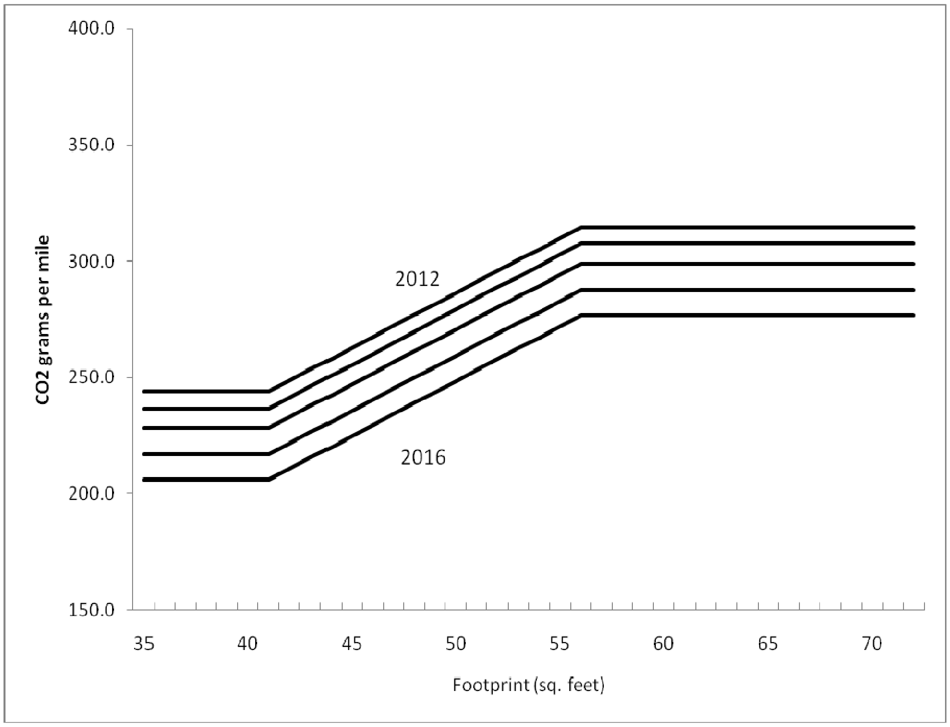

Figure 3-12 CO_2 (g/mi) Car standard curves

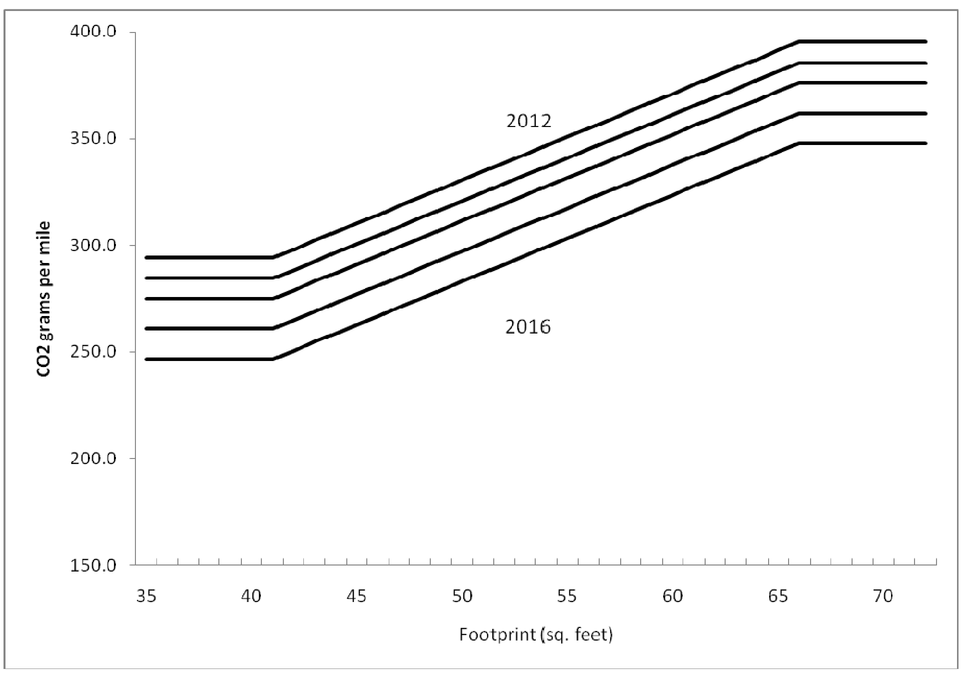

Figure 3-13 CO2 (g/mi) Truck standard curves

Implementing the CO2 emission standards in this manner provides consistency with NHTSA's CAFE standards. Section II of the preamble and Chapter 2 of the joint TSD contain more information on how EPA and NHTSA defined the piecewise linear CO2 target function.

References

References can be found in EPA docket **EPA-HQ-OAR-2009-0472.**

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

[2] NHTSA Model Year 2011 Rule. RIN 2127-AK29. Average Fuel Economy Standards. Passenger Cars and Light Trucks. Model Year 2011. [Docket No. NHTSA-2009-0062]

[3] NHTSA Model Year 2011 Rule. RIN 2127-AK29. Average Fuel Economy Standards. Passenger Cars and Light Trucks. Model Year 2011. [Docket No. NHTSA-2009-0062]

[4] NHTSA Model Year 2011 Rule. RIN 2127-AK29. Average Fuel Economy Standards. Passenger Cars and Light Trucks. Model Year 2011. [Docket No. NHTSA-2009-0062]

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

[6] National Academy of Sciences, "Effectiveness and Impact of Corporate Average Fuel Economy (CAFE) Standards," National Academy Press, Washington, DC, 2002. ISBN 0-309-07601-3. Available for online viewing or hard copy purchase from the National Academy Press at http://books.nap.edu/openbook.php?isbn=0309076013.

[7] 71 FR at 17620-21; see also 2002 NAS Report at 24 (ISBN 0-309-07601-3).

[8] 71 FR at 17596; 2002 NAS Report at 24 (ISBN 0-309-07601-3).

[9] 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

[10] 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

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

CHAPTER 4: Results of Final and Alternative Standards

4.1 Introduction

There are many ways for a manufacturer to reduce CO_2 emissions from any given vehicle. 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 (within the constraints of sufficient lead time). 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. As part of the process of developing the proposed rule, EPA 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. EPA created OMEGA in 2008 and has continued to update its algorithms through the present. OMEGA underwent a formal peer review process in the Spring of 2009, and version 1.0 became publicly available in the NPRM docket and on EPA's web site shortly after publication of the NPRM. The model and a summary of the peer review process can be found on EPA's web site at: http://www.epa.gov/otaq/climate/models.htm. EPA continues to use the OMEGA model here to estimate the technology and cost associated with the final CO2 emission standards.

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 Joint TSD contains a description of how the vehicle reference fleets were created for modeling purposes, and includes a discussion on how EPA defined the 19 vehicle types. In addition, the degree to which each vehicle already reflects the effectiveness and cost of each available technology in the 2008 baseline fleet must 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 Regulatory Impact Analysis (RIA) contains a detailed discussion of how EPA accounts for technology present in the baseline fleet in OMEGA.

The second type of input data 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 (see chapter 1 of this RIA) 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 RIA and Chapter 3 of the Joint TSD. In all cases, the order of the technologies or technology packages for a particular vehicle type is designated by the model user in the input files prior to running the model. Several criteria can be used to develop a reasonable ordering of technologies or packages. These are described in Chapter 1 of the RIA.

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

The fourth type of data describes the CO_2 emission standards being modeled. These include the CO_2 emission equivalents of the 2011 MY CAFE standards and the final CO_2 standards for 2016. As described in more detail in Chapter 2 of this RIA 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 the 2008 model year vehicles which comprise our baseline fleet may already 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. While we received no adverse comment on how this process was conducted for the NPRM, we have improved this process and hopefully made it easier for interested parties to perform their own analyses in the future.

The first step in the updated process is to breakdown the available GHG control technologies into five groups: 1) engine-related, 2) transmission-related, 3) hybridization, 4) weight reduction and 5) other. Within each group we gave each individual technology a ranking which generally followed the degree of complexity, cost and effectiveness of the technologies within each group. More specifically, the ranking is based on the premise that a technology on a 2008 baseline vehicle with a lower ranking would be replaced by one with a higher ranking which was contained in one of the technology packages which we included in our OMEGA modeling. The corollary of this premise is that a technology on a 2008 baseline vehicle with a higher ranking would be not be replaced by one with an equal or lower ranking which was contained in one of the technology packages which we chose to include in our OMEGA modeling. Table 4-1 presents the technologies and the rankings which we developed for the analyses supporting the final rule. We do not show any rankings in Table 4-1 for the “other” technologies, such as improved rolling resistance, electric power steering, etc. These technologies are assumed to be added to baseline vehicles which do not already have these technologies.

Table 4-1 Rankings of Individual Technologies

Ranking	Engine	Trans-mission	Hybrid	Weight
1	Intake Cam Phasing Cylinder Deactivation - OHV	CVT 6 Speed Auto		3%
2	Dual or Coupled Cam Phasing	6 Speed Manual Dual Clutch	42 Volt Start-Stop	5%
3	Cylinder Deactivation - OHC		Integrated Motor Assist	10%
4	Variable valve lift			
5	Diesel			
6	Power-Split 2-Mode	Power-Split 2-Mode	Power-Split 2-Mode	
7	Plug-In Electric	Plug-In Electric	Plug-In Electric	
8	Battery Electric	Battery Electric	Battery Electric	

Each baseline vehicle was assigned a ranking in each of four categories based on the maximum ranking of any of its applicable technologies in each technology category. For example, a vehicle with an OHC engine with both coupled cam phasing and cylinder deactivation was assigned an engine technology ranking of “3”, the ranking applicable to cylinder deactivation, since its ranking is higher than that for coupled cam phasing. The same was done for the technology packages. The engine technology for this example baseline vehicle was left alone whenever a technology package had an engine ranking of 3 or less.

It should be noted that the strong hybrid packages were assigned engine and transmission rankings, as well as hybrid rankings. The application of strong hybrid technology affects the type of engine used in the vehicles. For example, it is not reasonable to add cylinder deactivation or variable valve lift to vehicles which already have power-split or 2-model hybrid systems.

Two engine-related technologies are not shown in Table 4-1: gasoline direct injection and turbocharging. Whenever a technology package included gasoline direct injection, the baseline engine was converted to gasoline direct injection. If the baseline engine was already of gasoline direct injection design, this aspect of the engine was left unchanged.

The possibility that a baseline engine was already turbocharged was handled slightly differently in order to maintain the manufacturer's established tendency to turbocharge its engines. If the engine of a baseline vehicle was turbocharged, this turbocharging was assumed to continue with the addition of any technology package which did not include strong hybridization (i.e., power-split, 2-mode, plug-in or battery electric). In addition, if a package included either cylinder deactivation or variable valve lift, neither of these technologies was added with the addition of that package. The turbocharger was assumed to supplant this technology.

In the second step of the process, we used these rankings to estimate the complete list of technologies which would be present on each baseline vehicle after the application of each technology package. We then used the EPA lumped parameter model to estimate the total percentage CO2 emission reduction associated with the technology present on the baseline vehicle (termed package 0), as well as the total percentage reduction after application of each package. This process was repeated to determine the total cost of all of the technology present on the baseline vehicle and after the application of each applicable technology package.

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

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

Where

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

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

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

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

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

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

Where

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

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

i = the technology package being evaluated

i-1 = the previous technology package

The values of CEB and TEB are capped at 1.0 or less, since a vehicle cannot have more than the entire package already present on it. In other words, the addition of a technology package cannot increase emissions nor reduce costs. (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 value of a specific TEB or CEB can be negative, however. This implies that the incremental effectiveness or the incremental cost of adding a package can be greater than that when adding the packages in sequence to a vehicle with no baseline technology.

An example of this is a baseline vehicle with a 6 speed manual transmission. All of our technology package effectiveness and cost estimates are estimated for specified baseline vehicles, all of which have 4 speed automatic transmissions. Our technology packages improve this transmission, sometimes to a 6 speed automatic transmission and then a dual clutch transmission and sometimes directly to a dual clutch transmission. Subsequent packages may then strongly hybridize the vehicle. If a baseline vehicle has a 6 speed manual transmission, this transmission is unaffected by the technology packages which include either a 6 speed automatic transmission or a dual clutch transmission, since the manual transmission is both cheaper and/or more efficient than these other transmissions. However, when the vehicle is hybridized, this manual transmission is replaced. The incremental cost of changing this vehicle to a power-split hybrid design, for example, is greater than that for a vehicle with a dual clutch transmission, since the credit for removing the manual transmission is less than that for the dual clutch transmission. The negative CEB causes the OMEGA model to apply a cost for this power-split package which is slightly higher than that for the typical baseline vehicle.

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 final CO2 standards.

Table 4-2 and Table 4-3 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 4-2 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
1	12.7%	16.9%	1.2%	-2.3%	0.0%
2	21.2%	24.5%	12.5%	-0.7%	0.0%
3	18.5%	19.6%	2.9%	0.0%	0.0%
4	17.6%	33.6%	0.0%	-3.6%	-0.5%
5	21.3%	33.5%	5.9%	-0.1%	-0.6%
6	18.2%	41.4%	6.6%	-0.7%	0.0%
7	14.2%	15.6%	0.2%	2.5%	-4.5%
8	0.2%	0.2%	-0.9%	0.2%	-0.1%
9	1.0%	0.1%	-0.5%	0.1%	-0.1%
10	4.1%	5.2%	0.6%	0.0%	0.0%
11	5.3%	0.8%	-4.1%	0.9%	0.0%
12	11.2%	13.4%	0.1%	0.2%	0.0%
13	34.0%	32.0%	6.5%	-0.1%	0.3%
14	8.5%	32.1%	0.0%	0.5%	0.0%
15	0%	0%	0%	0%	0%
16	15.0%	27.4%	2.8%	2.0%	0.0%
17	19.1%	40.8%	0.3%	3.5%	0.0%
18	21.7%	13.0%	1.0%	0.0%	0.0%
19	26.2%	45.0%	0.0%	0.0%	0.0%

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

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

Vehicle Type	1	2	3	4	5
1	1.8%	30.4%	1.5%	-0.6%	0.0%
2	3.7%	33.7%	19.1%	0.0%	0.0%
3	7.9%	24.5%	4.0%	0.0%	0.0%
4	4.3%	36.4%	0.0%	4.6%	-3.3%
5	10.2%	25.5%	8.4%	-0.2%	0.1%
6	3.1%	32.4%	6.4%	3.7%	0.0%
7	6.4%	27.9%	0.2%	1.6%	-0.1%
8	0.2%	0.1%	0.0%	0.0%	0.0%
9	0.3%	0.1%	0.0%	0.0%	0.0%
10	0.6%	4.2%	0.4%	0.5%	0.0%
11	1.4%	1.0%	0.0%	0.0%	0.0%
12	1.5%	4.6%	0.0%	0.0%	0.0%
13	3.9%	14.2%	7.7%	-0.5%	0.0%
14	0.0%	14.1%	0.0%	0.4%	0.0%
15	0.0%	0.0%	0.0%	0.0%	0.0%
16	2.6%	52.5%	3.7%	2.6%	0.0%
17	2.3%	48.3%	1.5%	4.3%	0.0%
18	11.9%	27.8%	0.0%	0.0%	0.0%
19	2.1%	48.3%	0.0%	0.0%	0.0%

As mentioned above, for the market data input file utilized by OMEGA characterizing 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 TSD Chapter 3. Because EPA chose to apply technologies in packages, (a methodology endorsed by many commenters and not challenged by any) 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%. 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. The development of these factors is described in detail in the previous sub-section.

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.

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

OMEGA then adds technology cost according to the equations below, where CEB refers to the "cost effectiveness basis", or in other words, the technology cost that is present in 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.

EPA received no adverse comment on this approach and no changes in this methodology have been made since the NPRM.

4.3 Modeling Process

In order to determine the technology costs associated with this final 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, pursuant to 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 rule. In other words, absent any further rulemaking, this is the vehicle fleet EPA would expect to see through 2016 -- the "status quo". In order to calculate the costs and benefits of this final rule alone, EPA seeks to subtract out any costs associated with meeting any existing standards related to GHG emissions. EPA consequently ran OMEGA a second time to calculate the cost of meeting the EPA's final standards in 2016, and then subtracted the results of the reference case model run to determine the costs of this final 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 final 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 (for example) in the final regulations which governs 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 these vehicles' footprint values. When evaluating the 2011 MY CAFE standards, the car-truck trading was limited to 1.2 mpg. When evaluating the final 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 final 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 RIA to this final rule. When evaluating the 2016 standards using OMEGA, the final 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 10.2 g/mi of A/C credit in 2016 for each car sold and 11.5 g/mi of A/C credit for each truck sold. Thus, the sales-weighted 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 this credit was estimated separately. This is consistent with the final 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 purchasers value improved fuel economy since it reduces the cost of operating the vehicle. Typical vehicle purchasers are assumed to value the fuel savings accrued over the period of time which they will own the vehicle, 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:

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

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 rule, but a measure of the private cost, (i.e., a measure of the vehicle purchaser's willingness to pay more for a vehicle with higher fuel efficiency). Since vehicle operators pay the full price of fuel, including taxes, they value fuel costs or savings at this level, and the manufacturers will consider this when choosing among the technology options.

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 rule, this factor was not included in the determination of manufacturer-based net cost-effectiveness in the analyses performed in support of this final rule.

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 believes this manufacturer-based net cost-effectiveness metric is appropriate for ranking technology in this final program because it considers effectiveness values that may vary widely among technology packages when determining the order of technology addition..

4.4 Modeling of CAA Compliance Flexibilities

EPA's final rule incorporates several compliance flexibilities. See generally section III.C of the preamble to the final rule. 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 final CO_2 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 CO_2 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 of this RIA, 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 CO_2 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 CO_2). OMEGA currently combines all sources of CO_2 tailpipe emissions (i.e., those measured over the 2-cycle compliance test and those from A/C usage). Adding 14 g/mi CO_2 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 CO_2 effectiveness of technologies included in the Technology file applies to all sources of CO_2 emissions. Since the base 2-cycle CO_2 emission level of vehicles varies, the additional 14 g/mi of indirect A/C emissions would represent a different percentage of total CO_2 emissions of each vehicle. A single effectiveness value for the benefit of high efficiency A/C systems would therefore produce a slightly different CO_2 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 final A/C credit system. Neither direct nor indirect A/C emissions are included in the compliance determination towards the final 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 final CO2 emission standards accordingly. Thus, the effective 2016 final 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 final 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, the OMEGA model published with the NPRM has been upgraded to directly facilitate the trading of car-truck credits on a total lifetime CO2 emission basis, consistent with the provisions of the proposed and final CO2 rule. For example, if a manufacturer over-complies with its applicable CO2 standard for cars by 3 g/mi,sells 1,000,000 cars, and cars have a lifetime VMT of 195,264 miles, it generates 585,792 metric tons of CO2 credits. If these credits are used to compensate for under-compliance towards the truck CO2 standard and truck sales are 500,000, with a lifetime truck VMT of 225,865 miles, the manufacturer's truck CO2 emission level could be as much as 5.2 g/mi CO2 above the standard.

Under the final rule, 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 the CAFE 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. This credit decreases to 0.8 mpg in 2016. Car-truck trading is also allowed under the CAFE program, up to 1.0 mpg in 2011. This car-truck credit trading limitation increases to 1.5 mpg in 2016. Our reference case is a 2016 vehicle fleet complying with the 2011 CAFE standards. Thus, there is some basis for utilizing the FFV and car-truck credit limits applicable in 2016. However, as the changes to the FFV and car-truck credit limits over time are part of EISA itself, and the fuel economy side of these joint NHTSA-EPA rules implements a provision of EISA, these changes to the FFV credit and car-truck credit trading can be considered to be part of the fuel economy regulation being promulgated and not part of the baseline or reference case existing prior to this rule. We believe that this latter classification is the most appropriate for this rule analysis. Thus, in our reference case, we limit FFV credits to 1.2 mpg and car-truck trading is limited to 1.0 mpg.

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 21.5 mpg if the manufacturer generated sufficient credits from its car fleet. These two fuel economy levels represent CO2 emission levels of 395 and 413 g/mi, respectively, assuming all the vehicles are fueled with gasoline, a difference of 18 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 370 and 386 g/mi, respectively, a difference of 16 g/mi CO2. In both cases, the difference in terms of mpg is 1.0. However, the difference in terms of CO2 emissions decreases as the base fuel economy increases.

The fact that the same limit in terms of fuel economy translates into differing limits in terms of CO2 emissions complicates the modeling of CO2 emission compliance using the OMEGA model. The model currently only accepts a single limit on car-truck trading in terms of g/mi CO2 emissions. However, since the limit of 1.0 mpg on car-truck trading results in a different limit for each manufacturer, this necessitates a separate model run for each manufacturer when the trading of credits might approach the 1.0 mpg limit. Also, the OMEGA model is not yet set up to accept FFV credits in terms of mpg. Thus, the CO2 standards applicable to those manufacturers expected to utilize FFV credits must be adjusted outside of the model. (Work is underway to facilitate these credits within the model, but was not completed in time for this final rule analysis.)

Thus, we adjusted the footprint-based standard for each manufacturer expected to use FFV credits by the level of CO2 emissions equivalent to the maximum 1.2 mpg FFV credit. 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).

In addition, for manufacturers expected to pay CAFE fines in lieu of compliance, we substituted the achieved fuel economy levels from NHTSA's Volpe Model evaluations of the 2011 CAFE standards for these manufacturers' CAFE standards. The only manufacturer found to prefer paying fines over compliance was Porsche, and then only for its cars.

We initially ran the OMEGA model with unlimited trading of car-truck credits to determine the degree of trading which was likely to occur. We then determined the car-truck trading limit in terms of g/mi CO2 for each manufacturer equivalent to 1.0 mpg and determined if this limit had been exceeded. Only three manufacturers were found to exceed the trading limit in the unlimited trading runs, Mitsubishi, Suzuki and Tata. The OMEGA input and output files using the latest version of the model can be found under "EPA OMEGA Model" in the docket to this rule.

4.5 Manufacturer-Specific Standards and Achieved CO2 Levels

As described in RIA 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 targets calculated for the final 2016 model year are presented in **Error! Reference source not found.**Table 4-4.

Table 4-4 2016 Projected Standards by Manufacturer

	Car	Truck	Production Weighted Average◊	VMT Weighted Average*
BMW	228.4	282.5	243.9	245.6
Chrysler	232.2	295.0	265.8	268.1
Daimler	238.3	294.3	256.1	257.9
Ford	229.2	304.7	257.1	259.7
General Motors	230.5	315.7	270.5	273.6
Honda	222.1	280.6	243.7	245.7
Hyundai	222.2	278.3	230.6	231.7
Kia	224.3	289.3	235.5	237.0
Mazda	221.2	270.8	228.4	229.4
Mitsubishi	219.4	269.1	239.3	241.1
Nissan	225.7	294.4	245.4	247.5
Porsche	206.1	286.9	233.0	235.7
Subaru	215.5	267.1	234.2	235.9
Suzuki	207.5	271.9	218.0	219.3
Tata	249.9	272.5	258.8	259.6
Toyota	221.1	294.4	245.0	247.4
Volkswagen	218.6	292.7	231.6	233.2
Overall	225.1	297.7	250.1	252.5

◊ Production weighted CO_2 levels include reductions from A/C improvements and are weighted by production only.
*VMT weighted CO2 levels include reductions from A/C improvements and are weighted by both production and VMT for consistency with CO2 standard levels.

The VMT weighted car and truck standards average out to an overall industry CO2 stringency of 252.5 g/mi. This number is based on sales and lifetime VMT weightings of the applicable car and truck standards. The 2016 industry combined CO2 level of 250 g/mi presented by President Obama in his announcement on May 19, 2009 was calculated by weighting car and truck CO2 by sales only and did not consider trading on a lifetime VMT basis. As shown above, when the combined car and truck standards above are calculated using a sales weighting alone, the industry combined average results in 250.1g/mi.

The majority of manufacturers representing the vast majority of sales in 2016 are projected to comply with the final 2016 standards with the addition of technology under the penetration limits described in Section 4.7 below. However, several smaller volume manufacturers (at least with respect to U.S. sales) are projected to fall short of compliance. For a more complete discussion of the feasibility of the standards, please see Section III.D in the preamble. Table 4-5 below contains the projected achieved levels of CO2 emissions for each manufacturer from the OMEGA model. Overall, these levels are very similar to those projected in the NPRM.

Table 4-5 Projected Achieved CO2 Levels in 2016

	Car	Truck	Production Weighted Average◊	VMT Weighted Average*
BMW	236.3	278.7	248.5	249.8
Chrysler	227.9	298.2	265.6	268.1
Ford	233.4	298.3	257.3	259.6
Subaru	218.2	263.0	234.4	235.9
General Motors	241.3	305.1	271.3	273.6
Honda	207.6	302.0	242.5	245.7
Hyundai	214.5	315.6	229.8	231.7
Tata	258.6	323.6	284.2	286.5
Kia	213.1	335.2	234.3	237.0
Mazda	218.2	285.6	228.1	229.4
Daimler	246.3	297.8	262.6	264.3
Mitsubishi	223.3	264.0	239.6	241.1
Nissan	223.2	299.8	245.2	247.5
Porsche	244.1	332.0	273.4	276.3
Suzuki	197.3	317.7	216.8	219.3
Toyota	212.8	308.6	244.0	247.1
Volkswagen	223.5	326.6	241.6	243.9
Overall	223.8	302.5	250.8	253.5

◊ Production weighted CO_2 levels include reductions from A/C improvements and are weighted by production only.
*VMT weighted CO2 levels include reductions from A/C improvements and are weighted by both production and VMT for consistency with CO2 standard levels.

4.6 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, which is the reference case for this analysis. OMEGA estimates that, on average, manufacturers will need to spend $78 per vehicle to meet the current MY 2011 CAFE standards. [A] Reference case costs are provided in Table 4-6 below.

Table 4-6 Incremental Technology Cost of the Reference Case

	Car	Truck	Combined
BMW	$ 346	$ 423	$ 368
Chrysler	$ 33	$ 116	$ 77
Ford	$ 73	$ 161	$ 106
Subaru	$ 68	$ 62	$ 66
General Motors	$ 31	$ 181	$ 102
Honda	$ -	$ -	$ -
Hyundai	$ -	$ 69	$ 10
Tata	$ 611	$ 1,205	$ 845
Kia	$ -	$ 42	$ 7
Mazda	$ -	$ -	$ -
Daimler	$ 468	$ 683	$ 536
Mitsubishi	$ 328	$ 246	$ 295
Nissan	$ -	$ 61	$ 18
Porsche	$ 473	$ 706	$ 550
Suzuki	$ 49	$ 232	$ 79
Toyota	$ -	$ -	$ -
Volkswagen	$ 228	$ 482	$ 272
Total	$ 63	$ 138	$ 89

EPA then used OMEGA to calculate the costs of meeting the final 2016 standards, which are displayed in Table 4-7 below, and two alternative scenarios for sensitivity. In Table 4-7 and Table 4-17, 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.

[A] 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 4-7 Incremental Technology Cost of the Final 2016 CO2 Standards

	Car	Truck	Combined
BMW	$ 1,558	$ 1,195	$ 1,453
Chrysler	$ 1,129	$ 1,501	$ 1,329
Ford	$ 1,108	$ 1,442	$ 1,231
Subaru	$ 962	$ 790	$ 899
General Motors	$ 899	$ 1,581	$ 1,219
Honda	$ 635	$ 473	$ 575
Hyundai	$ 802	$ 425	$ 745
Tata	$ 1,181	$ 680	$ 984
Kia	$ 667	$ 247	$ 594
Mazda	$ 855	$ 537	$ 808
Daimler	$ 1,536	$ 931	$ 1,343
Mitsubishi	$ 817	$ 1,218	$ 978
Nissan	$ 686	$ 1,119	$ 810
Porsche	$ 1,506	$ 759	$ 1,257
Suzuki	$ 1,015	$ 537	$ 937
Toyota	$ 381	$ 609	$ 455
Volkswagen	$ 1,848	$ 972	$ 1,694
Total	$ 870	$ 1,099	$ 948

EPA estimates that the additional technology required for manufacturers to meet the GHG standards for this final rule will cost on average $948/vehicle. This cost is roughly $100 lower than that projected in the NPRM. This difference is due primarily to a reduction in the estimated cost for the various technologies being added to the vehicles.

4.7 Technology Penetration

The major technologies chosen by OMEGA are described in the Table 4-8 through Table 4-12 for the reference case and in Tables 4-11 through 4-13 for the control case for cars, trucks, and combined fleets. 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

Manufacturer	SGDI	DEAC-OHC	Turbo	Diesel	6 SPD Auto	DCT	42 V S-S	IMA	Power Split	2-Mode	% Weight Reduction
BMW	53%	10%	43%	0%	40%	45%	12%	0%	0%	0%	1.8%
Chrysler	0%	0%	1%	0%	5%	0%	0%	0%	0%	0%	0.0%
Daimler	23%	20%	5%	2%	47%	32%	21%	0%	0%	0%	1.1%
Ford	0%	0%	4%	0%	32%	0%	0%	0%	0%	0%	0.0%
General Motors	6%	0%	3%	0%	14%	0%	0%	0%	0%	0%	0.0%
Honda	0%	9%	0%	0%	0%	0%	0%	3%	0%	0%	0.0%
Hyundai	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0.0%
Kia	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0.0%
Mazda	11%	0%	11%	0%	15%	0%	0%	0%	0%	0%	0.0%
Mitsubishi	45%	0%	3%	0%	25%	50%	0%	0%	0%	0%	1.6%
Nissan	0%	0%	0%	0%	0%	0%	0%	0%	1%	0%	0.0%
Porsche	88%	0%	88%	0%	0%	41%	15%	0%	0%	0%	2.8%
Subaru	0%	0%	12%	0%	0%	0%	0%	0%	0%	0%	0.0%
Suzuki	80%	0%	0%	0%	0%	80%	80%	0%	0%	0%	4.0%
Tata	85%	64%	0%	0%	34%	64%	64%	0%	0%	0%	3.8%
Toyota	7%	0%	0%	0%	21%	0%	0%	0%	15%	0%	0.0%
Volkswagen	87%	3%	84%	0%	13%	77%	4%	0%	0%	0%	2.4%
Fleet	12%	2%	8%	0%	15%	8%	2%	0%	3%	0%	0.3%

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

Manufacturer	SGDI	DEAC-OHC	Turbo	Diesel	6 SPD Auto	DCT	42 V S-S	IMA	Power Split	2-Mode	% Weight Reduction
BMW	20%	16%	0%	0%	84%	16%	16%	0%	0%	0%	1.6%
Chrysler	0%	0%	0%	0%	28%	0%	0%	0%	0%	0%	0.0%
Daimler	24%	24%	16%	16%	62%	38%	38%	0%	0%	0%	3.8%
Ford	1%	0%	0%	0%	19%	0%	0%	0%	0%	0%	0.0%
General Motors	0%	0%	0%	0%	17%	0%	0%	0%	0%	0%	0.0%
Honda	4%	0%	4%	0%	0%	0%	0%	0%	0%	0%	0.0%
Hyundai	0%	0%	0%	0%	23%	0%	0%	0%	0%	0%	0.0%
Kia	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0.0%
Mazda	26%	0%	26%	0%	48%	0%	0%	0%	0%	0%	0.0%
Mitsubishi	13%	0%	0%	0%	25%	13%	0%	0%	0%	0%	0.4%
Nissan	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0.0%
Porsche	100%	0%	50%	0%	15%	84%	85%	0%	0%	0%	6.6%
Subaru	0%	0%	3%	0%	0%	0%	0%	0%	0%	0%	0.0%
Suzuki	18%	0%	0%	0%	18%	0%	0%	0%	0%	0%	0.5%
Tata	85%	37%	51%	0%	15%	85%	85%	0%	0%	0%	8.5%
Toyota	7%	0%	0%	0%	16%	0%	0%	0%	6%	0%	0.0%
Volkswagen	99%	17%	69%	1%	15%	85%	85%	0%	0%	0%	5.1%
Fleet	7%	2%	3%	0%	18%	4%	4%	0%	1%	0%	0.3%

Table 4-10 2016 Technology Penetration in the Reference Case - Combined Cars and Trucks

Manufacturer	SGDI	DEAC-OHC	Turbo	Diesel	6 SPD Auto	DCT	42 V S-S	IMA	Power Split	2-Mode	% Weight Reduction
BMW	44%	12%	30%	0%	53%	37%	13%	0%	0%	0%	1.7%
Chrysler	0%	0%	0%	0%	18%	0%	0%	0%	0%	0%	0.0%
Daimler	23%	22%	8%	6%	52%	34%	26%	0%	0%	0%	2.0%
Ford	0%	0%	3%	0%	27%	0%	0%	0%	0%	0%	0.0%
General Motors	3%	0%	1%	0%	15%	0%	0%	0%	0%	0%	0.0%
Honda	2%	6%	2%	0%	0%	0%	0%	2%	0%	0%	0.0%
Hyundai	0%	0%	0%	0%	3%	0%	0%	0%	0%	0%	0.0%
Kia	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0.0%
Mazda	13%	0%	13%	0%	20%	0%	0%	0%	0%	0%	0.0%
Mitsubishi	32%	0%	2%	0%	25%	35%	0%	0%	0%	0%	1.1%
Nissan	0%	0%	0%	0%	0%	0%	0%	0%	1%	0%	0.0%
Porsche	92%	0%	75%	0%	5%	55%	38%	0%	0%	0%	4.1%
Subaru	0%	0%	9%	0%	0%	0%	0%	0%	0%	0%	0.0%
Suzuki	70%	0%	0%	0%	3%	67%	67%	0%	0%	0%	3.4%
Tata	85%	54%	20%	0%	27%	73%	73%	0%	0%	0%	5.7%
Toyota	7%	0%	0%	0%	19%	0%	0%	0%	12%	0%	0.0%
Volkswagen	89%	5%	81%	0%	14%	78%	18%	0%	0%	0%	2.8%
Fleet	10%	2%	7%	0.2%	16%	7%	3%	0.2%	2.5%	0.0%	0.3%

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

Manufacturer	SGDI	DEAC-OHC	Turbo	Diesel	6 SPD Auto	DCT	42 V S-S	IMA	Power Split	2-Mode	% Weight Reduction
BMW	78%	19%	62%	8%	13%	61%	63%	0%	4%	10%	4.7%
Chrysler	85%	1%	7%	0%	30%	55%	56%	0%	0%	0%	6.2%
Daimler	78%	28%	54%	6%	10%	72%	65%	0%	3%	10%	4.8%
Ford	85%	12%	15%	0%	32%	56%	57%	0%	0%	0%	4.9%
General Motors	56%	3%	13%	0%	4%	53%	53%	0%	0%	0%	4.7%
Honda	59%	9%	0%	0%	0%	70%	21%	3%	0%	0%	3.6%
Hyundai	61%	0%	1%	0%	0%	61%	38%	0%	0%	0%	3.4%
Kia	39%	0%	1%	0%	0%	63%	4%	0%	0%	0%	2.2%
Mazda	59%	0%	12%	1%	11%	48%	47%	0%	0%	0%	3.9%
Mitsubishi	67%	0%	7%	1%	21%	67%	67%	0%	0%	0%	6.3%
Nissan	62%	0%	3%	0%	1%	57%	52%	0%	1%	0%	4.8%
Porsche	75%	15%	73%	12%	0%	34%	58%	0%	0%	15%	3.5%
Subaru	82%	0%	12%	0%	0%	79%	58%	0%	0%	0%	4.2%
Suzuki	80%	0%	0%	0%	0%	80%	80%	0%	0%	0%	4.0%
Tata	85%	64%	17%	0%	14%	70%	70%	0%	4%	11%	4.3%
Toyota	22%	2%	4%	0%	15%	49%	2%	0%	15%	0%	1.7%
Volkswagen	79%	16%	74%	13%	10%	67%	57%	0%	2%	13%	3.9%
Fleet	58%	6%	14%	1%	11%	58%	39%	0%	4%	2%	3.8%

Table 4-12 2016 Technology Penetration in the Control Case-Trucks

	SGDI	DEAC-OHC	Turbo	Diesel	6 SPD Auto	DCT	42 V S-S	IMA	Power Split	2-Mode	% Weight Reduction
BMW	86%	28%	57%	0%	15%	69%	70%	0%	0%	15%	4.1%
Chrysler	74%	25%	25%	0%	32%	50%	53%	0%	0%	0%	5.7%
Daimler	72%	35%	52%	2%	15%	70%	70%	0%	0%	15%	5.1%
Ford	83%	35%	25%	0%	18%	68%	68%	0%	0%	0%	6.6%
General Motors	80%	50%	16%	0%	12%	70%	70%	0%	0%	0%	6.5%
Honda	16%	0%	4%	0%	0%	12%	12%	0%	0%	0%	1.2%
Hyundai	44%	0%	0%	0%	56%	0%	0%	0%	0%	0%	1.3%
Kia	1%	0%	0%	0%	0%	1%	1%	0%	0%	0%	0.1%
Mazda	65%	0%	27%	0%	48%	39%	7%	0%	0%	0%	1.7%
Mitsubishi	85%	0%	72%	0%	4%	85%	85%	0%	0%	0%	5.9%
Nissan	76%	23%	29%	0%	3%	72%	73%	0%	0%	0%	6.4%
Porsche	100%	15%	42%	0%	15%	69%	70%	0%	0%	15%	5.4%
Subaru	21%	0%	3%	0%	0%	21%	21%	0%	0%	0%	2.1%
Suzuki	61%	0%	0%	0%	61%	0%	0%	0%	0%	0%	1.8%
Tata	85%	40%	42%	0%	15%	70%	70%	0%	6%	9%	7.0%
Toyota	34%	17%	0%	0%	9%	20%	17%	0%	6%	0%	2.0%
Volkswagen	99%	29%	56%	0%	15%	70%	70%	0%	0%	15%	4.2%
Fleet	62%	27%	18%	0%	13%	49%	48%	0%	1%	1%	4.5%

Table 4-13 2016 Technology Penetration in the Control Case – Combined Cars and Trucks

Manufacturer	SGDI	DEAC-OHC	Turbo	Diesel	6 SPD Auto	DCT	42 V S-S	IMA	Power Split	2-Mode	% Weight Reduction
BMW	80%	21%	61%	6%	13%	63%	65%	0%	3%	12%	4.5%
Chrysler	79%	13%	17%	0%	31%	52%	54%	0%	0%	0%	5.9%
Daimler	76%	30%	53%	5%	12%	72%	67%	0%	2%	12%	4.9%
Ford	84%	21%	19%	0%	27%	60%	61%	0%	0%	0%	5.5%
General Motors	67%	25%	14%	0%	8%	61%	61%	0%	0%	0%	5.5%
Honda	43%	6%	2%	0%	0%	49%	18%	2%	0%	0%	2.7%
Hyundai	59%	0%	1%	0%	8%	52%	32%	0%	0%	0%	3.1%
Kia	33%	0%	1%	0%	0%	52%	4%	0%	0%	0%	1.8%
Mazda	60%	0%	14%	1%	17%	47%	41%	0%	0%	0%	3.5%
Mitsubishi	74%	0%	33%	0%	14%	74%	74%	0%	0%	0%	6.2%
Nissan	66%	7%	11%	0%	2%	62%	58%	0%	1%	0%	5.3%
Porsche	83%	15%	62%	8%	5%	45%	62%	0%	0%	15%	4.1%
Subaru	60%	0%	9%	0%	0%	58%	44%	0%	0%	0%	3.4%
Suzuki	77%	0%	0%	0%	10%	67%	67%	0%	0%	0%	3.6%
Tata	85%	55%	27%	0%	14%	70%	70%	0%	4%	11%	5.4%
Toyota	26%	7%	3%	0%	13%	40%	7%	0%	12%	0%	1.8%
Volkswagen	82%	18%	71%	11%	10%	68%	60%	0%	1%	14%	3.9%
Fleet	60%	13%	15%	0.9%	12%	55%	42%	0%	3%	1%	4.1%

As can be seen, the overall reduction in vehicle weight is projected to be 4.3%. As there has been a concern in the past that weight reductions are associated with increased safety risk, a more specific breakdown of the projected weight reduction by vehicle class and weight range is provided below. For cars below 2950 pounds curb weight, the estimated reduction is 2.3% (62 pounds), while it was estimated to be 4.4% (154 pounds) for cars above 2950 curb weight. For trucks below 3850 pounds curb weight, the projected 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 estimated 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 4-14.

Table 4-14 Breakdown of Weight Reduction in Modeling Results

	Weight Category	Average Weight Reduction	% Weight Reduction
Cars	< 2950 lbs	75 lbs	2.8%
	> 2950 lbs	153 lbs	4.3%
Trucks with 3850 lb break point	< 3850 lbs	163 lbs	4.7%
	> 3850 lbs	240 lbs	5.1%
Trucks with 5000 lb break point	< 5000 lbs	186 lbs	4.4%
	> 5000 lbs	376 lbs	7.0%

4.8 Alternative Program Stringencies

EPA also analyzed the technology cost of two alternative stringency scenarios: 4%/year and 6%/year. The manufacturers's CO2 targets and achieved levels for standards with these alternative stringincies are presented in Table 4-15 and Table 4-16 below.

Table 4-15 2016 Standards by Manufacturer in the 4% Sensitivity Case

	Achieved CO2 Levels			CO2 Standards		
	Car	Truck	Combined	Car	Truck	Combined
BMW	236.3	278.7	249.8	232.1	287.4	249.7
Chrysler	228.7	305.2	272.5	235.9	299.9	272.5
Ford	237.3	302.7	263.7	242.0	299.3	265.1
Subaru	218.2	271.7	239.4	233.0	309.6	263.3
General Motors	245.6	308.1	277.3	234.2	320.6	278.0
Honda	211.1	305.3	249.1	225.8	285.5	249.9
Hyundai	216.2	329.3	235.5	225.9	283.3	235.7
Tata	258.6	323.6	286.5	228.0	294.3	256.4
Kia	217.7	335.7	240.7	224.9	275.7	234.8
Mazda	222.9	285.6	233.3	223.1	274.0	231.5
Daimler	246.3	297.8	264.3	229.4	299.3	253.9
Mitsubishi	227.5	268.4	245.3	209.8	291.8	245.6
Nissan	229.2	299.8	251.6	219.2	272.1	236.0
Porsche	244.1	332.0	276.3	211.3	276.9	235.3
Suzuki	197.3	334.3	222.4	253.6	277.4	258.0
Toyota	217.5	311.6	251.2	224.8	299.3	251.5
Volkswagen	223.5	326.6	243.9	222.3	297.7	237.2
Overall	227.3	305.9	256.9	229.2	299.7	255.8

Table 4-16 2016 Standards by Manufacturer in the 6% Sensitivity Case

	Achieved CO2 Levels			CO2 Standards		
	Car	Truck	Combined	Car	Truck	Combined
BMW	236.3	278.7	249.8	210.4	258.8	225.8
Chrysler	210.7	273.9	246.9	214.2	271.3	246.9
Ford	214.2	285.0	242.7	220.3	270.7	240.6
Subaru	207.6	227.8	215.6	211.3	281.0	238.9
General Motors	213.6	290.9	252.7	212.5	292.1	252.8
Honda	194.7	270.9	225.5	204.1	256.9	225.5
Hyundai	202.9	260.9	212.8	204.2	254.7	212.8
Tata	258.6	323.6	286.5	206.3	265.7	231.8
Kia	189.4	335.2	217.9	203.2	247.1	211.8
Mazda	203.9	243.8	210.5	201.4	245.4	208.7
Daimler	246.3	297.8	264.3	207.8	270.7	229.8
Mitsubishi	212.2	260.6	233.4	188.1	263.2	220.9
Nissan	200.2	286.8	227.7	197.5	243.5	212.1
Porsche	244.1	332.0	276.3	189.6	248.3	211.1
Suzuki	186.8	260.6	200.3	231.9	248.8	235.0

Toyota	192.9	288.3	227.1	203.1	270.7	227.4
Volkswagen	223.5	326.6	243.9	200.6	269.1	214.2
Overall	206.6	284.9	236.1	207.5	271.2	231.5

With the reference case the same as that described above in Section 4.1, the costs of the two alternative control cases are presented in Tables 4-17 and 4-18, respectively, and the technology penetrations are presented in Table 4-17 through Table 4-24, below.

Table 4-17 2016 Technology Cost in the 4% sensitivity case

	Car	Truck	Combined
BMW	$ 1,558	$ 1,195	$ 1,453
Chrysler	$ 1,111	$ 1,236	$ 1,178
Ford	$ 1,013	$ 1,358	$ 1,140
Subaru	$ 962	$ 616	$ 836
General Motors	$ 834	$ 1,501	$ 1,148
Honda	$ 598	$ 411	$ 529
Hyundai	$ 769	$ 202	$ 684
Tata	$ 1,181	$ 680	$ 984
Kia	$ 588	$ 238	$ 527
Mazda	$ 766	$ 537	$ 733
Daimler	$ 1,536	$ 931	$ 1,343
Mitsubishi	$ 733	$ 1,164	$ 906
Nissan	$ 572	$ 1,119	$ 729
Porsche	$ 1,506	$ 759	$ 1,257
Suzuki	$ 1,015	$ 179	$ 879
Toyota	$ 323	$ 560	$ 400
Volkswagen	$ 1,848	$ 972	$ 1,694
Total	$ 811	$ 1,020	$ 883

Table 4-18 2016 Technology Cost in the 6% sensitivity case

	Car	Truck	Combined
BMW	$ 1,558	$ 1,195	$ 1,453
Chrysler	$ 1,447	$ 2,156	$ 1,827
Ford	$ 1,839	$ 2,090	$ 1,932
Subaru	$ 1,173	$ 1,316	$ 1,225
General Motors	$ 1,728	$ 2,030	$ 1,870
Honda	$ 894	$ 891	$ 893
Hyundai	$ 1,052	$ 1,251	$ 1,082
Tata	$ 1,181	$ 680	$ 984
Kia	$ 1,132	$ 247	$ 979
Mazda	$ 1,093	$ 1,083	$ 1,092
Daimler	$ 1,536	$ 931	$ 1,343
Mitsubishi	$ 1,224	$ 1,840	$ 1,471
Nissan	$ 1,151	$ 1,693	$ 1,306
Porsche	$ 1,506	$ 759	$ 1,257
Suzuki	$ 1,426	$ 1,352	$ 1,414
Toyota	$ 747	$ 906	$ 799
Volkswagen	$ 1,848	$ 972	$ 1,694
Total	$ 1,296	$ 1,538	$ 1,379

Table 4-19 2016 Technology Penetration in the 4% sensitivity case- Cars

Manufacturer	SGDI	DEAC-OHC	Turbo	Diesel	6 SPD Auto	DCT	42 V S-S	IMA	Power Split	2-Mode	% Weight Reduction
BMW	78%	19%	62%	8%	13%	61%	63%	0%	4%	10%	4.7%
Chrysler	85%	0%	7%	0%	30%	55%	55%	0%	0%	0%	6.1%
Daimler	78%	28%	54%	6%	10%	72%	65%	0%	3%	10%	4.8%
Ford	73%	8%	15%	0%	26%	56%	57%	0%	0%	0%	4.6%
General Motors	57%	3%	6%	0%	11%	46%	46%	0%	0%	0%	4.2%
Honda	48%	9%	0%	0%	0%	59%	21%	3%	0%	0%	3.2%
Hyundai	61%	0%	1%	0%	0%	61%	33%	0%	0%	0%	3.2%
Kia	45%	0%	1%	0%	0%	68%	0%	0%	0%	0%	2.4%
Mazda	82%	0%	12%	1%	11%	71%	69%	0%	0%	0%	6.1%
Mitsubishi	85%	0%	3%	0%	25%	63%	64%	0%	0%	0%	6.6%
Nissan	65%	0%	3%	0%	1%	60%	56%	0%	1%	0%	5.2%
Porsche	75%	15%	73%	12%	0%	34%	58%	0%	0%	15%	3.5%
Subaru	82%	0%	12%	0%	0%	79%	58%	0%	0%	0%	4.2%
Suzuki	80%	0%	0%	0%	0%	80%	80%	0%	0%	0%	4.0%
Tata	85%	64%	17%	0%	14%	70%	70%	0%	4%	11%	4.3%
Toyota	9%	2%	0%	0%	18%	35%	2%	0%	15%	0%	1.1%
Volkswagen	79%	16%	74%	13%	10%	67%	57%	0%	2%	13%	3.9%
Fleet	55%	5%	12%	1%	12%	54%	38%	0%	4%	2%	3.6%

Table 4-20 2016 Technology Penetration in the 4% sensitivity case- Trucks

	SGDI	DEAC-OHC	Turbo	Diesel	6 SPD Auto	DCT	42 V S-S	IMA	Power Split	2-Mode	% Weight Reduction
BMW	86%	28%	57%	0%	15%	69%	70%	0%	0%	15%	4.1%
Chrysler	52%	24%	25%	0%	24%	50%	52%	0%	0%	0%	5.0%
Daimler	72%	35%	52%	2%	15%	70%	70%	0%	0%	15%	5.1%
Ford	83%	35%	19%	0%	24%	62%	62%	0%	0%	0%	6.2%
General Motors	69%	49%	16%	0%	4%	69%	69%	0%	0%	0%	6.1%
Honda	37%	0%	4%	0%	0%	32%	4%	0%	0%	0%	1.2%
Hyundai	0%	0%	0%	0%	23%	0%	0%	0%	0%	0%	0.0%
Kia	1%	0%	0%	0%	0%	1%	0%	0%	0%	0%	0.0%
Mazda	65%	0%	27%	0%	48%	39%	7%	0%	0%	0%	1.7%
Mitsubishi	85%	0%	72%	0%	4%	85%	85%	0%	0%	0%	5.9%
Nissan	76%	23%	29%	0%	3%	72%	73%	0%	0%	0%	6.4%
Porsche	100%	15%	42%	0%	15%	69%	70%	0%	0%	15%	5.4%
Subaru	54%	0%	3%	0%	0%	54%	0%	0%	0%	0%	1.6%
Suzuki	18%	0%	0%	0%	18%	0%	0%	0%	0%	0%	0.5%
Tata	85%	40%	42%	0%	15%	70%	70%	0%	6%	9%	7.0%
Toyota	27%	17%	0%	0%	2%	20%	17%	0%	6%	0%	1.8%
Volkswagen	99%	29%	56%	0%	15%	70%	70%	0%	0%	15%	4.2%
Fleet	58%	27%	17%	0%	10%	50%	46%	0%	1%	1%	4.2%

Table 4-21 2016 Technology Penetration in the 4% sensitivity case – Cars and Trucks Combined

	SGDI	DEAC-OHC	Turbo	Diesel	6 SPD Auto	DCT	42 V S-S	IMA	Power Split	2-Mode	PHEV/EV	MS1	MS2	MS3	% Weight Reduction
BMW	80%	21%	61%	6%	13%	63%	65%	0%	3%	12%	0.1%	0%	51%	20%	4.5%
Chrysler	67%	13%	17%	0%	26%	52%	54%	0%	0%	0%	0.0%	14%	6%	48%	5.5%
Daimler	76%	30%	53%	5%	12%	72%	67%	0%	2%	12%	0.0%	0%	45%	26%	4.9%
Ford	77%	18%	16%	0%	25%	58%	59%	0%	0%	0%	0.0%	18%	25%	34%	5.2%
General Motors	62%	24%	11%	0%	7%	57%	57%	0%	0%	0%	0.0%	5%	14%	42%	5.1%
Honda	44%	6%	2%	0%	0%	49%	15%	2%	0%	0%	0.0%	34%	0%	15%	2.5%
Hyundai	52%	0%	1%	0%	3%	52%	28%	0%	0%	0%	0.0%	24%	17%	11%	2.7%
Kia	37%	0%	1%	0%	0%	57%	0%	0%	0%	0%	0.0%	43%	14%	0%	2.0%
Mazda	79%	0%	14%	1%	17%	66%	60%	0%	0%	0%	0.0%	9%	17%	44%	5.5%
Mitsubishi	85%	0%	31%	0%	16%	72%	72%	0%	0%	0%	0.0%	13%	26%	46%	6.3%
Nissan	69%	7%	11%	0%	2%	64%	61%	0%	1%	0%	0.0%	7%	16%	45%	5.5%
Porsche	83%	15%	62%	8%	5%	45%	62%	0%	0%	15%	0.0%	0%	57%	13%	4.1%
Subaru	72%	0%	9%	0%	0%	70%	37%	0%	0%	0%	0.0%	35%	29%	8%	3.3%
Suzuki	70%	0%	0%	0%	3%	67%	67%	0%	0%	0%	0.0%	3%	67%	0%	3.4%
Tata	85%	55%	27%	0%	14%	70%	70%	0%	4%	11%	0.0%	0%	32%	38%	5.4%
Toyota	15%	7%	0%	0%	13%	30%	7%	0%	12%	0%	0.0%	23%	2%	6%	1.3%
Volkswagen	82%	18%	71%	11%	10%	68%	60%	0%	1%	14%	0.0%	0%	61%	9%	3.9%
Fleet	56%	13%	14%	0.8%	11%	53%	41%	0%	3%	1%	0.0%	16%	17%	25%	3.9%

Table 4-22 2016 Technology Penetration in the 6% Sensitivity Case - Cars

	SGDI	DEAC-OHC	Turbo	Diesel	6 SPD Auto	DCT	42 V S-S	IMA	Power Split	2-Mode	PHEV/EV	MS1	MS2	MS3	% Weight Reduction
BMW	78%	19%	62%	8%	13%	61%	63%	0%	4%	10%	0.2%	0%	48%	23%	4.7%
Chrysler	85%	4%	37%	0%	1%	84%	85%	0%	0%	0%	0.0%	0%	2%	83%	8.4%
Daimler	78%	28%	54%	6%	10%	72%	65%	0%	3%	10%	0.0%	0%	47%	24%	4.8%
Ford	85%	11%	55%	0%	5%	74%	75%	0%	5%	5%	0.0%	0%	12%	63%	6.9%
General Motors	85%	6%	50%	0%	2%	83%	84%	0%	0%	1%	0.0%	0%	5%	79%	8.2%
Honda	72%	9%	0%	0%	0%	70%	70%	3%	0%	0%	0.0%	0%	13%	57%	6.3%
Hyundai	70%	0%	1%	0%	9%	61%	61%	0%	0%	0%	0.0%	9%	21%	40%	5.3%
Kia	75%	0%	1%	0%	0%	75%	74%	0%	0%	0%	0.0%	1%	24%	51%	6.3%
Mazda	85%	0%	14%	1%	3%	80%	83%	0%	0%	0%	0.0%	0%	29%	55%	6.9%
Mitsubishi	84%	1%	28%	1%	4%	78%	78%	0%	6%	1%	0.0%	0%	3%	76%	7.7%
Nissan	84%	0%	37%	1%	0%	80%	83%	0%	1%	0%	0.0%	0%	4%	80%	8.2%
Porsche	75%	15%	73%	12%	0%	34%	58%	0%	0%	15%	0.0%	0%	70%	0%	3.5%
Subaru	83%	0%	12%	1%	2%	79%	80%	0%	0%	0%	0.0%	2%	46%	36%	5.9%
Suzuki	85%	0%	85%	0%	0%	85%	85%	0%	0%	0%	0.0%	0%	0%	85%	8.5%
Tata	85%	64%	17%	0%	14%	70%	70%	0%	4%	11%	0.0%	0%	53%	17%	4.3%
Toyota	71%	2%	4%	0%	15%	56%	53%	0%	15%	0%	0.0%	3%	39%	14%	3.4%
Volkswagen	79%	16%	74%	13%	10%	67%	57%	0%	2%	13%	0.0%	0%	63%	7%	3.9%
Fleet	79%	7%	30%	1%	6%	71%	70%	0%	4%	2%	0.0%	1%	23%	49%	6.0%

Table 4-23 2016 Technology Penetration in the 6% Sensitivity Case-Trucks

	SGDI	DEAC -OHC	Turbo	Diesel	6 SPD Auto	DCT	42 V S-S	IMA	Power Split	2-Mode	PHEV/EV	MS1	MS2	MS3	% Weight Reduction
BMW	86%	28%	57%	0%	15%	69%	70%	0%	0%	15%	0.0%	0%	57%	13%	4.1%
Chrysler	85%	21%	61%	0%	4%	79%	82%	0%	0%	3%	0.0%	0%	5%	77%	7.9%
Daimler	72%	35%	52%	2%	15%	70%	70%	0%	0%	15%	0.0%	0%	38%	32%	5.1%
Ford	85%	16%	60%	0%	3%	76%	76%	0%	4%	5%	0.0%	0%	11%	65%	7.0%
General Motors	85%	46%	34%	0%	2%	82%	82%	0%	0%	3%	0.0%	0%	12%	70%	7.6%
Honda	61%	0%	28%	0%	4%	56%	56%	0%	0%	0%	0.0%	4%	24%	32%	4.5%
Hyundai	85%	9%	76%	0%	12%	76%	76%	0%	0%	0%	0.0%	0%	85%	0%	4.3%
Kia	1%	0%	0%	0%	0%	1%	1%	0%	0%	0%	0.0%	0%	0%	1%	0.1%
Mazda	89%	0%	45%	0%	13%	80%	80%	0%	0%	0%	0.0%	5%	41%	39%	6.1%
Mitsubishi	85%	9%	62%	0%	4%	70%	70%	0%	6%	9%	0.0%	0%	42%	28%	4.9%
Nissan	85%	29%	39%	0%	0%	74%	74%	0%	4%	6%	0.0%	0%	24%	50%	6.2%
Porsche	100%	15%	42%	0%	15%	69%	70%	0%	0%	15%	0.0%	0%	31%	39%	5.4%
Subaru	85%	0%	28%	0%	6%	79%	79%	0%	0%	0%	0.0%	6%	25%	54%	6.8%
Suzuki	85%	0%	85%	0%	0%	85%	85%	0%	0%	0%	0.0%	0%	67%	18%	5.1%
Tata	85%	40%	42%	0%	15%	70%	70%	0%	6%	9%	0.0%	0%	0%	70%	7.0%
Toyota	70%	17%	7%	0%	32%	34%	34%	0%	6%	0%	0.0%	29%	0%	34%	4.3%
Volkswagen	99%	29%	56%	0%	15%	70%	70%	0%	0%	15%	0.0%	0%	56%	14%	4.2%
Fleet	78%	23%	37%	0%	10%	66%	66%	0%	2%	4%	0.0%	6%	16%	50%	6.0%

Table 4-24 2016 Technology Penetration in the 6% Sensitivity Case – Cars and Trucks combined

	SGDI	DEAC-OHC	Turbo	Diesel	6 SPD Auto	DCT	42 V S-S	IMA	Power Split	2-Mode	PHEV/EV	MS1	MS2	MS3	% Weight Reduction
BMW	80%	21%	61%	6%	13%	63%	65%	0%	3%	12%	0.1%	0%	51%	20%	4.5%
Chrysler	85%	13%	50%	0.05%	3%	82%	83%	0%	0%	2%	0.0%	0%	4%	80%	8.2%
Daimler	76%	30%	53%	5%	12%	72%	67%	0%	2%	12%	0.0%	0%	45%	26%	4.9%
Ford	85%	13%	57%	0%	4%	74%	75%	0%	5%	5%	0.0%	0%	12%	64%	6.9%
General Motors	85%	25%	43%	0%	2%	83%	83%	0%	0%	2%	0.0%	0%	8%	75%	7.9%
Honda	68%	6%	10%	0%	1%	65%	65%	2%	0%	0%	0.0%	1%	17%	48%	5.7%
Hyundai	73%	1%	12%	0%	9%	64%	64%	0%	0%	0%	0.0%	8%	31%	34%	5.2%
Kia	62%	0%	1%	0%	0%	62%	61%	0%	0%	0%	0.0%	1%	20%	42%	5.2%
Mazda	85%	0%	19%	1%	4%	80%	82%	0%	0%	0%	0.0%	1%	31%	52%	6.8%
Mitsubishi	85%	4%	42%	0%	4%	75%	75%	0%	6%	4%	0.0%	0%	18%	57%	6.6%
Nissan	85%	8%	38%	0%	0%	78%	81%	0%	2%	2%	0.0%	0%	10%	71%	7.6%
Porsche	83%	15%	62%	8%	5%	45%	62%	0%	0%	15%	0.0%	0%	57%	13%	4.1%
Subaru	84%	0%	18%	1%	3%	79%	80%	0%	0%	0%	0.0%	4%	38%	42%	6.3%
Suzuki	85%	0%	85%	0%	0%	85%	85%	0%	0%	0%	0.0%	0%	11%	74%	8.0%
Tata	85%	55%	27%	0%	14%	70%	70%	0%	4%	11%	0.0%	0%	32%	38%	5.4%
Toyota	71%	7%	5%	0%	20%	49%	47%	0%	12%	0%	0.0%	12%	26%	21%	3.7%
Volkswagen	82%	18%	71%	11%	10%	68%	60%	0%	1%	14%	0.0%	0%	61%	9%	3.9%
Fleet	79%	12%	33%	0.9%	7%	69%	69%	0%	4%	3%	0.0%	3%	21%	49%	6.0%

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 final 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 4-25 below.

Table 4-25 Penetration of Technology in 2008 Vehicles with 2008 Sales: Cars and Trucks

	SGDI	DEAC-OHC	Turbo	Diesel	6 Speed Auto Trans	DCT	42 V S-S	Hybrid	PHEV/EV
BMW	7.50%	0.00%	6.10%	0.00%	86.00%	0.90%	0.00%	0.00%	0.10%
Chrysler	0.00%	0.00%	0.50%	0.10%	14.00%	0.00%	0.00%	0.00%	0.00%
Daimler	0.00%	0.00%	6.50%	5.60%	76.00%	7.50%	0.00%	0.00%	0.00%
Ford	0.40%	0.00%	2.20%	0.00%	29.00%	0.00%	0.00%	0.00%	0.00%
General Motors	3.10%	0.00%	1.40%	0.00%	15.00%	0.00%	0.00%	0.30%	0.00%
Honda	1.40%	7.10%	1.40%	0.00%	0.00%	0.00%	0.00%	2.10%	0.00%
Hyundai	0.00%	0.00%	0.00%	0.00%	3.00%	0.00%	0.00%	0.00%	0.00%
Kia	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Mazda	13.60%	0.00%	13.60%	0.00%	26.00%	0.00%	0.00%	0.00%	0.00%
Mitsubishi	0.00%	0.00%	0.00%	0.00%	10.00%	0.00%	0.00%	0.00%	0.00%
Nissan	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.80%	0.00%
Porsche	58.60%	0.00%	14.90%	0.00%	49.00%	0.00%	0.00%	0.00%	0.00%
Subaru	0.00%	0.00%	9.80%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Suzuki	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Tata	0.00%	0.00%	17.30%	0.00%	99.00%	0.00%	0.00%	0.00%	0.00%
Toyota	6.80%	0.00%	0.00%	0.00%	21.00%	0.00%	0.00%	11.60%	0.00%
Volkswagen	50.60%	0.00%	39.50%	0.00%	69.00%	13.10%	0.00%	0.00%	0.00%
Overall	3.80%	0.80%	2.60%	0.10%	19.10%	0.50%	0.00%	2.20%	0.00%

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 final 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 final 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.

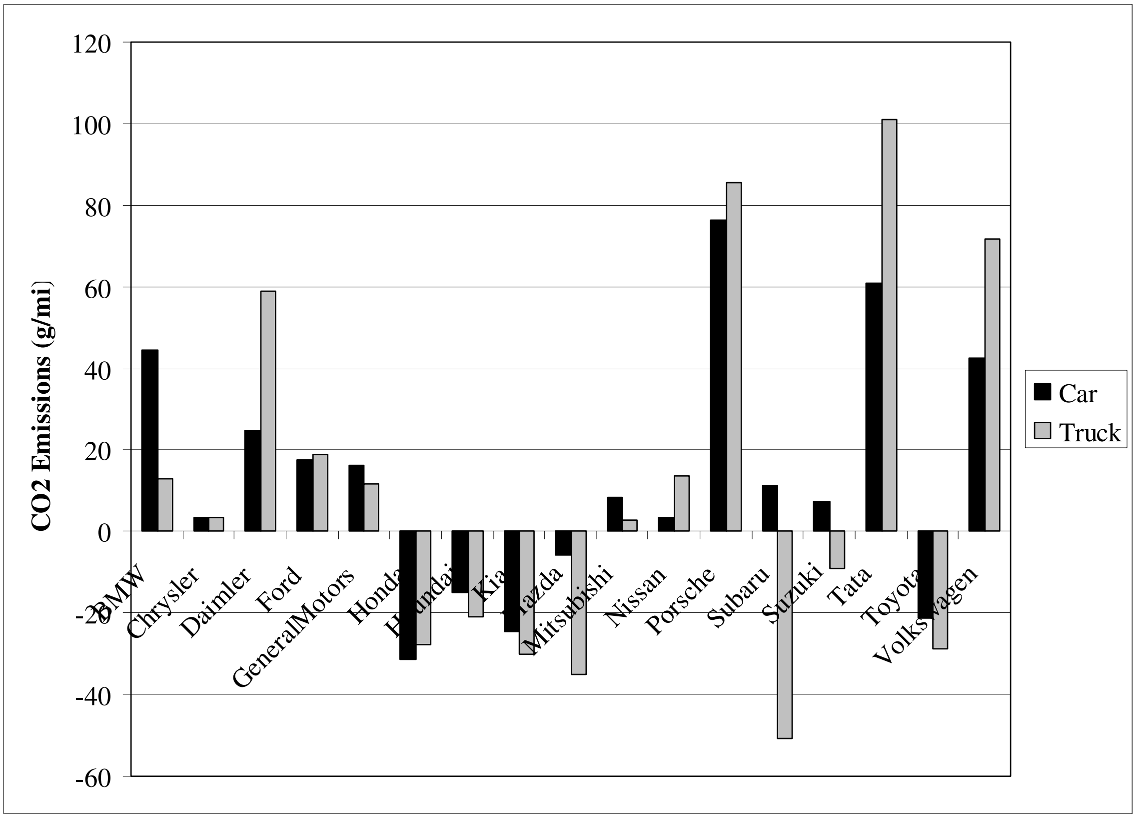

Figure 4-1 CO2 Emissions Relative to Fleet Adjusted for Technology and Footprint

The manufacturers projected in Table 4-25 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 4-25, 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 final 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 4-26 shows each manufacturer's average ratios of weight to footprint and horsepower to weight.

Table 4-26 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 4-27.

Table 4-27 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 final 2016 standards and subtracted the difference for the industry as a whole. The results are shown in Figure 4-2.

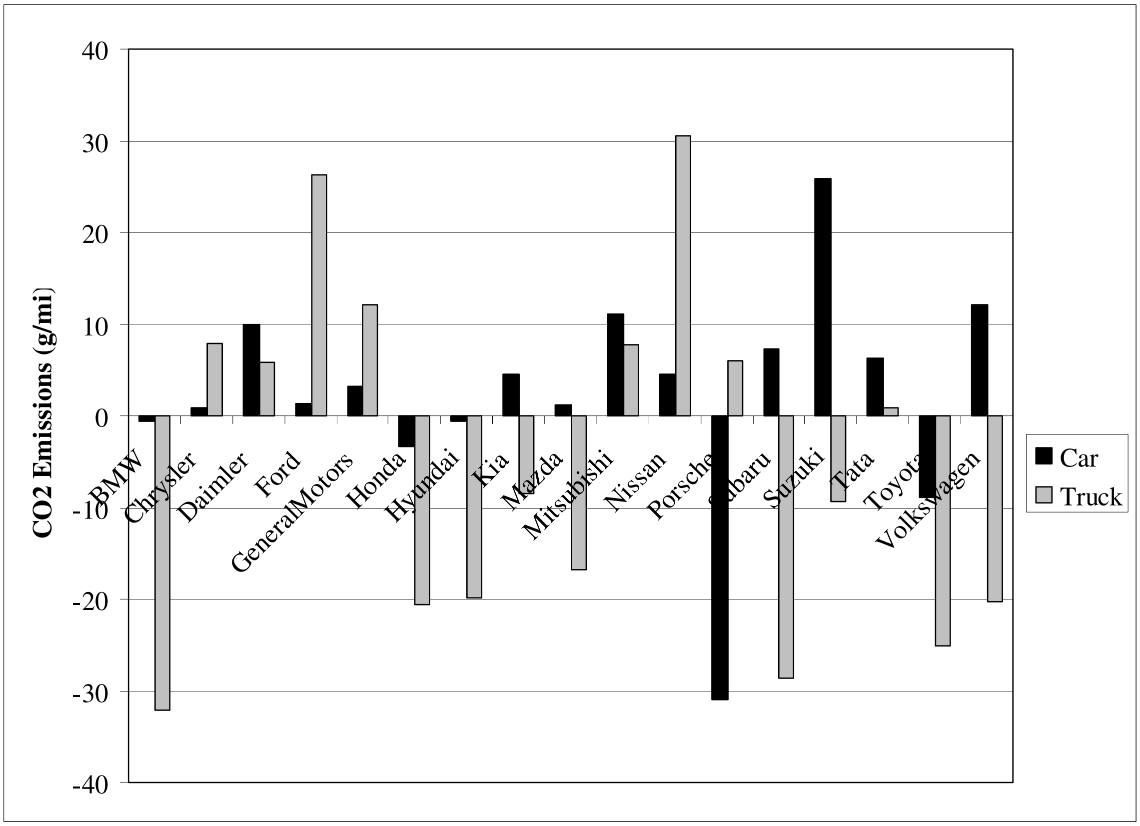

Figure 4-2 CO2 Emissions Relative to Fleet Adjusted for Technology, Footprint, Weight at Footprint, and Performance

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 4-27 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 final CO_2 standards.

CHAPTER 5: Emissions Impacts

5.1 Overview

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. The primary GHGs of concern are carbon dioxide (CO_2), methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride.[1] Mobile sources emitted 31 percent of all U.S. GHG in 2007 (transportation sources, which do not include certain off-highway sources, account for 28 percent) and have been the fastest-growing source of U.S. GHG since 1990.[2] Mobile sources addressed in the recent endangerment finding under CAA section 202(a)--light-duty vehicles, heavy-duty trucks, buses, and motorcycles--accounted for 23 percent of all U.S. GHG in 2007.[3] Light-duty vehicles emit four GHGs--CO_2 , methane, nitrous oxide, and hydrofluorocarbons--and are responsible for nearly 60 percent of all mobile source GHGs and over 70 percent of Section 202(a) mobile source GHG. For light-duty vehicles in 2007, CO_2 emissions represent about 94 percent of all greenhouse emissions (including HFCs), and the CO_2 emissions measured over the EPA tests used for fuel economy compliance represent about 90 percent of total light-duty vehicle greenhouse gas emissions.[4,5]

Today's rule 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 rule 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 several air toxics (including benzene, 1,3-butadiene, formaldehyde, acetaldehyde, and acrolein).

Most analyses in this chapter of the RIA were updated between proposal and final rulemaking. Most significantly, as a result of public comments and updated economic data, the attribute based CO_2 curves have been revised, as discussed in detail in Section II.B of this preamble and Chapter 2 of the Joint TSD. This update in turn affects costs, benefits, and other impacts of the final standards. Thus EPA's overall projection of the impacts of the final rule standards have been updated and the results are different than for the NPRM, though in general not by a large degree.

Beyond updated CO_2 curves, other new inputs includes revised sales projections of the MY 2012-2016 fleet, and updated economic input data. All changes to inputs are documented in the TSD, and are further described in this document.

Downstream (tailpipe) emission impacts were developed using 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). Non-CO_2

emissions were calculated using data from EPA's Motor Vehicle Emission Simulator (MOVES2010).

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.[6] Based on these analyses, the control programs set forth in this chapter would account for 307 MMT CO_2EQ of annual GHG reduction in the year 2030 and 506 MMT per year in 2050. Fuel savings resulting from the GHG standards are projected at 41.5 billion gallons of fuel savings in Calendar Year 2050 (Table 5-1).

Table 5-1 Impacts of 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	156.3	0.8	12.6
2030	307.4	1.6	24.7
2040	401.5	2.1	32.6
2050	505.9	2.7	41.5

The emissions of non-GHG air pollutants due to light duty vehicles are also expected to be affected by today's final rule. These effects are due to changes in driver behavior (the "rebound effect")[A] and also reflect ethanol volume assumptions that are not due to the new GHG vehicle standards. The delta values shown here include both upstream and downstream contributions.

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

Table 5-2 Impacts of 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	-95.1	-0.38%	-21.1	-0.10%
Δ Acetaldehyde	760.0	2.26%	668.1	2.18%
Δ Acrolein	0.8	0.01%	4.7	0.07%
Δ Benzene	-889.9	-0.48%	-523.1	-0.29%
Δ Carbon Monoxide	3,980.3	0.01%	170,648.6	0.56%
Δ Formaldehyde	-49.4	-0.06%	15.1	0.02%
Δ Oxides of Nitrogen	-5,916.1	-0.02%	-21,845.0	-0.07%
Δ Particulate Matter (below 2.5 micrometers)	-2,402.9	-0.03%	-4,574.8	-0.05%
Δ Oxides of Sulfur	-13,853.4	-0.42%	-27,492.8	-0.82%
Δ Volatile Organic Compounds	-60,305.4	-0.51%	-115,816.5	-1.02%

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 final rule. These results, including both upstream and downstream GHG contributions, are presented below (Table 5-3).

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	88.8	7.3	173.1
2013	130.2	10.5	250.35
2014	174.2	13.9	330.5
2015	244.2	19.5	464.7
2016	324.7	26.5	630.7
Total Program Benefit	**962.0**	**77.6**	**1,849.3**

5.2 Introduction

5.2.1 Scope of Analysis

Today's program finalizes new standards for the greenhouse gas (GHG) emissions of light duty vehicles from model year 2012 through model year 2016. The 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 final rule 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 final rule.

This chapter describes the development of inventories for emissions of the gaseous pollutants impacted by the 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 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 final rule on greenhouse gases in calendar years 2020, 2030, 2040 and 2050. Non-greenhouse gas inventories are shown in 2020 and 2030. The program was quantified as the difference in mass emissions between the 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

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. 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 final rule is new standards for tailpipe emissions produced during vehicle operation. 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 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,[B] 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. The implications for non-GHG emissions of changes in fuel supply were analyzed for the final rulemaking and are discussed in Section 5.3.3.5.

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. 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.[7]

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).[8]

The global warming potentials (GWP) used in this analysis are consistent with the 2007 Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4). At this time, the 1996 IPCC Second Assessment Report (SAR) global warming potential values

[B] Described in Joint TSD Chapter 4

have been agreed upon as the official U.S. framework for addressing climate change and are used in the official U.S. greenhouse gas inventory submission to the United Nations climate change framework. This is consistent with the use of the SAR global warming potential values in current international agreements.

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) in conjunction with EPA's Motor Vehicle Emission Simulator (MOVES2010). Broadly speaking, OMEGA is used to predict the most likely paths by which manufacturers would meet tailpipe CO_2 emission standards. OMEGA applies technologies with varying degrees of cost and effectiveness to a defined vehicle fleet in order to meet a specified GHG emission target and calculates the costs and benefits of doing so. The 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 impacts (emission reductions, monetized co-benefits) of the analyzed program.

The OMEGA post-processor was updated with emission rates MOVES2010.[9,10] CO_2 emission and fuel consumption rates are drawn from OMEGA results, with all co-pollutant emission rates derived from the MOVES2010 emission rate database. Air conditioning inventories (including HFC and CO_2 contributions) were separately calculated in spreadsheet analyses, and are based on previous EPA research.[11] Both MOVES and OMEGA are published, publicly available models and continue to be actively developed. [12,13] No public comments were received on the selection of either MOVES or the OMEGA post-processor for calculating the impacts of this rule.

Upstream emissions were calculated using the same tools as were used for the Renewable Fuel Standard 2 (RFS2) rule analysis,[14] 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.[15, 16] 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 rulemaking 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. No public comments were received on EPA's use of the modified version of GREET in this analysis.

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 analysis, and each is described below.[17] 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,[18] while the control scenario CO_2 emissions are based upon the program set forth 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.

As in the proposal, for this analysis we attribute decreased fuel consumption from this program to gasoline only, while assuming no effect on volumes of ethanol and other renewable fuels because they are mandated under the Renewable Fuel Standard (RFS2). However, because this rule does not assume RFS2 volumes of ethanol in the baseline, the result is a greater projected market share of E10 in the control case.[19] In fact, the GHG standards will not be affecting the market share of E10, because EPA's analysis for the RFS2 rule predicts 100% E10 penetration by 2014.[20]

In the proposal, EPA stated these same fuel assumptions and qualitatively noted that there were likely unquantified impacts on non-GHG emissions between the two cases. In RIA Chapter 5, EPA indicated its plans to quantify these impacts in the air quality modeling and in the final rule inventories. Upstream emission impacts depend only on fuel volumes, so the impacts presented here reflect only the reduced gasoline consumption.

The inventories presented in this rulemaking include an analysis of these fuel effects which was conducted using EPA's Motor Vehicle Emission Simulator (MOVES2010). The most notable impact, although still relatively slight, is a 2.2 percent increase in 2030 in national acetaldehyde emissions over the baseline scenario. It should be noted that these emission impacts are not due to the new GHG vehicle standards. These impacts are instead a consequence of the assumed ethanol volumes. This program does not mandate an increase in

E10, nor any particular fuel blend. The emission impact of this shift was also modeled in the RFS2 rule.

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. 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 less than 1% (Section 5.3.3.5).

The relationship between fuel composition and emission impacts used in MOVES2010 and applied in this analysis match those developed for the recent Renewable Fuels Standard (RFS2) requirement, and are extensively documented in the RFS2 RIA and supporting documents.[21]

5.3.2.1 Sales and Fleet Composition

Fleet composition has a significant effect upon the impacts of the program. 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.[22] 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

As explained in section II.B of the preamble to the final rule and chapter 1 of the Joint TSD, EPA updated its fleet projection for the final rulemaking analysis.[23] As a result of this change, all calculations which depend upon fleet composition (ie, emission inventories, impacts of flexibilities, and fuel savings) were updated from those in chapter 5 of the RIA.

Total volumes of projected sales of classic cars and trucks for calendar years 2012-2035 were drawn from the Energy Information Administration Annual Energy Outlook (AEO) 2010 Early Release projection (December 2010).[24] The AEO 2010 Early Release is an update of the April 2009 AEO projections used in the proposal analysis.[25] Based on EPA analysis of the projected MY 2012-2016 fleet,[26] approximately 20% of the classic truck fleet is anticipated to be reclassified as Passenger Automobiles under the new standards. The AEO 2010 sales projections, which are based on the classic fleet, were then reclassified using PA and NPA definitions by shifting 19.91% of AEO's truck sales projection to car sales. For calendar years 2035-2050, which are beyond the scope of AEO's projections, 0.88% annual growth in the sales of cars and trucks was assumed. The annual growth rate of 0.88% is the average year-on-year sales growth projected by AEO from years 2017-2035.

A more complete discussion of the process for developing the MY 2012-2016 fleet is available in TSD chapter 1.

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	14,921,031	15,835,190	16,178,725	16,452,676	16,501,102
Classic Car Fraction	51.8%	52.9%	54.3%	55.8%	57.1%
PA Fraction	59.2%	61.1%	61.9%	63.2%	64.6%
PAs Sold	7,922,992	9,123,197	9,797,738	10,231,974	10,627,055

5.3.2.2 Fleet Average CO_2 Targets

In this section, the term "target" is used to refer to the output of the footprint equations described in Preamble Section II. The term "achieved emission level" is similar, but includes the impacts of program flexibilities.

As documented in Preamble Section II, under both reference and control scenarios, each manufacturer has a unique fleet average target based on their vehicle footprints and production.

Fleet average targets are calculated by weighting the individual PA and NPA targets 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, post- 2016 vehicles are assumed to maintain model year 2016 emissions. Because the fleet composition continues to change post-MY 2016, the fleet average emission level continues to vary. No public comments were received on this methodology.

Below, PA and NPA tailpipe CO_2 fleet average emission targets and achieved emission levels during MY 2012-2016 are shown for reference and control scenarios.

5.3.2.2.1 Reference Case

5.3.2.2.1.1 CO_2 Emission Targets

The reference scenario targets 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 joint TSD and chapter 4 of the RIA).[27] Average car and truck fuel economy targets were calculated from the coefficients in the MY 2011 rule and the projected MY 2012-2016 fleet.[28,29] Average fuel economy targets were calculated for each manufacturer's fleet, and then combined based on projected sales.

A ratio of 8,887 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 8,887 factor can be seen in previous EPA publications.[30]

Minor changes in the emission targets are due to projected changes in the average new vehicle footprint between 2012 and 2016 (Table 5-8).

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

MODEL YEAR	PA EMISSION LEVEL	NPA EMISSION LEVEL	MY EMISSION LEVEL
2012	292	365	320
2013	291	365	319
2014	291	364	318
2015	292	364	317
2016	292	364	316

5.3.2.2.1.2 Achieved CO_2 Emission Levels

The emission targets shown in Table 5-8 do not reflect the impact of several program flexibilities in CAFE program, 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 otherwise allows. Additionally, some manufacturers overcomply with the standards, and this overcompliance is not reflected in the CAFE targets.

While the CAFE program is complex, the most significant portions of the program flexibilities were accounted for. In this analysis, manufacturer overcompliance, credit trading, FFV credits, and fine paying manufacturers were included. Credit banking was excluded.

In general, achieved emission levels were estimated by beginning with the more stringent of either (A) a manufacturer's CAFE target (in CO_2 space) or (B) estimated actual

MY 2008 CO_2 emission levels 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 it is anticipated that they will take advantage. Consistent with the use of the MY 2011 standards, the credits and trading limits available for MY 2011 were 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 Transfers

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 target (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 "transfered" 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 transfered 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 transfer 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 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 TRANSFERS	FFV	FINES	NET
2012	-5.1	7.5	1.0	3.5
2013	-6.1	7.1	0.6	1.5
2014	-6.4	6.6	0.2	0.3
2015	-6.7	6.4	0.1	-0.2
2016	-7.0	6.3	0.1	-0.6

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	286	383	324
2013	284	381	321
2014	283	379	318
2015	283	378	317
2016	283	378	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 establishing 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.B of the preamble to the final rule. 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 targets for the MY2012-2016 vehicles (Table 5-11).[31]

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

MODEL YEAR	PA EMISSION LEVEL	NPA EMISSION LEVEL	PROJECTED MY EMISSION TARGET
2012	263	346	295
2013	256	337	286
2014	247	327	276

2015	236	312	263
2016	225	298	250

5.3.2.2.2.2 Achieved CO_2 Emission Levels

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

The same basic methodology was used to calculate achieved fleet emission levels for the control case as in the reference case. In general, achieved emission levels were estimated by beginning with the more stringent of either (A) a manufacturer's calculated footprint-based emission target or (B) the 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 which we anticipate manufacturers will utilize. Manufacturers were always assumed to perform at least as well as they did in 2008.

Overcompliance and Credit Transfers

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 their target.

The achieved overcompliance on either PA or NPA could be "transfered" 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 program, there are no limits within the light duty fleet on such trading.[C] This transferance 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 transfers are VMT weighted, the resulting changes will be essentially environmentally neutral on both GHG and criteria pollutants.

Flex Fueled Vehicles

The flex fueled vehicle credit,consistent with the final rule is set at 1.2 MPG for MY 2012-2014, 1.0 MPG for MY 2015, and 0 MPG for MY 2016+. See also preamble section

[C] Preamble section III.B and III.C discusses credit transfers in more detail, including limits on credit life and various other restrictions.

III.C.2 As in the reference case, it was assumed that the manufacturers General Motors, Chrysler and Ford would utilize 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 6.3 grams CO_2 per mile for PA and 7.8 grams CO_2 per mile for NPA). In the proposal, we noted the inconsistent values between the direct A/C credit presented here, and the direct A/C credit discussed in RIA Chapter 2. We corrected this minor inconsistency for this FRM analysis. EPA assumed market penetration of the technology according to Table 5-17. A more complete discussion of the A/C credit program and inventories is provided in section 5.3.3.2, as well as RIA chapter 2.

Temporary Lead Time Allowance Alternative Standards (TLAAS)

In response to public comment, the TLAAS program includes certain additional features which expand its range. See preamble section III.B.5 and Appendix A to this RIA chapter. Specifically, the TLAAS program has been expanded into two distinct tiers, which are manufacturers with fewer than 400,000 sales and manufacturers with fewer than 50,000 sales. Manufacturers with less than 5,000 vehicles in sales were also temporarily exempted from this rulemaking. A brief summaryof the inputs used in this analysis appear below. For more on the TLAAS program, please see Appendix A to this RIA chapter.

For the larger manufacturers, we assumed that every potentially eligible manufacturer utilized the TLAAS program. Each qualifying manufacturer was assumed to use the full vehicle allocation according to the default production schedule shown in Section III.B.5 of the proposal preamble and reproduced in Table 5-12.

Table 5-12 – TLAAS default production schedule

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. For these companies, 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.

For the smaller manufacturers, the program was expanded to allow 50,000 vehicles in 2016, and 200,000 vehicles though 2015. These fleets were assumed to gradually phase into compliance. These TLAAS fleets are assumed to emit 1.25x more emissions than the manufacturer's sales weighted target in 2012, and by 2016, they were assumed to emit 1.05x more emissions.

In each case, the TLAAS vehicles were then proportionally averaged into the manufacturer's achieved emission level.

The aggregate impacts of these program flexibilities are listed in Table 5-13.

Table 5-13 Estimated Impacts of Program Flexibilities (grams/mile CO2 EQ)

MODEL YEAR	OVERCOMPLIANCE, CREDITS AND TRANSFERS	FFV	DIRECT A/C	INDIRECT A/C	TLAAS	NET
2012	-0.1	6.5	1.7	1.4	1.2	**10.7**
2013	0.0	5.8	2.7	2.3	0.9	**11.7**
2014	0.0	5.0	4.1	3.4	0.6	**13.1**
2015	0.0	3.7	5.5	4.6	0.3	**14.0**
2016	0.0	0.0	5.8	4.8	0.1	**10.7**

Based on these impacts, the achieved emission level by PA, NPA and fleet are displayed in Table 5-14. 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 5-14 Federal GHG Program Anticipated Emission Levels (grams/mile CO2)

MODEL YEAR	ANTICIPATED PA EMISSION LEVEL	ANTICIPATED NPA EMISSION LEVEL	ANTICIPATED MY EMISSION LEVEL
2012	270	365	307
2013	264	354	298
2014	258	344	290
2015	248	330	277
2016	236	309	261

Table 5-14 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.

As in the proposal, the OMEGA also predicts slight undercompliance in 2016 for several manufacturers, while the results presented here assume full compliance. The net undercompliance is approximately 0.8 grams in 2016. A more complete discussion of the OMEGA cost modeling is available in RIA chapter 4.

5.3.3 Calculation of Downstream Emissions

As stated in Section 5.1, the downstream analysis conducted in the proposal has been updated in the analysis shown here. To reiterate, the 2012-2016 CO_2 standards (i.e., the attribute-based curves for cars and light trucks) were revised slightly,[D] and several tools were updated; Draft MOVES2009 was updated to MOVES2010 and minor changes were made to the OMEGA post-processor. Beyond these changes, the analysis of GHG emissions was similarly conducted between NPRM and FRM. While public comments were received on several of the economic inputs used in the modeling (see TSD chapter 4), no substantive comments were received concerning the methodology or resulting inventories.

As mentioned in Section 5.2.2, the analysis of non-GHG emissions was updated to include fuel effects. The FRM upstream analysis was updated with the new fuel savings volumes, but is otherwise unchanged.

A model year lifetime analysis, considering only the five model years specifically regulated by 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 Calculation of Tailpipe CO_2 Emissions

The fleet inputs (achieved CO_2 emission levels by model year and vehicle sales) were incorporated into a spreadsheet along with emission rates derived from MOVES2010 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.

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 1 - 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.

[D] See Preamble Section II.B

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 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 accumulation schedule for that vehicle class, model year, and age.

Future vehicle sales were drawn from AEO 2010 Early Release (as discussed in Section 5.3.2.1), while historic vehicle sales are drawn from the Transportation Energy Data Book,[32] Post MY 2011 vehicles were reclassified in order to correspond to the PA/NPA definitions.

As described in the TSD, mileage accumulation by age was calculated using inputs from the NHTSA "Vehicle Survivability and Travel Mileage Schedules" and additional inputs unique to this analysis.[33,34] In brief, a 1.15% per vehicle annual VMT growth rate was assumed, but additional factors such as achieved fuel consumption and the price of gasoline also contributed to the precise schedule for each MY.

The vehicle 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 5-15).[35]

Table 5-15 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 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 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:

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

Equation 2 - 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 supporting that figure is explored in greater depth in chapter 4 of the 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 5-14, SO_2 emission rates are derived from fuel sulfur levels, and the emission rates for the remaining pollutants are derived from the MOVES2010 database. For a more complete discussion of these emission rates, please refer to joint TSD chapter 4.[36]

EPA is not projecting any reductions in tailpipe CH_4 or N_2O emissions as a result of these emission caps.Similar to other pollutants, there are downstream emission impacts due to changes in fuel supply and increased driving (rebound), as well as upstream impacts due to decreases in fuel production, transport, and distribution.

5.3.3.1.4 Tailpipe CO2 Emissions from Vehicles

CO_2 emission rates were derived from the achieved CO_2 emission levels in

Table 5-10 & Table 5-14. Previous EPA analysis has shown that an approximately 20% gap exists between CAFE space fuel economy and on-road fuel economy.[37] The on-road gap is more fully documented in the joint TSD chapter 4.

The 20% gap, while approximate, includes average effects of energy consumption 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 CO_2 emission impacts of running a mobile vehicle air conditioning system. In this analysis, CO_2 emissions are assumed to remain unchanged throughout the vehicle's lifetime.

By dividing a CAFE-space CO_2 emission rate by one minus the on-road gap, one can approximate the actual on-road CO_2 emission rate experienced by drivers, and this analysis used this means of reflecting the on-road gap. By including VMT, we estimate the on-road tailpipe CO_2 emissions.

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

Equation 3 - Tailpipe CO2 Emissions Excluding A/C

Based on Equation 3, 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 5-16 Tailpipe CO_2 Emissions including Baseline A/C Usage (MMT)

	2020	2030	2040	2050
Tailpipe CO_2 Emissions (Reference)	1,173	1,313	1,609	2,030
Δ Tailpipe CO_2 Emissions (Control) including 10% rebound	-101.2	-199.6	-263.4	-335.3
Δ Tailpipe CO_2 Emissions due to 10% rebound	10.3	19.9	26.1	33.2

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 RIA Chapter 2.

EPA's analysis, shown in RIA chapter 2, indicates that A/C- related emissions accounted for approximately 8% of the GHG emissions from in-use cars and light trucks in 2005. EPA is finalizing credit provisions which we expect all manufacturers to utilize which are expected to reduce direct leakage emissions by 50% and to reduce indirect A/C emissions (A/C related CO_2 tailpipe 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 5-17. The 85% cap is roughly linearized across the five year period (Table 5-17). Because HFC leakage is somewhat independent of vehicle miles traveled, the HFC fraction is based upon the proportion of new vehicles that have HFC leakage containment technology. By contrast, the indirect A/C reduction fraction is dependent upon the travel fraction, and is proportional to the VMT traveled by vehicles with the control technology.

Table 5-17 – AC Control by Model Year (Reduction from Base Emissions)

	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016+
Market Penetration of technology	25%[E]	40%	60%	80%	85%
HFC Reduction %	-13%	-21%	-30%	-40%	-43%
Indirect Reduction %	-10%	-16%	-24%	-32%	-34%

5.3.3.2.1 Direct A/C (HFC) Emissions

The projected HFC baseline inventories are derived from previous EPA analyses.[38] The methodology used in the proposal was updated with the new estimates of vehicle sales and miles traveled.

As noted, HFC emissions are a leakage type emission, similar to other evaporative emissions from a vehicle.[39] 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)[40] 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. As noted in the proposal and reiterated here, preliminary EPA analysis indicates that air conditioner charge size is decreasing, which implies that the analysis presented here may 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 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 4**).

[E] In Preamble Section III, the expected penetration of A/C control technology is shown to be 28% in MY 2012. The slightly lower penetration number used in the emission modeling indicates a slight underestimation of the emission reductions from MY 2012, and consequently the benefits from this rule.

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

Equation 4 - HFC Inventory Calculation

Table 5-18 shows baseline HFC inventory and control scenario reductions.

Table 5-18 HFC (Direct A/C) Emissions

Calendar Year	Baseline HFC (MMT CO2EQ)	Reduction From Baseline (%)	Reduction from Baseline (MMT CO2EQ)
2010	56.9	0%	0.0
2020	61.3	-22%	-13.3
2030	67.8	-38%	-26.0
2040	73.7	-42%	-30.9
2050	80.4	-42%	-34.2

5.3.3.2.2 Indirect A/C (CO_2) 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 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 RIA 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 put forth 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 methodology used in the proposal was updated with the new estimates of vehicle sales and mileage traveled. The OMEGA post processor was used to calculate the contribution of the indirect A/C program to the overall inventory. Reference and control scenario emissions attributable to indirect A/C systems are shown in Table 5-19.

Table 5-19 –Indirect A/C Emissions

Calendar Year	Baseline Indirect A/C (MMT CO2EQ)	Reduction From Baseline (%)	Reduction from Baseline (MMT CO2EQ)
2010	53.1	-0%	0
2020	53.6	-20%	-10.6
2030	63.1	-32%	-20.2
2040	78.5	-34%	-26.5

2050	99.3	-34%	-33.8

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 Methane (CH_4) and Nitrous Oxide (N_2O) Emissions from Vehicles

MOVES2010 does not include fuel effects for either nitrous oxide or methane emissions. Therefore, the only modeled difference in N_2O and CH_4 between control and reference cases are emissions which occur during rebound driving. These emissions, like all rebound emissions, were calculated in the modified OMEGA post-processor.

The reference inventories shown in Table 5-20 were calculate using MOVES2010 as described in Section 5.3.3.5.1.

Table 5-20 Downstream CH_4 and N_2O Emissions (Metric Tons)

	Reference Emissions		Control Emissions (including rebound)		Delta Emissions	
	2020	**2030**	**2020**	**2030**	**2020**	**2030**
Gasoline Vehicles						
CH_4	41,828	44,464	42,130	45,096	302	632
N_2O	29,898	21,620	29,898	21,904	135	284
Diesel Vehicles						
CH_4	661.6	810.3	661.7	810.6	0.1	0.3
N_2O	829.8	999.3	830.0	999.7	0.2	0.4

5.3.3.4 Fuel Savings

The 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 CO2 avoided (including CO2 due to driving and indirect A/C use) using a conversion factor of 8887 grams of CO2 per gallon of gasoline. All fuel saved is considered 100% gasoline without any oxygenate.[F,41]

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. [42]

[F] Based on the documentation of the on-road gap, it would be justifiable to assume an ethanol percentage of approximately 2.3%. This volume of ethanol would result in a total energy difference of less than 1%. See the fuel labeling rule technical support document, EPA420-R-06-017, for further details.

Table 5-21 - Fuel Consumption Changes by Calendar Year (Billions of Gallons of Gasoline Equivalent)

	2020	2030	2040	2050
Fuel Consumption (Reference)	137.9	154.8	190	239.6
Δ Total Fuel Consumption due to EPA Program	-12.6	-24.7	-32.6	-41.6
Δ Fuel Consumption due to 10% rebound	1.2	2.2	2.9	3.7
Δ Fuel Consumption due to A/C controls	-1.2	-2.3	-3.0	-3.8

5.3.3.5 Downstream Criteria and Air Toxic Emissions

This rule affects tailpipe co-pollutant emissions in two significant ways. The first, modeled in the proposal, is an increase in emissions due to the rebound effect. The second effect, newly analyzed here, is an increase in the market share of ethanol blended gasoline. As modeled, this rule will reduce the consumption and production of gasoline (E0), while the production of ethanol is held constant due to the Renewable Fuel Standards. Consequently, the fraction of fuel which is blended to 10% ethanol (E10) is assumed to increase. However, the increased E10 market share is projected to occur regardless of this rule; in the RFS2 analysis we project 100% E10 by 2014. These fuel effects were not quantified in the proposal; as a result the proposal emission inventories differ from those shown here.

For today's analysis, MOVES2010 was used to generate base inventories for both reference and control fuel supplies using a single base VMT. Using the control scenario fuel supply, the OMEGA post-processor provided rebound emission quantities.

5.3.3.5.1 Base Criteria and Air Toxic Emission Inventories

MOVES2010 was run in the following manner in order to provide base inventories for both reference and control cases.

The fuel supplies in each case were calculated by sequentially:

A) estimating the light duty energy demand in 2020 and 2030 based on the energy consumption projections from this rule.

B) determining the total energy demand from light duty, heavy duty, motorcycle and non-road sources from AEO and other reference sources

C) determining the total ethanol volume from AEO 2007, which does not include increased renewable fuel volumes due to EISA.[G]

[G] Due to the long lead times required for this analysis, it was completed before the second Renewable Fuel Standard (RFS2) was signed. The increased renewable fuel volume attributable to this regulation is therefore not assumed in this analysis.

D) calculating E10 market share

The resulting 2020 and 2030 E10 market shares are shown in Table 5-22.

Table 5-22 E10 market shares

Calendar Year	Reference Case E10 fraction	Control Case E10 Fraction	Delta
2020	85%	92%	7%
2030	82%	97%	15%[H]

For simplicity, we used the same MOVES fuel supply table as used in the Renewable Fuel Standard 2 analysis as our reference case fuel supply. This table is approximately 90% E10. For the control case, we created a table where 100% of the fuel supply was E10. These tables were used in both of the modeled years (2020 and 2030). This slightly overstates the delta in E10 usage in 2020 and slightly understates the delta in 2030. The simplified analysis still captures the approximate deltas shown in Table 5-22.

To maintain consistency with the MOVES runs conducted for the Air Quality analysis, temperatures from 2005 were also input to MOVES, and used in both years of analysis.

Four separate MOVES runs were conducted. All valid sourcetype/fuel type combinations in the MOVES2010 database were included in the MOVES runs. For each of the control case and reference case, one run was used to calculate evaporative emissions, and one run was set for all other processes (running exhaust, start exhaust, brakewear, tirewear, crankcase, refueling, and extended idle). Diesel toxic emissions were not produced by the MOVES model, but were post-processed from VOC emissions using published ratios

[H] As the production of petroleum based fuels decreases, the market share of E10 is projected to gradually increase. E10 has slightly less energy than E0, a consequence of which may be a slight reduction in the quantity of retail gasoline gallons saved by this rule. The total energy savings would remain as predicted by this rule.

Assuming that a gallon of ethanol contains approximately 77,000 BTU of energy and that a gallon of gasoline contains approximately 115,000, a gallon of E10 contains 3.3% less energy than a gallon of gasoline. A 15% increase in E10 market share in 2030, as described in table 5-22, would indicate that the average gallon of gasoline sold in the control case in 2030 would contain 0.5% less energy than in the reference case. This difference in energy content would be less in the near term, before the program is fully phased in.

All else being equal, the difference in energy content would result in additional gallons of fuel being purchased to meet the energy demands of the control case. Assuming that gasoline prices would not be affected by ethanol or energy content, this would result in a very slight overestimate of the monetized fuel savings predicted by this rule and discussed in RIA Chapter 6.

identical to those in MOVES.[43] All emission results except for evaporative emissions were post-processed and scaled based on the ratios of VMT between the MOVES output and the VMT used for air quality modeling. Evaporative emissions, which are largely dependent on vehicle population, were not scaled. As the air quality modeling was only conducted in 2030, 2020 VMT was created by scaling the air quality modeling VMT by the ratio of 2020 to 2030 VMT in MOVES. The resulting factor (82%) was universally applied to the 2030 VMT to produce 2020 VMT for each sourcetype.

The VMT developed for air quality modeling is more completely documented in Section 5.8.

5.3.3.5.2 Criteria and Air Toxic Emissions due to the Rebound Effect

As a result of the additional rebound VMT, the downstream emissions of several co-pollutants increase in the control case. The emissions due to rebound were calculated in the OMEGA post-processor in a similar manner to the CO_2 emissions. Rebound VMT was broken into distribution by vehicle age and was then multiplied by the appropriate emission factor. These emissions by age were then summed by calendar year (Equation 5).

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

Equation 5 - Emissions by Calendar Year

The EPA reference fleet assumes a small number of diesel vehicles are sold in each year (approximately 20 thousand vehicles out of approximately13-16 million). For the analysis of criteria emissions due to the rebound effect, 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.[I]

5.3.3.5.3 Tabulation of Downstream Criteria and Air Toxic Impacts

This section contains a table of the downstream criteria and air toxic emissions.

[I] 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 5-23 - Downstream non-GHG Emissions (Short Tons)

	Reference Emissions		Control Emissions (including rebound)		Delta Emissions	
	CY 2020	CY 2030	CY 2020	CY 2030	CY 2020	CY 2030
Gasoline Vehicles						
1,3-Butadiene	4,777	3,448	4,683	3,429	-93.7	-18.5
Acetaldehyde	10,805	7,909	11,571	8,590	766.6	681.0
Acrolein	569	419	571	426	1.7	6.4
Benzene	30,633	22,048	29,882	21,799	-750.4	-249.2
CO	20,764,531	20,615,741	20,774,455	20,797,866	9,924.0	182,125.6
Formaldehyde	11,268	8,196	11,270	8,311	1.4	114.6
NO_x	1,493,306	1,059,567	1,506,643	1,075,547	13,336.7	15,979.4
$PM_{2.5}$	40,685	42,855	40,915	43,455	229.8	599.7
SO_2	22,130	25,700	20,103	21,451	-2,027.7	-4,248.5
VOC	1,290,008	1,006,387	1,294,309	1,017,550	4,301.6	11,163.3
Diesel Vehicles						
1,3-Butadiene	1,397	1,434	1,397	1,434	0.2	0.4
Acetaldehyde	5,562	5,709	5,562	5,709	0.2	0.5
Acrolein	741	761	741	761	0.1	0.2
Benzene	2,620	2,689	2,620	2,690	0.3	0.9
CO	612,037	567,933	612,270	568,595	232.2	662.2
Formaldehyde	15,279	15,684	15,280	15,686	0.7	1.7
NO_x	1,502,844	1,192,334	1,502,917	1,192,498	73.7	163.2
$PM_{2.5}$	41,483	15,678	41,484	15,680	1.2	2.6
SO_2	4,565	5,538	4,565	5,538	Attributed to gasoline	
VOC	203,977	209,384	203,994	209,428	17.1	44.1

In summary, the downstream emissions of the criteria pollutants CO, NOx, $PM_{2.5}$, and VOC increase due to the additional rebound VMT. SO_2 emissions decrease because the CO_2 standards lead to a decreased volume of fuel consumption and less resulting emissions of sulfur compounds.

Air toxic emissions, which are sensitive to fuel effects, vary more between cases. Acetaldehyde emissions increase roughly proportionally to the increase in ethanol penetration. Similarly, benzene and 1,3 butadiene decrease proportionally to the decrease in gasoline emissions. These changes are the result of our ethanol volume assumptions and are not due to the new GHG vehicle standards. For a more complete discussions of ethanol effects on air toxic emissions, please refer to the EPA RFS2 analysis.[44]

As will be 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 those pollutants such as carbon monoxide (CO), acetaldehyde, and formaldehyde, where a relatively small of US emissions comes from upstream sources.

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."[45] The results of this analysis are shown in Table 5-30. No public comments were received on the methodologies used in the calculation of upstream inventories.

5.4 Greenhouse Gas Emission Inventory

This section presents total program calendar year impacts by sector (Table 5-24, Table 5-25,Table 5-26). Upstream, downstream, and total program impact are presented.

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

	2020	2030	2040	2050
Δ CO2 (Metric Tons)	-111,867,639	-219,811,320	-289,887,109	-368,990,880
Δ CH4 (Metric tons)	302.0	631.8	853.1	1,087.4
Δ N2O (Metric tons)	134.9	284.1	383.9	489.6
Δ HFC (Metric tons)	-9,324	-18,189	-21,642	-23,899
Δ GHG (MMT CO2 EQ)	-125.2	-245.7	-320.7	-403.0
Δ Fuel Consumption (billion gallons per year)	-12.6	-24.7	-32.6	-41.5

Table 5-25 Upstream GHG Change vs. Reference Case

	2020	2030	2040	2050
Δ CO2 (Metric Tons)	-27,200,175.2	-53,446,255.6	-70,484,907.4	-89,718,677.3
Δ CH4 (Metric tons)	-154,246.0	-303,081.5	-399,703.8	-508,774.1
Δ N2O (Metric tons)	-437.2	-859.1	-1,133.0	-1,442.2
Δ GHG (MMT CO2 EQ)	-31.2	-61.3	-80.8	-102.9

Table 5-26 Total GHG and Fuel Consumption Changes vs. Reference Case

	2020	2030	2040	2050
Δ CO2 (Metric Tons)	-139,067,814.2	-273,257,576.1	-360,372,016.8	-458,709,557.6
Δ CH4 (Metric tons)	-153,944.0	-302,449.7	-398,850.7	-507,686.7
Δ N2O (Metric tons)	-302.3	-575.0	-749.1	-952.6
Δ HFC (Metric tons)	-9,324.1	-18,189.3	-21,641.7	-23,899.2
Δ GHG (MMT CO2 EQ)	-156.3	-307.0	-401.5	-505.9
Δ Fuel Consumption (billion gallons per year)	-12.6	-24.7	-32.6	-41.5

5.5 Non-Greenhouse Gas Emission Inventory

The reference case emission inventories used for this 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.

The onroad mobile source numbers have been updated from the NPRM with the MOVES data produced for this final rule analysis. For onroad mobile sources, the MOVES 2010 model was used as described in Section 5.3.3.5. This model estimates emissions from light-duty and heavy-duty gasoline and diesel vehicles. These inventories have previously been shown in Section 5.3.3.5.1. In some cases, particularly VOC, CO and NOx, the change from the MOBILE model to a MOVES based inventory has led to large changes in reference inventories from the proposal. These changes are due to model updates rather than program changes.

Most nonroad equipment was modeled with NONROAD2005d, 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).[46, 47] This version of NONROAD does not include the county specific detail that is provided when NONROAD is run using NMIM. Some precision is lost using this method.

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.[46, 48] 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 5-27 and Table 5-28 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 5-27 2020 Reference Case Emissions by Sector (annual short tons)

	VOC	CO	NOX	SO2	PM2.5
Onroad Gasoline	1,290,008	20,764,531	1,493,306	22,130	40,685
Onroad Diesel	203,977	612,037	1,502,844	4,565	41,483
Nonroad SI[a]	1,289,918	14,286,250	242,828	49,019	15,413
Other Nonroad[b]	234,870	1,424,643	3,389,761	210,509	943,226
Stationary/Area	8,740,057	11,049,239	5,773,927	3,047,714	7,864,681
Total	11,758,830	29,756,282	30,783,084	3,333,937	8,905,488

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

TABLE 5-27 CONTINUED	BENZENE	1,3-BUTADIENE	ACETAL-DEHYDE	FORMAL-DEHYDE	ACROLEIN
Onroad Gasoline	30,633	4,777	10,805	11,268	569
Onroad Diesel	2,620	1,397	5,562	15,279	741
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	185,212	25,038	33,602	82,957	6,319

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

Table 5-28 2030 Reference Case Emissions by Sector (annual short tons)

	VOC	CO	NOX	SO2	PM2.5
Onroad Gasoline	1,006,387	20,615,741	1,059,567	25,700	42,855
Onroad Diesel	209,384	567,933	1,192,334	5,538	15,680
Nonroad SI[a]	1,198,679	15,815,805	243,515	50,816	17,270
Other Nonroad[b]	238,652	1,411,393	3,427,832	229,183	1,426,994
Stationary/Area	8,740,057	11,049,239	5,773,927	3,047,714	7,864,681
Total	11,393,159	30,528,338	30,628,948	3,358,951	9,367,480

Table 5-28 continued	Benzene	1,3-Butadiene	Acetal-dehyde	Formal-dehyde	Acrolein
Onroad Gasoline	22,048	3,448	7,909	8,196	419
Onroad Diesel	2,689	1,434	5,709	15,684	761
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	179,709	20,523	30,683	81,442	6,276

[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 on Non-GHG Emissions

The non-GHG emission results shown here (Table 5-29) are a summary of the previous analysis, and are combination of output from MOVES2010 and the OMEGA post-processor.

Table 5-29 Downstream Emission Changes of 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	-93.6	-0.37%	-18.1	-0.09%
Δ Acetaldehyde	766.9	2.28%	681.5	2.22%
Δ Acrolein	1.7	0.03%	6.5	0.10%
Δ Benzene	-750.0	-0.40%	-248.3	-0.14%
Δ Carbon Monoxide	10,156.3	0.03%	182,787.8	0.60%
Δ Formaldehyde	2.1	0.00%	116.3	0.14%
Δ Oxides of Nitrogen	13,410.3	0.04%	16,142.6	0.05%
Δ Particulate Matter (below 2.5 micrometers)	231.0	0.00%	602.3	0.01%
Δ Oxides of Sulfur	-2,027.7	-0.06%	-4,248.5	-0.13%
Δ Volatile Organic Compounds	4,318.7	0.04%	11,207.4	0.10%

5.5.2 Upstream Impacts of Program on Non-GHG Emissions

Non-GHG fuel production and distribution emission impacts of the 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) 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 joint TSD for today's rule.

Results of these emission inventory impact calculations relative to the reference case for 2020 and 2030 are shown in Table 5-30 for the criteria pollutants and individual air toxic pollutants.

The 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 5-30 Upstream Emission Changes of 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	-1.5	-0.01%	-3.0	-0.01%
Δ Acetaldehyde	-6.8	-0.02%	-13.4	-0.04%
Δ Acrolein	-0.9	-0.01%	-1.8	-0.03%
Δ Benzene	-139.6	-0.08%	-274.3	-0.15%
Δ Carbon Monoxide	-6,164.6	-0.02%	-12,113.0	-0.04%
Δ Formaldehyde	-51.4	-0.06%	-101.0	-0.12%
Δ Oxides of Nitrogen	-19,291.0	-0.06%	-37,905.4	-0.12%
Δ Particulate Matter (below 2.5 micrometers)	-2,629.1	-0.03%	-5,165.9	-0.06%
Δ Oxides of Sulfur	-11,804.1	-0.35%	-23,194.1	-0.69%
Δ Volatile Organic Compounds	-64,505.9	-0.55%	-126,749.1	-1.11%

5.5.3 Total non-GHG Program Impact

Table 5-31 shows the combined impacts of downstream and upstream aspects of the program. The net impacts of the program on VOC, NOx, and PM2.5, 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 emissions are driven by the rebound effect on VMT, which are only partially offset by upstream reductions.

Net emissions depend on the relative impacts of the reductions from upstream emissions versus increases due to the rebound effect and ethanol volume assumptions (that are not due to the GHG vehicle standards) on the downstream emissions. All changes in non-

GHG emissions are less than 2.5% of the national inventory, with the net impact on most non-GHG emissions at less than a single percent.

Table 5-31 Total Non-GHG Emission Changes of 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	-95.1	-0.38%	-21.1	-0.10%
Δ Acetaldehyde	760.0	2.26%	668.1	2.18%
Δ Acrolein	0.8	0.01%	4.7	0.07%
Δ Benzene	-889.6	-0.48%	-522.5	-0.29%
Δ Carbon Monoxide	3,991.6	0.01%	170,674.8	0.56%
Δ Formaldehyde	-49.3	-0.06%	15.3	0.02%
Δ Oxides of Nitrogen	-5,880.7	-0.02%	-21,762.8	-0.07%
Δ Particulate Matter (below 2.5 micrometers)	-2,398.1	-0.03%	-4,563.6	-0.05%
Δ Oxides of Sulfur	-13,831.8	-0.42%	-27,442.5	-0.82%
Δ Volatile Organic Compounds	-60,187.1	-0.51%	-115,541.7	-1.01%

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 joint TSD chapter 4. 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 5-32).

The ethanol volumes used in this analysis are from AEO 2007. As there are proportionally few vehicles subject to the new GHG standards in the first few years of these vehicle's lifetimes, which is when the majority of driving occurs, little change is anticipated in the fuel supply which these vehicles use. Therefore, no fuel effects are calculated in the MY lifetime analysis.

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

Table 5-32 Updated Survival Fraction and Mileage Accumulation by Age

AGE	PA SURVIVAL FRACTION	PA MILEAGE	NPA SURVIVAL FRACTION	NPA MILEAGE
0	0.9950	17,270	0.9950	19,219
1	0.9900	16,943	0.9741	18,782
2	0.9831	16,599	0.9603	18,419
3	0.9731	16,163	0.9420	17,946
4	0.9593	15,761	0.9190	17,502
5	0.9413	15,337	0.8913	16,952
6	0.9188	14,881	0.8590	16,439
7	0.8918	14,429	0.8226	15,829
8	0.8604	13,940	0.7827	15,218
9	0.8252	13,495	0.7401	14,648
10	0.7866	12,964	0.6956	13,992
11	0.7170	12,510	0.6501	13,450
12	0.6125	11,990	0.6042	12,832
13	0.5094	11,470	0.5517	12,212
14	0.4142	10,997	0.5009	11,600
15	0.3308	10,543	0.4522	11,069
16	0.2604	10,125	0.4062	10,617
17	0.2028	9,714	0.3633	10,125
18	0.1565	9,307	0.3236	9,650
19	0.1200	8,891	0.2873	9,238
20	0.0916	8,546	0.2542	8,882
21	0.0696	8,285	0.2244	8,667
22	0.0527	8,136	0.1975	8,400
23	0.0399	7,896	0.1735	8,395
24	0.0301	7,699	0.1522	8,197
25	0.0227	7,530	0.1332	8,188
26	0.0000	7,432	0.1165	8,218
27	0.0000	7,297	0.1017	8,216
28	0.0000	7,198	0.0887	8,213
29	0.0000	7,138	0.0773	8,211
30	0.0000	7,136	0.0673	8,210
31	0.0000	7,133	0.0586	8,208
32	0.0000	7,128	0.0509	8,203
33	0.0000	7,117	0.0443	8,196
34	0.0000	7,103	0.0385	8,182
35	0.0000	7,086	0.0334	8,167

5.6.2 Results

The GHG emission reductions are shown for each model year, as are the co-pollutant impacts (Table 5-33, Table 5-34).

Table 5-33 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	-59.1	-84.0	-108.9	-153.9	-214.5	-620.4
Δ Downstream Indirect A/C	-5.5	-9.4	-14.4	-19.6	-20.9	-69.9
Δ Downstream Direct A/C	-6.6	-11.2	-17.2	-23.4	-25.0	-83.4
Δ Downstream CH4	0.0	0.0	0.0	0.0	0.0	0.1
Δ Downstream N2O	0.0	0.0	0.1	0.1	0.1	0.3
Total Δ Downstream	-71.2	-104.6	-140.5	-196.8	-260.3	-773.4
Δ Upstream CO_2	-15.7	-22.7	-30.0	-42.2	-57.2	-167.8
Δ Upstream CH4	-1.9	-2.7	-3.6	-5.0	-6.8	-20.0
ΔUpstream N2O	-0.1	-0.1	-0.1	-0.2	-0.3	-0.8
Total Δ Upstream	-17.7	-25.5	-33.7	-47.4	-64.3	-188.7
Total Program Δ GHG Emissions	-88.8	-130.2	-174.2	-244.2	-324.6	-962.0
Δ Fuel Consumption (Billion Barrels)	-0.17	-0.25	-0.33	-0.46	-0.63	-1.85

Table 5-34 Lifetime non-GHG Emissions vs. Reference Case (Short Tons)

	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016	Total
Downstream						
Δ VOC	2,246.9	3,281.5	4,336.4	6,055.7	8,181.5	24,102.0
Δ NO_X	4,334.4	6,414.4	8,465.9	11,745.4	15,872.5	46,832.5
Δ $PM_{2.5}$	202.8	296.7	392.0	547.0	739.1	2,177.6
Δ CO	86,963.0	127,079.2	167,922.1	234,434.9	316,325.0	932,724.2
Δ SO_2	-1,362.3	-1,970.4	-2,601.0	-3,657.6	-4,964.0	-14,555.2
Δ Benzene	76.1	111.2	146.9	205.1	276.7	816.0
Δ 1,3 Butdiene	12.8	18.7	24.7	34.5	46.5	137.2
Δ Formaldehyde	30.7	44.8	59.2	82.7	111.5	328.9
Δ Acetaldehyde	29.2	42.6	56.3	78.7	106.2	313.1
Δ Acrolein	1.4	2.1	2.7	3.8	5.2	15.3
Upstream						
Δ VOC	-41,066.1	-59,394.3	-78,404.6	-110,253.7	-149,633.5	-438,752.1
Δ NO_X	-12,281.2	-17,762.4	-23,447.5	-32,972.3	-44,749.1	-131,212.5
Δ $PM_{2.5}$	-1,673.7	-2,420.7	-3,195.5	-4,493.6	-6,098.6	-17,882.2
Δ CO	-3,924.6	-5,676.1	-7,492.9	-10,536.6	-14,300.0	-41,930.1
Δ SO_2	-7,514.8	-10,868.7	-14,347.4	-20,175.5	-27,381.7	-80,288.1
Δ Benzene	-88.9	-128.5	-169.7	-238.6	-323.8	-949.4
Δ 1,3 Butdiene	-1.0	-1.4	-1.8	-2.6	-3.5	-10.3
Δ Formaldehyde	-32.7	-47.3	-62.5	-87.9	-119.3	-349.8
Δ Acetaldehyde	-4.4	-6.3	-8.3	-11.7	-15.9	-46.5
Δ Acrolein	-0.6	-0.9	-1.1	-1.6	-2.2	-6.4
Total						
Δ VOC	-38,819.2	-56,112.8	-74,068.1	-104,197.9	-141,452.0	-414,650.1
Δ NO_X	-7,946.8	-11,348.0	-14,981.6	-21,226.9	-28,876.7	-84,379.9
Δ $PM_{2.5}$	-1,470.9	-2,124.1	-2,803.5	-3,946.6	-5,359.6	-15,704.6
Δ CO	83,038.4	121,403.1	160,429.2	223,898.3	302,025.0	890,794.0
Δ SO_2	-8,877.1	-12,839.0	-16,948.4	-23,833.1	-32,345.7	-94,843.3
Δ Benzene	-12.7	-17.4	-22.8	-33.4	-47.1	-133.4
Δ 1,3 Butdiene	11.8	17.3	22.9	31.9	43.0	126.9
Δ Formaldehyde	-2.1	-2.6	-3.3	-5.2	-7.8	-20.9
Δ Acetaldehyde	24.9	36.3	48.0	67.0	90.3	266.6
Δ Acrolein	0.8	1.2	1.6	2.2	3.0	8.9

5.7 Alternative 4% and 6% Scenarios

For this final rule, two alternative control scenarios were evaluated characterized by 4% and 6% annual growth in the GHG standards from the MY 2011 standard. Like the previous analyses, this analysis has been updated from the proposal using the new economic inputs. Other than the standards, these scenarios share all inputs with the 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 5-35 and the achieved levels are shown in Table 5-36.

Table 5-35 4% Scenario Standards

MODEL YEAR	PA EMISSION LEVEL	NPA EMISSION LEVEL	ANTICIPATED MY EMISSION LEVEL
2012	277	365	311
2013	267	352	299
2014	257	329	287
2015	248	327	276
2016	239	315	265

Table 5-36 4% Scenario Achieved Levels

MODEL YEAR	ANTICIPATED PA EMISSION LEVEL	ANTICIPATED NPA EMISSION LEVEL	ANTICIPATED MY EMISSION LEVEL
2012	277	380	317
2013	269	367	306
2014	261	349	293
2015	251	335	281
2016	239	315	265

5.7.1.2 Results

Results are shown relative to the same reference scenario as the EPA program. Both calendar year and model year lifetime results are shown.

Table 5-37 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)	-89.8	-183.4	-243.0	-309.5
ΔIndirect A/C CO_2(MMT CO_2 EQ)	-10.6	-20.1	-26.5	-33.7
Δ Direct A/C HFC (MMT CO_2 EQ)	-13.3	-26.0	-30.9	-34.2
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)	-113.9	-229.5	-300.3	-377.2
Upstream				
Δ CO_2 (MMT CO_2 EQ)	-24.5	-49.5	-65.5	-83.5
Δ CH_4 (MMT CO_2 EQ)	-3.5	-7.0	-9.3	-11.8
Δ N_2O (MMT CO_2 EQ)	-0.1	-0.2	-0.3	-0.3
Δ Total GHG	-28.0	-56.7	-75.1	-95.7
Total				
Δ Total GHG	-141.9	-286.2	-375.4	-472.9
Δ Fuel Consumption (Annual, Billion gallons)	-11.3	-22.9	-30.3	-38.6

Table 5-38 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)	-20.7	-53.3	-94.2	-140.0	-198.0	-506.2
ΔIndirect A/C CO_2(MMT CO_2 EQ)	-5.5	-9.4	-14.4	-19.6	-20.9	-69.8
Δ Direct A/C HFC (MMT CO_2 EQ)	-6.6	-11.2	-17.2	-23.4	-25.0	-83.3
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)	-32.8	-73.9	-125.7	-182.9	-243.8	-659.0
Upstream						
Δ CO_2 (MMT CO_2 EQ)	-6.4	-15.2	-26.4	-38.8	-53.2	-140.1
Δ CH_4 (MMT CO_2 EQ)	-0.8	-1.8	-3.1	-4.6	-6.3	-16.7
Δ N_2O (MMT CO_2 EQ)	0.0	-0.1	-0.1	-0.2	-0.3	-0.7
Δ Total GHG	-7.2	-17.1	-29.7	-43.6	-59.8	-157.4
Total						
Δ Total GHG	-39.9	-100.0	-155.4	-226.5	-303.6	-816.4
Δ Fuel Consumption (Billion gallons)	-2.9	-7.1	-12.2	-18.0	-24.6	-64.8

5.7.2 6% Scenario

5.7.2.1 Standards and Achieved Levels

The program standards are shown in Table 5-35 and the achieved levels are shown in Table 5-36.

Table 5-39 6% Scenario Standards

MODEL YEAR	ANTICIPATED PA EMISSION LEVEL	ANTICIPATED NPA EMISSION LEVEL	ANTICIPATED MY EMISSION LEVEL
2012	272	358	305
2013	257	339	288
2014	243	320	272
2015	230	303	256
2016	217	286	241

Table 5-40 6% Scenario Achieved Levels

MODEL YEAR	ANTICIPATED PA EMISSION LEVEL	ANTICIPATED NPA EMISSION LEVEL	ANTICIPATED MY EMISSION LEVEL
2012	274	374	313
2013	261	350	295
2014	247	329	277
2015	232	310	260
2016	217	286	241

5.7.2.2 Results

Results are shown relative to the same reference scenario as the EPA program. Both calendar year and model year lifetime results are shown.

Table 5-41 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)	-137.4	-274.9	-363.2	-462.4
ΔIndirect A/C CO_2(MMT CO_2 EQ)	-10.7	-20.3	-26.7	-34.0
Δ Direct A/C HFC (MMT CO_2 EQ)	-13.3	-26.0	-30.9	-34.2
Δ CH_4 (MMT CO_2 EQ)	0.0	0.0	0.0	0.0
Δ N_2O (MMT CO_2 EQ)	0.0	0.1	0.1	0.2
Δ Total GHG (MMT CO_2 EQ)	-161.4	-321.1	-420.7	-530.4
Upstream				
Δ CO_2 (MMT CO_2 EQ)	-36.0	-71.8	-94.8	-120.7
Δ CH_4 (MMT CO_2 EQ)	-5.1	-10.2	-13.4	-17.1
Δ N_2O (MMT CO_2 EQ)	-0.2	-0.3	-0.5	-0.6
Δ Total GHG	-41.3	-82.3	-108.7	-138.4
Total				
Δ Total GHG	-202.7	-403.4	-529.4	-668.8
Δ Fuel Consumption (Annual, Billion gallons)	-16.7	-33.2	-43.9	-55.9

Table 5-42 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)	-37.7	-96.9	-158.1	-222.8	-295.1	-810.6
ΔIndirect A/C CO_2(MMT CO_2 EQ)	-5.5	-9.4	-14.5	-19.7	-21.1	-70.2
Δ Direct A/C HFC (MMT CO_2 EQ)	-6.6	-11.2	-17.3	-23.5	-25.1	-83.8
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)	-49.8	-117.5	-189.8	-265.9	-341.2	-964.2
Upstream						
Δ CO_2 (MMT CO_2 EQ)	-10.5	-25.8	-42.0	-59.0	-76.9	-214.2
Δ CH_4 (MMT CO_2 EQ)	-1.3	-3.1	-5.0	-7.0	-9.2	-25.5
Δ N_2O (MMT CO_2 EQ)	-0.1	-0.1	-0.2	-0.3	-0.4	-1.1
Δ Total GHG	-11.8	-29.0	-47.2	-66.3	-86.4	-240.7
Total						
Δ Total GHG	-61.7	-146.5	-237.0	-332.2	-427.6	-1,204.9
Δ Fuel Consumption (Billion gallons)	-4.9	-12.0	-19.4	-27.3	-35.6	-99.1

5.8 Inventories Used for Air Quality Analyses

This section describes the processes used in calculating the inventories for the air quality (AQ) modeling analysis. Air quality modeling requires significant lead time, and consequently the air quality inventories were completed significantly before the inventories presented in this final rule.

5.8.1 Upstream Emissions

5.8.1.1 Petroleum Production and Refining Emissions

Petroleum production includes crude oil extraction and transport to refineries. As in the nationwide analysis presented in the proposed rule as well as this final rule, we assumed that (a) 50% of the change in gasoline supply was projected to come from domestic refineries, and (b) 10% of the change in crude being used by domestic refineries would be domestic crude. Thus, using our assumption that 1.0 gallon less of gasoline equates to approximately 1.0 gallon less crude throughput, the reduction in crude extraction and transport would equal about 5% of the change in gasoline volume. To generate the emission inventory adjustment factors for air quality modeling these reductions were applied to the projected crude supply to US refineries, per AEO 2009 (stimulus version).[49] The resulting estimates are shown in Table 5-43. Only the 2030 values were used in the air quality modeling. The percent reductions were applied to the NEI projected inventories for 2030. The 0.61% reduction was applied to all SCCs associated with petroleum extraction, and the 6.09% reduction was applied to all SCCs associated with gasoline refining.[50]

Table 5-43 Crude Oil and Gasoline Volume Reductions Associated with LD GHG Rule

PARAMETER	2020	2030
Crude Supply to US Refineries (bgal/yr)[2]	211.96	214.94
Reduction in Gasoline Consumption (bgal/yr)	13.35	26.18
Reduction in Domestic-Refined Gasoline (bgal/yr)	6.68	13.09
Reduction in Domestic Refining of Crude (US & Imported Crude) (bgal/yr)	6.68	13.09
Reduction in Domestic-Refined Gasoline from Domestic Crude (bgal/yr)	0.67	1.31
Reduction in Domestic Crude Production & Transport to refineries (bgal/yr)	0.67	1.31
Percent Reduction in Domestic Refining	3.17%	6.09%
Percent Reduction in Domestic Crude Production & Transport	0.32%	0.61%

Note that this method used for AQ county allocation is not directly comparable with the method used for nationwide impacts, for which we used the GREET-based upstream impacts spreadsheet model to calculate the absolute change in tons for each stage of the upstream inventory.

5.8.1.2 Gasoline Transport, Storage and Distribution emissions (vapor)

With the reduced gasoline consumption associated with this rule there would be changes in the quantity of vapor losses during the transport and distribution of gasoline. The analysis of these impacts was separated into two segments: refinery to bulk terminal (RBT) and bulk terminal to pump (BTP). The reference case analyzed would include some amount of E0 (zero percent ethanol) in the BTP segment, but the reduced gasoline production projected with this rule, combined with unchanged ethanol volumes, means that essentially all gasoline would be blended with at least 10 percent ethanol. Thus the transport of E0 gasoline would only occur between refineries and blending terminals in the control case, i.e., the RBT segment. The BTP segment would include both E10 and E85. No changes in volumes of E10 or E85 were assumed for this analysis.

E0 – Refinery to Bulk Terminal (RBT)

E0 – Bulk Terminal to Pump (BTP, used for reference cases only)

E10 – Bulk Terminal to Pump (BTP)

E85 – Bulk Terminal to Pump (BTP)

For each of the above fuel type and transport stage combinations, nationwide VOC impacts (ton deltas) (and benzene and ethanol vapor) were calculated using EPA's upstream impacts spreadsheet model for the control scenario versus the reference case. For air quality modeling the three BTP values were combined into a total BTP impact for each scenario. These impact values were renormalized to be ton deltas relative to the reference case. Then all the SCCs in the NEI related to gasoline transport, storage, and distribution (TS&D) were categorized as either RBT or BTP, and the NEI VOC emissions were summed for each category. The nationwide VOC percent change for the control case relative to the reference case for RBT was calculated as the control case RBT delta tons (versus AEO) divided by the NEI RBT tons. Similarly, the nationwide VOC percent change for the control case for BTP was calculated as the control case BTP delta tons (versus AEO) divided by the NEI BTP tons. The projected reference case VOC and calculated adjustments are shown in Table 5-44.

Table 5-44 Gasoline Distribution Emission Reductions Associated with LD GHG Rule

GASOLINE DISTRIBUTION SEGMENT	FUEL	NEI VOC (TON/YR)	VOC CHANGE (TON/YR)	PERCENT CHANGE VS NEI
Refinery to Bulk Terminal	E0	273,513	-50,042	-18.30%
Bulk Terminal to Pump	E0		-92,034	
	E10		0	
	E85		0	
	Total	490,236	-92,034	-18.77%

The county level AQ inventories for the control case were then calculated by applying these percent changes in VOC to the corresponding sets of SCCs (point and non-point sources) for every county. The same adjustment factors were applied to benzene evaporative emissions.[51]

5.8.1.3 Downstream Emissions from Onroad vehicles and Nonroad Equipment except Aircraft, Locomotives, and Commercial Marine Vessels

5.8.1.4 Introduction

Downstream emissions are those resulting from mobile-source operation, including onroad vehicles and nonroad vehicles and equipment. This section describes the development of emissions from all onroad vehicles and from nonroad equipment modeled by the NONROAD Model. Emissions from aircraft, locomotives, and commercial marine vessels are discussed in Section 0.

The emissions discussed in this section were developed using three EPA models: MOVES, MOBILE6, and NONROAD. MOBILE6 and NONROAD were run using the National Mobile Inventory Model (NMIM), which is software that runs MOBILE6 and NONROAD at the county-month level by accessing a county database, preparing input files, and aggregating the output.

Similar to the emission inventories for the final rule, both VMT rebound and the effects of increasing ethanol proportions in the fuel supply (which are not due to the GHG vehicle standards) were accounted for in the air quality modeling inventories. Additional details on the downstream inventories used for the air quality modeling are available in a docket memo.[52]

5.8.1.5 Onroad

For onroad mobile sources except motorcycles, EPA executed an internal draft version of MOVES dated 8/25/2009 (MOVES20090825), which is similar to Draft MOVES2009[53] with a number of improvements to the fuel effects data and code. This version of MOVES used default database MOVESDB20090902. A slightly later version, MOVES20091113, was run for evaporative runs to correct a bug in the code that processed evaporative emissions. This version of MOVES used default database MOVESDB20091109. User-supplied fuel and temperature tables were used for these runs. Historical temperature and humidity data for 2005 was used for all years. For motorcycles, we relied on the MOBILE6.2 model as run using the NMIM platform with county-specific fuel properties and temperatures. MOVES supplied all pollutants except SO2 and NH3, which came from NMIM runs. Onroad inventories were generated by multiplying MOVES emission factors by VMT developed for the Office of Air Quality Planning and Standards's 2002 Version 3 Modeling Platform (PF02v3)[54] and used in the recently published Locomotive-Marine Rule.[55] This VMT, which was based on AEO2006,[56] was adjusted to match the annual VMT from AEO2009,[57] but with county allocations preserved. AEO2009 growth factors from 2005 to 2030 were applied to 2005 NEI VMT using the three AEO categories: light duty, commercial light trucks and heavy duty. Assignments to MOBILE6 categories are straightforward except for Commercial Light Trucks, which are only gasoline in the AEO classification. The MOBILE6 Model was M6203ChcOxFixNMIM, a special version that includes cold-start VOC and the cold-start controls of the Mobile Source Air Toxics Rule that go into effect in 2011 and used in the recently published Locomotive-Marine rule. Onroad emissions generated at the state-month level from MOVES were distributed to the county-month level using the results from MOBILE6 as run by NMIM.

5.8.1.6 Nonroad

Nonroad equipment except for aircraft, locomotives, and commercial marine vessels was modeled with the latest publically released NONROAD version NONROAD2008a.[58] This version of the NONROAD includes the benefits of the two nonroad regulations published in 2008 (the Locomotive and Marine Rule and the Small Spark-Ignition And Recreational Marine Engine Rule[59]) plus all previous nonroad regulations.

5.8.1.7 Summaries

The two tables below are national-annual emissions in U.S. tons by mobile-source sector for the reference and control cases in 2030. There are differences between these inventories and those produced for the Final Rule because the latter used the final version of MOVES2010 and an earlier version was used for the air quality modeling inventories. This difference was unavoidable due to the long lead time required for air quality modeling. However, the proportional difference in downstream inventories between the Control and Reference cases is nearly the same in the two sets of inventories, so the air quality modeling adequately reflects the effects of the rule.

Table 5-45 2030 Reference Case. National annual emissions in U.S. tons

pollutant	Sector					
	Light duty Gasoline	Light duty Diesel	Heavy Duty Gasoline	Heavy Duty Diesel	Non-road Diesel	Non-Road Gasoline
VOC	635,169	1,122	22,921	167,574	67,377	1,170,391
NO_x	1,245,018	7,776	63,982	979,298	481,698	207,374
CO	17,901,362	8,441	783,117	477,617	165,956	15,148,540
SO_2	33,384	884	2,185	3,633	1,314	1,104
PM2.5	24,224	112	829	16,258	18,817	48,012
Benz	15,723	23	606	1,843	1,371	23,952
Acet	5,823	14	231	5,054	3,576	3,284
Buta	2,520	10	98	1,070	125	3,924
Formal	5,996	44	235	13,723	7,961	6,188
Acro	275	4	22	614	204	358

Table 5-46 2030 Control Case. National annual emissions in U.S. tons.

pollutant	Sector					
	Light duty Gasoline	Light duty Diesel	Heavy Duty Gasoline	Heavy Duty Diesel	Non-road Diesel	Non-Road Gasoline
VOC	651,538	1,139	23,160	167,574	67,377	1,170,521
NO_x	1,268,205	7,893	64,179	979,298	481,698	216,640
CO	18,126,698	8,578	780,432	477,617	165,956	14,706,415
SO_2	27,975	740	2,185	3,633	1,314	1,106
PM2.5	24,575	113	829	16,258	18,817	48,012
Benz	15,652	23	593	1,843	1,371	23,009
Acet	6,341	14	248	5,054	3,576	3,470
Buta	2,519	10	97	1,070	125	3,974
Formal	6,108	44	235	13,723	7,961	6,258
Acro	280	4	22	614	204	352

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. As a change from the proposed rule, the final rule allows that manufacturers with total domestic sales of less than 50,000 in MY 2009 to place up to 250,000 vehicles from model years 2012-2016 into a separate fleet[J,K]. 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.B.5 of the preamble). One commenter, the American Council for an Energy Efficient Economy, voiced concerns that EPA (A) underestimated the impact of the TLAAS program, and (B) did not provide documentation of the relevant calculations. As in the proposal, EPA has provided documentation of the calculation in this appendix, with the relevant spreadsheets available in the docket.[60] EPA has also revised its estimates of the TLAAS provision for this final rule. Please see the Response to Comments document for additional details. Several manufacturer decisions and marketplace events will ultimately 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 37 MMT of CO_2 emissions, in all cases the TLAAS program has a proportionally small impact (< 4%) on the total program benefits over the model years 2012-2016. The maximum impact presented here has increased approximately proportional to the increase in program size from the proposal; i.e., the maximum potential impact described in the NPRM was 25 MMT for 1.1 million vehicles, while the maximum impact described here is 37 MMT for 1.55 million vehicles.

Under the estimation procedure used in the emission inventory analysis (as opposed to the bracketing analysis mentioned immediately above), the TLAAS program is projected to result in an approximately 14 MMT decrease in greenhouse gas benefits from this rule over the lifetime of vehicles manufactured in model years 2012-2016 (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).

While 14 MMT is a small fraction of the overall program benefits (approximately one percent of the estimated GHG reductions), 14 MMT is an increase over the 3.4 MMT impact

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[J] These manufacturers could place up to 200,000 vehicles into the TLAAS fleet between MYs 2012-2015, and up to an additional 50,000 vehicles into that fleet in MY 2016.

[K] The final rule also deters regulation of manufacturers of vehicles with 2008 or 2009 domestic sales of less than 5,000 vehicles whose three-year rolling average of domestic sales remain less than 5,000 vehicles, and which demonstrate inability to purchase credits. The deferral is respect to the CO_2 standards only. These vehicles are not considered in the analysis above.

estimated in the proposal. This is largely due to several changes in the TLAAS program made in response to public comment, as discussed below. There was also a calculation error in the analysis for the proposal, which would have increased the estimate of the TLAAS, as proposed to 4.9 MMT.

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, Jaguar, Mazda, Mitsubishi, Suzuki, Daimler, Subaru, BMW, Volkswagen, Hyundai, and Kia. Three of the above manufacturers are expected to be eligible for the expanded TLAAS program. These manufacturers are Suzuki, Porsche and Jaguar.

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

As explained in section III.B of the preamble to the final rule, the TLAAS program is predicated on the need for additional lead time for certain manufacturers, and is a reasonable exercise of EPA's section 202 (a) to consider lead time in crafting standards. The TLAAS provides needed flexibility to manufacturers in order to comply with the CO_2 standards for the earlier model years, , thereby providing needed lead time for these manufacturers to bring their entire fleet into compliance with the stringent 2016 MY standards or, for manufacturers eligible for TLAAS in MY 2016, to be fully compliant with the standards by the 2017 model year. 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.

Further, when the TLAAS program ends, manufacturers' entire fleets must 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.

<u>Size and Classification of the Vehicles Placed in the TLAAS Fleet</u>

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 in estimating its impacts. 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 which 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 CO_2 emission standard. 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, plus 250,000 vehicles over a five-year period for eligible smaller manufacturers 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 976 MMT GHG reduced over lifetime of model years 2012-2016 (i.e. impact of the TLAAS is zero), while the upper bound impact was 938 MMT GHG reduced over the same period. Thus, the maximum potential impact of the program, even under this most extreme scenario is approximately 37 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 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 RIA chapter 5. In this analysis, all eight TLAAS manufacturers were assumed to use the example vehicle allocation schedule from Section III of the proposal Preamble, replicated in Table 5-47. 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 5-47 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. For these eight manufacturers, the TLAAS fleet allotment was assumed to emit as much CO_2 per mile as expected from the largest complying footprint car or truck in each manufacturer's fleet. For emission estimation purposes, upsizing the fleet effectively lowers the stringency of the target. 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 emission level.

For the three manufacturers eligible for the expanded TLAAS, the phase-in schedule shown in the table below was used. As this allocation encompasses almost all of the manufacturers' sales in the early years, a different allocation was used for each manufacturer. Almost all of Porsche's fleet, both cars and trucks, is covered. Tata is assumed to split the allocation between car and trucks. Suzuki is assumed to use the entire allocation for its cars.

As the compliance gap for the smaller manufacturers is on average significantly larger than the average compliance gap for the other 8 manufacturers, these manufacturers were assumed to make a more intense use of the TLAAS program. For these manufacturers, their TLAAS fleets are assumed to emit 1.25x more emissions than the manufacturer's sales weighted target in 2012, and by 2016, they were assumed to emit 1.05x more emissions. This schedule assumes a gradual decrease in CO2 emissions, which would project that the manufacturers to reach complicance with the main program CO2 standards by 2017. The volumes assumes slight growth from the 2009 base year and are based on the EPA fleet data file. There is uncertainty in these estimates, as discussed above.

Table 5-48 Volumes and Usage Ratios in Expanded TLAAS Analysis

MODEL YEAR	2012	2013	2014	2015	2016
Sales Volume	60,000	60,000	50,000	40,000	40,000
Usage Ratio	1.25	1.20	1.15	1.10	1.05

The expanded TLAAS program grows the program by approximately 40% (1.55 million vehicles now / 1.1 million vehicles in the proposal). The increased program size, combined with the assumption that the users of the expanded TLAAS program will use it more heavily accounts for the increased estimate of impacts. As in the proposal, small volume manufacturers are not included in this final rule analysis.

In this analysis, the total TLAAS program results in an emission impact of approximately 14 MMT CO_2 over the lifetime of the 2012-2016 MY vehicles.

The gram per mile impacts are listed here for each of these scenarios.

Table 5-49 Gram per Mile per Year

	TLAAS impact (Grams CO_2 Emissions Per Mile)		
Model Year	**Lower Bound Scenario**	**Upper Bound Scenario**	**Estimate Used In Emission Analysis**
2012	0.0	2.6	1.2
2013	0.0	2.1	0.9
2014	0.0	1.6	0.6
2015	0.0	1.0	0.3
2016	0.0	0.5	0.1

5.B Appendix to Chapter 5: Impacts of Advanced Technology Vehicle Incentives for Electric Vehicles

5.B.1 Introduction and Summary

As described in Preamble Section III, EPA is finalizing provisions that provide a temporary regulatory incentive for the commercialization of certain advanced vehicle power trains—electric vehicles (EVs), plug-in hybrid electric vehicles (PHEVs), and fuel cell vehicles (FCVs)—for model year 2012-2016 light-duty and medium-duty passenger vehicles. EPA is finalizing two changes to the proposed incentive program—deleting the vehicle multiplier and adding an individual automaker cap on the cumulative vehicle production eligible for the zero gm/mi compliance value —that will limit the loss in GHG savings due to these incentives. These incentives apply for the model years 2012-2016 covered by this final rule, and EPA will revisit this issue in rulemakings for future model years.

This section provides an analysis of the emission impacts of 500,000 electric vehicles produced under the zero gram per mile incentive during the 2012-2016 timeframe. As stated in Preamble Section III, it is impossible to predict the number of EVs that will be produced between 2012 and 2016. EPA believes that sales of 500,000 "un-capped" EVs is a reasonable scenario. Fewer EVs, or a combination of 500,000 EVs and PHEVs, would lessen the loss in GHG benefits. Conversely, additional sales of "un-capped" EVs would increase the loss in GHG benefits.

Based on the analysis presented here, sales of 500,000 uncapped electric vehicles would produce a net reduction in GHG benefits of 25 MMT over the program without this provision.

5.B.2 Assumptions behind the Analysis

This analysis is intended as a preliminary exercise in an emerging field. The net impacts of the EV provision are dependent on several assumptions, and the assessment published here is intended to be demonstrative. Several assumptions are conservative; most significantly, the assumptions regarding manufacturer usage of the EV provision are meant to be a boundary analysis.

We assume that manufacturers utilize the full benefit of the EV provision to manufacture internal combustion engine vehicles that emit more than they would otherwise. As an example, the fleet target of a typical manufacturer would be 250 grams CO_2 per mile in 2016. If the manufacturer sold EVs under this program, the manufacturer could place less technology on their conventional vehicles, so long as their net achieved level met their target. In essence, the downstream (tailpipe) benefit of the EV would be canceled out. Because the same amount of gasoline would be consumed regardless of the EV provision, sales of EVs would therefore not impact total fuel savings or total emissions from gasoline vehicles. Upstream emissions for electric vehicles sold beyond the individual automaker cap would be accounted for by this rule, and would therefore have no negative environmental impact.

We assume 500,000 electric vehicles are sold in the 2012-2016 timeframe, which is a significant increase over current electric vehicle sales, which are near zero in EPA's 2008 baseline market data file. Similarly, EPA's OMEGA modeling does not predict the need for significant electrification of the fleet over the time frame presented in this rulemaking.

We assume that EVs are only sold as cars, and that they are driven for the same lifetime VMT as a conventional vehicle.

5.B.3 Inputs

As stated previously, we assume that there is no downstream benefit of electric vehicles, and therefore the net impact of electric vehicles is equivalent to the net impact of the electricity generated to fuel these vehicles. To calculate the net impact over the vehicle lifetime of all the EVs sold, the formula is as follows:

EV emission impact = (Lifetime VMT) x (kWh/mile) x (Emissions/kWh) x (sales)

Equation 6- EV Impacts

The inputs used for this calculation are shown below (Table 5-51). Given that Equation 6 is linear, a change to any of these variables would produce a proportional and linear change in the results of the analysis.

Table 5-50 Inputs for EV Analysis

LIFETIME VMT	195,264
kWh/mile	0.329
GHG Emissions g CO2e/kWh	768

The lifetime VMT is described in TSD Chapter 4 and in **Table 5-32,** and is assumed to be the same between conventional vehicles and electric vehicles.

The kWh per mile value is intended as a rough estimate of the potential electricity usage of typical mid-size EV in the 2012-2016 timeframe. Based on preliminary EPA analysis, an EV of approximately 3200 pounds is projected to consume 230 Wh/mile over the combined FTP and HWFE tests. It is assumed that on-road energy consumption will be about

43% higher than the tested energy consumption[L]. Based on these assumptions, we project a mid-size EV would have a real world electrical energy consumption rate of 329 Wh/mile.

Table 5-51 EV energy required

FTP/HWFE Fuel Energy required	230
FTP/HWFE Real World Energy Required	329

Accounting for the CO_2e emissions from EVs requires accounting for emissions during the feedstock gathering, power generation, power distribution, and vehicle charging stages. In other words, accounting for electricity for EVs requires accounting for the efficiencies of the various stages of the combustion of fossil fuels at the power plant, as well as the inefficiencies in transmitting the electricity from plant to the vehicle. For this analysis, the electricity is generated at the 2005 national average emission level (633 g CO_2/ kWh).[61M]

This value must be adjusted for emissions due to charging inefficiencies ("wall to vehicle" losses) of 10%, and transmission and distribution losses ("plant to wall") of 7%, resulting in an actual upstream emission impact of 768 g CO_2e for each kWh used at the vehicle.

The emission factors used in this analysis could be higher or lower depending on when users charge their vehicles, and whether this causes additional natural gas or coal power plants to be shunted on-line. If the CO_2e emissions from powerplants were 10% higher or lower, the resulting impacts from the EV provision would be proportionally higher or lower.

5.B.4 Computation

The inputs from Table 5-51 were inserted in Equation 6, with the resulting impact shown below.

[L] Based on preliminary data, we assume that on-road EV shortfall is greater for electric vehicles than typical ICE vehicles. This accounts for performance in different climates, as well as other issues. We assume this shortfall to be about 30%, if measured in terms of fuel economy. If converted to an increase in energy consumption, that factor becomes 1/0.7 or a 43% increase.

[M] The value 633 g CO_2/kWh was derived by beginning with the EPA eGrid 2007 v 1.1 emissions, combining N2O, CH4 and CO2 using GWP values stated in Table 5-5, and adding 6% for feedstock gathering based on Greet 1.8.

195,265 miles x 329 kWh/mile x 0.768 g CO2/kWh x 500,000 sales / (10^{12} conversion of grams to MMT)

= 24.8MMT

References

[1] Intergovernmental Panel on Climate Change Working Group I. 2007. Climate Change 2007 - The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.

[2] U.S. Environmental Protection Agency. 2009. Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2007. EPA 430-R-09-004. Available at http://epa.gov/climatechange/emissions/downloads09/GHG2007entire_report-508.pdf

[3] U.S. EPA. 2009 Technical Support Document for Endangerment and Cause or Contribute Findings for Greenhouse Gases under Section 202(a) of the Clean Air Act. Washington, DC. pp. 180-194. Available at http://epa.gov/climatechange/endangerment/downloads/Endangerment%20TSD.pdf

[4] U.S. Environmental Protection Agency. 2009. Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2007. EPA 430-R-09-004. Available at http://epa.gov/climatechange/emissions/downloads09/GHG2007entire_report-508.pdf

[5] RIA Chapter 2

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

[7] 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

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

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

[10] U.S. EPA 2009. Updated OMEGA Post-Processor Spreadsheet. February 2010.

[11] 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 Docket ID: EPA-HQ-OAR-2009-0472-0116

[12] MOVES documentation and technical documents can be seen at http://www.epa.gov/otaq/models/moves/index.htm.

[13] EPA's OMEGA model, documentation, and technical documents can be found http://www.epa.gov/oms/climate/models.htm. The model is also docketed EPA-HQ-OAR-2009-0472-0192.

[14] U.S. EPA 2010, Renewable Fuel Standard Program (RFS2) Regulatory Impact Analysis. EPA-420-R-10-006. February 2010. Docket EPA-HQ-OAR-2009-0472-11332. Chapters 2 and 3.

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

[16] U.S. EPA. 2008. RFS2 Modified version of GREET1.7 Upstream Emissions Spreadsheet, October 31, 2008. Docket ID: EPA-HQ-OAR-2009-0472-0191

[17] U.S. EPA, FRM Achieved CO_2 standards worksheet. 2010.

[18] NHTSA. 2009. Average Fuel Economy Standards, Passenger Cars and Light Trucks, Model Year 2011. Docket ID: NHTSA-2009-0062-0001. Docket ID : EPA-HQ-OAR-2009-0472-0060 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

[19] When this rule's analysis was initiated, the RFS2 rule was not yet final. Therefore, it assumes the ethanol volumes in Annual Energy Outlook 2007 (U.S. Energy Information Administration, Annual Energy Outlook 2007, Transportation Demand Sector Supplemental Table. http://www.eia.doe.gov/oiaf/archive/aeo07/supplement/index.html)

[20] EPA 2010, Renewable Fuel Standard Program (RFS2) Regulatory Impact Analysis. EPA-420-R-10-006. February 2010. Docket EPA-HQ-OAR-2009-0472-11332. see also 75 FR 14670, March 26, 2010

[21] EPA. 2009. Regulation of Fuels and Fuel Additives: Changes to Renewable Fuel Standard Program. EPA–HQ–OAR–2005–0161. http://www.epa.gov/otaq/renewablefuels/rfs2_1-5.pdf. Docket ID: EPA-HQ-OAR-2009-0472-0119

[22] 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. Docket ID : EPA-HQ-OAR-2009-0472-0060

[23] U.S. EPA. Baseline and Reference Fleet File, as documented in TSD chapter 1. August 2009. EPA-HQ-OAR-2009-0472-0085.

[24] Energy Information Administration. Annual Energy Outlook 2010 Early Release. Supplemental Transportation Tables. December 2009. http://www.eia.doe.gov/oiaf/aeo/supplement/sup_tran.xls.

[25] Energy Information Administration. Annual Energy Outlook 2009. Supplemental Transportation Tables. April 2009. http://www.eia.doe.gov/oiaf/aeo/supplement/sup_tran.xls. EPA-HQ-OAR-2009-0472-0121

[26]U.S. EPA. Baseline and Reference Fleet File, as documented in TSD chapter 1. February 2009..

[27] 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. Docket ID : EPA-HQ-OAR-2009-0472-0060

[28] 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. Docket ID : EPA-HQ-OAR-2009-0472-0060

[29] U.S. EPA. Baseline and Reference Fleet File, as documented in TSD chapter 1. February 2009..

[30] EPA. Emission Facts: Average Carbon Dioxide Emissions Resulting from Gasoline and Diesel Fuel. EPA420-F-05-001 February 2005. Docket ID: EPA-HQ-OAR-2009-0472-0122

[31] U.S. EPA. Baseline and Reference Fleet File, as documented in TSD chapter 1. February 2009.

[32] Office of Energy Efficiency and Renewable Energy, U.S. Department of Energy. Transportation Energy Data Book: Edition 27. Chapter 4. 2008. Docket ID: EPA-HQ-OAR-2009-0472-0280.

[33] NHTSA. Vehicle Survivability and Travel Mileage Schedules. 2006. Docket ID: EPA-HQ-OAR-2009-0472-0126

[34] Joint TSD Chapter 4

[35] NHTSA. Vehicle Survivability and Travel Mileage Schedules. 2006. Docket ID: EPA-HQ-OAR-2009-0472-0126

[36] Joint TSD Chapter 4

[37] EPA. Final Technical Support Document.Fuel Economy Labeling of Motor Vehicle Revisions to Improve Calculation of Fuel Economy Estimates. EPA-HQ-OAR-2009-0472-0281

[38] 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. Docket ID: EPA-HQ-OAR-2009-0472-0116

[39] RIA chapter 2.

[40] Office of Energy Efficiency and Renewable Energy, U.S. Department of Energy. Transportation Energy Data Book: Edition 27. 2008. Docket ID: EPA-HQ-OAR-2009-0472-0280.

[41] EPA. Final Technical Support Document. Fuel Economy Labeling of Motor Vehicle Revisions to Improve Calculation of Fuel Economy Estimates. EPA-HQ-OAR-2009-0472-0281

[42] EPA. Emission Facts: Average Carbon Dioxide Emissions Resulting from Gasoline and Diesel Fuel. EPA420-F-05-001 February 2005. Docket ID: EPA-HQ-OAR-2009-0472-0122

[43] EPA. Technical Description of the Toxics Module for MOBILE6.2 and Guidance on Its use for Emission Inventory Preparation. November 2002.

[44] U.S. EPA 2010, Renewable Fuel Standard Program (RFS2) Regulatory Impact Analysis. EPA-420-R-10-006. February 2010. Docket EPA-HQ-OAR-2009-0472-11332. Chapters 2 and 3.

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

[46] 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). Docket ID: EPA-HQ-OAR-2009-0472-0139

[47] Control of Emissions From Nonroad Spark-Ignition Engines and Equipment, Final Rule (Federal Register Vol 73, No. 196, page 59034, October 8, 2008). Docket ID: EPA-HQ-OAR-2009-0472-0282

[48] 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/ . Docket ID: EPA-HQ-OAR-2009-0472-0283

[49] Energy Information Administration. Annual Energy Outlook 2009. Supplemental Transportation Tables. April 2009. http://www.eia.doe.gov/oiaf/aeo/supplement/sup_tran.xls. EPA-HQ-OAR-2009-0472-0121

[50] U.S. EPA. 2009. "For LD GHG AQ Modeling, 2030 Control Case: Adjustments to Oil Refining, and Crude Production/Transport SCCs," spreadsheet file: "Oil_Prod_Transp_Refine_2030_adjust.xls," 11/6/2009.

[51] U.S. EPA. 2009. "Gasoline Distribution SCCs and Adjustments to apply for the LD GHG AQ Modeling 2030 Control Case," spreadsheet file: "LDGHG_SCC_GasDistrib_Adjust2.xls" 11/9/2009.

[52] Harvey Michaels, US EPA. "NMIM and MOVES Runs for LD GHG Air Quality Modeling: Memorandum" 3/18/2010. Accompanying physical DVD which contains relevant software and processing scripts. Title: "NMIM and MOVES Runs for LGR Air Quality Modeling: DVD".

[53] For information on Draft MOVES2009, see http://www.epa.gov/otaq/models/moves/movesback.htm.

[54] See http://www.epa.gov/ttn/chief/emch/index.html#2002.

[55] Final Rule: Control of Emissions of Air Pollution from Locomotives and Marine Compression-Ignition Engines Less Than 30 Liters per Cylinder (published May 6, 2008 and republished June 30, 2008). For details, see http://www.epa.gov/otaq/locomotives.htm#2008final.

[56] Energy Information Administration. Annual Energy Outlook 2009. See http://www.eia.doe.gov/oiaf/archive/aeo06/index.htmle

[57] Energy Information Administration. Annual Energy Outlook 2009. See http://www.eia.doe.gov/oiaf/archive/aeo09/index.html

[58] NONROAD Model 2008a. http://www.epa.gov/otaq/nonrdmdl.htm

[59] Final Rule: Control of Emissions from Nonroad Spark-Ignition Engines and Equipment (published October 8, 2008). For details, see http://www.epa.gov/otaq/equip-ld.htm. Docket ID: EPA-HQ-OAR-2009-0472-0282

[60] U.S. EPA, FRM Achieved CO_2 standards worksheet. 2010.

[61] U.S. EPA. 2009. eGrid2007 dataset. http://www.epa.gov/cleanenergy/energy-resources/egrid/index.html. Accessed February 3, 2010.

CHAPTER 6: Vehicle Program Costs Including Fuel Consumption Impacts

This chapter presents the costs of the 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 rule. 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 rule. Such impacts are presented in Chapter 8 of this RIA.

The costs presented here differ slightly from those presented in the proposal. The different costs for the vehicle program are the result of revised costs for a limited set of technologies expected to be used for compliance. Those revised costs stem from the continuing teardown cost estimation work being done by FEV for EPA. See 74 FR at 48502. At proposal, we used the tear down data to estimate the cost of stoichiometric gasoline direct injection and turbocharging with engine downsizing. We have expanded our use of FEV tear down costs for the final rule to estimate costs for the following technologies using new information available to us shortly after the proposal: stoichiometric gasoline direct injection and turbo charging with engine downsizing for a single overhead cam (SOHC) 3 valve/cylinder V8 engine downsized to a SOHC V6 engine; stoichiometric gasoline direct injection and turbo chargin with engine downsizing for a dual overhead cam (DOHC) V6 engine to a DOHC 4 cylinder engine; a 6 speed automatic transmission replacing a 5 speed automatic transmission; and a 6 speed wet dual clutch transmission replacing a 6 speed automatic transmission .

This costing methodology has been published and gone through a peer review.[1] In addition, FEV and EPA extrapolated the engine downsizing costs for the following scenarios that were outside of the noted study cases:[2]

1. Downsizing a SOHC 2 valve/cylinder V8 engine to a DOHC V6 engine.

2. Downsizing a DOHC V8 engine to a DOHC V6 engine.

3. Downsizing a SOHC V6 engine to a DOHC 4 cylinder engine.

4. Downsizing a DOHC 4 cylinder engine to a DOHC 3 cylinder engine.

For more detail on those revised technology costs refer to Chapter 3 (section 3.3.2.2) of the joint TSD. EPA fuel cost estimates have also been updated using the recent AEO 2010

Early Release. For more information about the updated fuel prices refer to Chapter 4 of the joint TSD. EPA has not changed technology cost or fuel cost estimates in response to comment and, in general, commenters agreed with or otherwise did not question EPA's cost estimates and methodology. This is true not only for our estimates of 2016 MY costs but also our estimate of costs for the intermediate years 2012-2015.

6.1 Vehicle Program Costs

Chapter 4 of this RIA presents the outputs of the OMEGA model for the model year 2016. Here, EPA builds on those results and calculates estimated costs for each model year beginning with 2012 and going through 2050. This is done on a per-vehicle basis and an annual basis. Costs here include costs associated with the A/C credit program. For details on the individual technology costs refer to Chapter 3 of the joint TSD. For details on the OMEGA model inputs (i.e., how the individual technology costs are combined into package costs) refer to Chapter 1 of this RIA. For details on the A/C costs, refer to Chapter 2 of this RIA.

6.1.1 Vehicle Compliance Costs on a Per-Vehicle Basis

As stated above, Chapter 4 of this RIA presents the estimated cost per 2016 MY vehicle for each manufacturer. Those 2016 MY costs are reproduced in Table 6-1. To estimate the cost per vehicle for model years 2012 through 2015, EPA projected CO_2 levels for each manufacturer's fleet for each model year 2011 though 2016. Those CO_2 levels are presented in

Table 6-2 for cars and Table 6-3 for trucks.[A]

[A] Note that the 2012-2015 CO_2 levels are estimates based upon assumptions of manufacturer fleetwide CO_2 averages in 2011, which are extrapolated from the 2008 baseline fleet. Consequently, the average CO_2 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 Subaru as shown in Table 6-5 is approximately 45% 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.

Table 6-1 Cost per Car and Truck, including A/C, for the 2016 MY Relative to the Cost of Complying with the 2011 CAFE Standards (2007 dollars)

MANUFACTURER	$/CAR	$/TRUCK
BMW	$1,557	$1,195
Chrysler	$1,128	$1,501
Daimler	$1,535	$930
Ford	$1,108	$1,441
General Motors	$898	$1,581
Honda	$634	$473
Hyundai	$802	$425
Kia	$667	$247
Mazda	$854	$537
Mitsubishi	$817	$1,217
Nissan	$686	$1,118
Porsche	$1,506	$758
Subaru	$961	$789
Suzuki	$1,014	$536
Tata	$1,180	$679
Toyota	$380	$609
Volkswagen	$1,847	$971
Overall	$869	$1,098

Table 6-2 Projected CO_2 Levels for MYs 2011-2016, Cars Only (g/mi CO_2)

MANUFACTURER	2011MY	2012MY	2013MY	2014MY	2015MY	2016MY
BMW	313.8	297.0	282.1	266.3	250.4	236.3
Chrysler	314.7	288.4	271.6	253.9	240.0	227.9
Daimler	323.2	306.5	291.7	276.0	260.2	246.3
Ford	311.3	276.9	268.8	259.9	247.1	233.4
General Motors	305.4	278.2	270.4	261.5	248.3	241.3
Honda	265.0	247.4	236.6	224.7	215.2	207.6
Hyundai	273.8	255.7	244.5	232.3	222.5	214.5
Kia	280.6	257.2	244.3	230.4	219.4	213.1
Mazda	290.2	261.6	252.9	243.9	232.2	218.2
Mitsubishi	286.8	262.1	252.7	239.6	226.6	223.3
Nissan	280.0	263.1	255.8	247.5	236.3	223.2
Porsche	339.0	318.7	300.3	281.0	261.6	244.1
Subaru	286.4	259.8	246.8	238.6	230.4	218.2
Suzuki	285.2	266.3	249.3	231.4	213.4	197.3
Tata	348.2	328.9	311.6	293.4	275.1	258.6
Toyota	253.1	243.7	236.3	227.8	219.4	212.8
Volkswagen	291.5	276.6	263.6	249.6	235.6	223.5
Overall	288.0	266.8	256.0	245.2	233.7	223.8

Table 6-3 Projected CO_2 Levels for MYs 2011-2016, Trucks Only (g/mi CO_2)

MANUFACTURER	2011MY	2012MY	2013MY	2014MY	2015MY	2016MY
BMW	369.8	350.1	332.6	313.9	295.3	278.7
Chrysler	380.9	355.7	339.9	322.9	309.5	298.2
Daimler	423.5	396.9	372.4	346.9	321.3	297.8
Ford	394.5	373.3	362.5	350.8	332.1	298.3
General Motors	402.5	384.1	372.5	362.2	344.0	305.1
Honda	354.9	338.7	328.8	317.8	308.9	302.0
Hyundai	356.8	344.1	336.6	327.9	320.8	315.6
Kia	366.9	356.1	350.4	343.7	337.9	335.2
Mazda	341.2	324.7	312.5	302.3	286.5	285.6
Mitsubishi	336.9	311.6	300.8	292.0	277.0	264.0
Nissan	399.3	361.0	350.8	339.5	321.0	299.8
Porsche	364.2	356.3	350.5	343.7	336.8	332.0
Subaru	335.8	307.5	293.6	284.8	275.9	263.0
Suzuki	338.3	332.7	329.2	324.7	320.2	317.7
Tata	377.5	365.2	355.1	343.9	332.8	323.6
Toyota	375.4	360.6	347.9	334.1	320.3	308.6
Volkswagen	420.3	400.1	382.0	362.9	343.7	326.6
Overall	384.4	364.7	352.8	339.7	324.5	302.5

The achieved CO_2 levels for 2012-2015 were derived using a similar process to that described in Chapter 5 of this RIA. As in Chapter 5, EPA estimated model year specific emission targets based on the GHG standard curves and each manufacturer's projected fleet mix. From these targets, EPA adjusted CO_2 emissions by the impact of anticipated FFV credit, A/C credit, and TLAAS usage. For the emission analysis presented in RIA Chapter 5, EPA also estimated the impact of credit transfers which increased net emissions; *i.e.*, several manufacturers 2008 baseline vehicles overcomplied with the 2011 MY CAFE standard for cars in the early program years. The credits associated with this overcompliance with the car standards could be traded to these manufacturers' trucks fleets with the result of a net emission increase relative to a scenario that restricted transfers (*i.e.*, required each manufacturer's trucks to meet the 2011 CAFE standard while retaining over-compliance for cars). Credit transfers beyond baseline overcompliance is environmentally neutral and were not required in the emission analysis presented in Chapter 5.

For the cost analysis presented here, EPA additionally considered environmentally neutral credit transfers. In order to reduce overall compliance costs, manufacturers may choose to overcomply with the GHG standard in either car or truck categories and "trade" (on a VMT weighted basis), their overcompliance to the other category. As detailed in RIA Chapter 4, OMEGA incorporates this flexibility and projects technology application based on the most cost effective path to compliance. Thus, the fleetwide CO_2 achieved emission levels from RIA chapter 5 had to be adjusted to incorporate environmentally neutral credit transders. In these adjustments, the VMT adjusted fleet average CO_2 by manufacturer remained the same, but the average emission levels for cars and trucks may be above or below the applicable CO_2 standards and was based on the results of the OMEGA modeling.

The cost effective achieved levels for the intermediate years were derived in the following manner. Car and truck CO_2 emissions in MY 2011 were taken directly from the reference fleet file.[3] This fleet consists of 2008 MY vehicles, with sales projected to 2011 and with emissions reduced to the extent necessary for each manufacturer to comply with the 2011 MY CAFEE standards, with one exception. This exception was that those manufacturers which traditionally have paid CAFE fines in lieu of compliance were allowed to do so when NHTSA's VOLPE model estimated that it was less expensive for these manufacturers to pay fines instead of adding additional technology to meet the 2011 MY standards. MY 2016 achieved CO_2 was determined from the OMEGA output described in RIA Chapter 4. To determine the CO_2 emissions by manufacturer for the intermediate years, an interpolation was performed between these two points. Two different forms of interpolation were used, as appropriate. Generally, for manufacturers projected by the OMEGA modeling to achieve the 2016 MY standards, the change between each manufacturer's 2011 and 2016 emission levels was weighted by the percent change between their fleet average (*i.e.*, car plus truck) standard for each year (as determined in RIA Chapter 5) relative to their 2011 MY emission level. For manufacturers that are projected by the OMEGA modeling to not achieve their MY 2016 standard, we assumed a linear improvement between their 2011 MY and 2016 MY emission levels (*i.e.,* 20% of the total change between 2011-2016 emission levels was applied each year).

Several manufacturers, including Subaru, Kia, Mazda, 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.[B] The analysis behind the cost effective achieved levels is contained in the EPA docket.[4]

We then used these CO_2 values to generate ratios that could be applied to the 2016 MY costs to arrive at cost estimates for each of the intervening years. However, it is important to remember that the technology costs and, subsequently, the package costs in the 2016 MY have undergone some adjustments to account for learning effects as described in Chapter 3 of the joint TSD. EPA 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. This was also done for the years following 2016 to reflect the effects of the near term and long term indirect cost multipliers (ICMs) as described in Chapter 3 of the 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 $898 in the 2016 MY while achieving a CO_2 average of 241 g/mi; for the 2011 and 2012 MYs, GM cars are projected to achieve a CO_2 average of 305 and 278, respectively. The ratio (305-278)/(305-241) can be applied to GM's 2016 cost of $898, and then apply the 2012 relative to 2016 cost factor of 119%, to arrive at an estimated 2012 cost of $453.[C] This process is carried out 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

[B] *Ibid.*

[C] Numbers in the text are rounded for clarity so results using numbers shown in the text may not match those in tables.

for cars and trucks combined. Table 6-8 shows the estimated industry average cost per car, cost per truck, and cost per vehicle (car/truck combined) for the 2012 and later model years.[D]

Table 6-4 Package Costs Measured Relative to the Package Costs for the 2016MY

YEAR	PACKAGE COSTS RELATIVE TO 2016
2012	119%
2013	117%
2014	109%
2015	102%
2016	100%
2017	100%
2018	100%
2019	100%
2020	100%
2021	100%
2022+	94%

[D] 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. Higher new vehicle costs are included for these latter items but do not account for higher replacement costs during vehicle lifetimes even though oil is changed many times and tires are changed once or twice. Using the incremental increase in maintenance costs (and savings) and discounting them back to present value would have little impact on the present value of the costs presented here. Note also that the expected penetration of A/C control technology is 28% in 2012 but was 25% in our emission modeling work (similarly small discrepancies exist for 2013-2015). The slightly lower penetration number used in the emission modeling indicates a slight underestimation of the emission reductions from MY 2012, and consequently a slight underestimation of the costs in 2012-2015.

Table 6-5 Cost per Car, including A/C, by Manufacturer Relative to the Cost of Complying with the 2011 CAFE Standards (2007 dollars)

MANUFACTURER	2012MY	2013MY	2014MY	2015MY	2016MY
BMW	$402	$746	$1,042	$1,300	$1,557
Chrysler	$408	$656	$862	$991	$1,128
Daimler	$397	$735	$1,027	$1,282	$1,535
Ford	$583	$708	$797	$932	$1,108
General Motors	$453	$575	$670	$816	$898
Honda	$230	$367	$485	$560	$634
Hyundai	$291	$464	$612	$708	$802
Kia	$275	$420	$540	$616	$667
Mazda	$404	$518	$599	$702	$854
Mitsubishi	$378	$514	$662	$790	$817
Nissan	$243	$342	$428	$538	$686
Porsche	$383	$718	$1,004	$1,252	$1,506
Subaru	$445	$653	$734	$805	$961
Suzuki	$259	$484	$677	$844	$1,014
Tata	$302	$563	$787	$982	$1,180
Toyota	$105	$186	$260	$324	$380
Volkswagen	$482	$887	$1,240	$1,547	$1,847
Overall	$342	$507	$631	$749	$869

Table 6-6 Cost per Truck, including A/C, by Manufacturer Relative to the Cost of Complying with the 2011 CAFE Standards (2007 dollars)

MANUFACTURER	2012MY	2013MY	2014MY	2015MY	2016MY
BMW	$307	$571	$799	$996	$1,195
Chrysler	$543	$871	$1,146	$1,321	$1,501
Daimler	$235	$442	$618	$771	$930
Ford	$377	$561	$714	$953	$1,441
General Motors	$355	$569	$713	$968	$1,581
Honda	$172	$273	$361	$419	$473
Hyundai	$156	$244	$325	$379	$425
Kia	$101	$150	$197	$230	$247
Mazda	$190	$324	$410	$538	$537
Mitsubishi	$502	$706	$818	$1,021	$1,217
Nissan	$512	$638	$732	$898	$1,118
Porsche	$222	$377	$527	$657	$758
Subaru	$365	$535	$603	$662	$789
Suzuki	$174	$276	$385	$481	$536
Tata	$184	$330	$461	$575	$679
Toyota	$161	$294	$410	$512	$609
Volkswagen	$249	$464	$649	$810	$971
Overall	$314	$496	$652	$820	$1,098

Table 6-7 Cost per Vehicle (car/truck combined), including A/C, by Manufacturer Relative to the Cost of Complying with the 2011 CAFE Standards (2007 dollars)

MANUFACTURER	2012MY	2013MY	2014MY	2015MY	2016MY
BMW	$363	$679	$959	$1,209	$1,453
Chrysler	$493	$781	$1,020	$1,171	$1,328
Daimler	$337	$622	$871	$1,089	$1,312
Ford	$511	$658	$768	$940	$1,228
General Motors	$406	$572	$691	$889	$1,219
Honda	$206	$330	$439	$507	$574
Hyundai	$273	$419	$553	$656	$745
Kia	$197	$312	$386	$459	$501
Mazda	$356	$471	$559	$672	$799
Mitsubishi	$400	$545	$685	$826	$876
Nissan	$334	$449	$537	$657	$823
Porsche	$334	$614	$825	$1,009	$1,206
Subaru	$419	$615	$692	$762	$912
Suzuki	$239	$432	$583	$719	$855
Tata	$295	$524	$728	$913	$1,099
Toyota	$125	$222	$312	$387	$455
Volkswagen	$437	$794	$1,106	$1,412	$1,693
Overall	$331	$503	$639	$774	$948

Table 6-8 Industry Average Cost per Car, Truck, and Combined by Year Relative to the Cost of Complying with the 2011 CAFE Standards (2007 dollars)

YEAR	$/CAR	$/TRUCK	$/VEHICLE
2012	$342	$314	$331
2013	$507	$496	$503
2014	$631	$652	$639
2015	$749	$820	$774
2016	$869	$1,098	$948
2017	$869	$1,098	$947
2018	$869	$1,098	$945
2019	$869	$1,098	$943
2020	$869	$1,098	$940
2021	$869	$1,098	$939
2022	$817	$1,032	$882
2023	$817	$1,032	$881
2024	$817	$1,032	$881
2025	$817	$1,032	$880
2026	$817	$1,032	$880
2027	$817	$1,032	$879
2028	$817	$1,032	$879
2029	$817	$1,032	$878
2030	$817	$1,032	$878
2031	$817	$1,032	$877
2032	$817	$1,032	$877
2033	$817	$1,032	$876
2034	$817	$1,032	$876
2035	$817	$1,032	$875
2036	$817	$1,032	$875
2037	$817	$1,032	$875
2038	$817	$1,032	$875
2039	$817	$1,032	$875
2040	$817	$1,032	$875
2041	$817	$1,032	$875
2042	$817	$1,032	$875
2043	$817	$1,032	$875
2044	$817	$1,032	$875
2045	$817	$1,032	$875
2046	$817	$1,032	$875
2047	$817	$1,032	$875
2048	$817	$1,032	$875
2049	$817	$1,032	$875
2050	$817	$1,032	$875

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, annual costs can be calculated 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.[E]

Table 6-9 Estimated Annual Car Sales by Manufacturer (# of Units)

MANUFACTURER	2012MY	2013MY	2014MY	2015MY	2016MY
BMW	289,631	293,905	369,979	411,653	422,874
Chrysler	409,462	426,454	411,319	392,483	399,762
Daimler	211,652	202,559	244,554	263,751	270,940
Ford	1,468,182	1,485,801	1,567,762	1,542,470	1,559,310
General Motors	1,586,094	1,544,975	1,452,559	1,487,318	1,514,479
Honda	906,096	1,064,848	1,087,076	912,434	930,350
Hyundai	376,284	395,573	395,515	511,236	518,445
Kia	299,611	326,652	427,191	538,717	548,055
Mazda	283,128	329,911	378,291	413,328	420,516
Mitsubishi	110,284	104,555	88,150	82,310	82,688
Nissan	824,030	831,607	854,131	925,478	946,518
Porsche	41,117	43,299	34,024	32,426	33,309
Subaru	183,486	175,170	184,521	204,746	206,903
Suzuki	72,297	81,781	90,597	100,600	103,003
Tata	36,377	50,527	49,316	63,751	65,489
Toyota	1,591,054	1,941,480	2,079,011	2,176,644	2,226,522
Volkswagen	434,412	498,641	517,978	567,711	583,185
Industry	9,123,197	9,797,738	10,231,974	10,627,055	10,832,348

[E] Note that the vehicle compliance costs presented here do not include costs associated with upgrading testing facilities to accommodate N_2O testing. Including those costs would have very little impact on the costs presented here for new vehicle technology.

Table 6-10 Estimated Annual Truck Sales by Manufacturer (# of Units)

MANUFACTURER	2012MY	2013MY	2014MY	2015MY	2016MY
BMW	204,197	183,550	191,010	175,612	170,749
Chrysler	692,115	594,092	514,802	475,312	462,150
Daimler	108,053	114,531	136,455	129,878	126,281
Ford	851,877	940,080	965,589	936,781	910,840
General Motors	1,510,917	1,536,070	1,336,797	1,379,813	1,341,604
Honda	634,705	676,729	634,606	560,745	545,217
Hyundai	58,164	101,529	103,857	94,606	91,986
Kia	87,643	102,773	114,423	118,391	115,113
Mazda	60,783	64,784	67,780	74,213	72,158
Mitsubishi	48,290	46,179	52,835	56,896	55,320
Nissan	405,017	391,572	406,045	391,733	380,886
Porsche	13,190	14,608	16,033	17,145	16,670
Subaru	97,935	89,944	99,293	116,055	117,295
Suzuki	4,593	16,557	20,060	20,547	19,978
Tata	29,647	33,749	40,294	43,703	42,493
Toyota	886,621	990,315	1,095,949	1,107,261	1,076,598
Volkswagen	104,842	141,421	151,992	127,888	124,346
Industry	5,798,588	6,038,484	5,947,819	5,826,579	5,669,683

Table 6-11 Estimated Annual Costs by Manufacturer, including A/C, for Cars Relative to the Cost of Complying with the 2011 CAFE Standards ($Millions of 2007 dollars)

MANUFACTURER	2012MY	2013MY	2014MY	2015MY	2016MY
BMW	$120	$220	$390	$540	$660
Chrysler	$170	$280	$350	$390	$450
Daimler	$80	$150	$250	$340	$420
Ford	$860	$1,050	$1,250	$1,440	$1,730
General Motors	$720	$890	$970	$1,210	$1,360
Honda	$210	$390	$530	$510	$590
Hyundai	$110	$180	$240	$360	$420
Kia	$80	$140	$230	$330	$370
Mazda	$110	$170	$230	$290	$360
Mitsubishi	$40	$50	$60	$70	$70
Nissan	$200	$280	$370	$500	$650
Porsche	$20	$30	$30	$40	$50
Subaru	$80	$110	$140	$160	$200
Suzuki	$20	$40	$60	$80	$100
Tata	$10	$30	$40	$60	$80
Toyota	$170	$360	$540	$710	$850
Volkswagen	$210	$440	$640	$880	$1,080
Industry	$3,120	$4,970	$6,460	$7,960	$9,410

Table 6-12 Estimated Annual Costs by Manufacturer, including A/C, for Trucks Relative to the Cost of Complying with the 2011 CAFE Standards ($Millions of 2007 dollars)

MANUFACTURER	2012MY	2013MY	2014MY	2015MY	2016MY
BMW	$60	$100	$150	$170	$200
Chrysler	$380	$520	$590	$630	$690
Daimler	$30	$50	$80	$100	$120
Ford	$320	$530	$690	$890	$1,310
General Motors	$540	$870	$950	$1,340	$2,120
Honda	$110	$180	$230	$240	$260
Hyundai	$10	$20	$30	$40	$40
Kia	$10	$20	$20	$30	$30
Mazda	$10	$20	$30	$40	$40
Mitsubishi	$20	$30	$40	$60	$70
Nissan	$210	$250	$300	$350	$430
Porsche	$0	$10	$10	$10	$10
Subaru	$40	$50	$60	$80	$90
Suzuki	$0	$0	$10	$10	$10
Tata	$10	$10	$20	$30	$30
Toyota	$140	$290	$450	$570	$660
Volkswagen	$30	$70	$100	$100	$120
Industry	$1,820	$2,990	$3,880	$4,780	$6,230

Table 6-13 Estimated Annual Costs by Manufacturer, including A/C, for Cars and Trucks Combined Relative to the Cost of Complying with the 2011 CAFE Standards ($Millions of 2007 dollars)

MANUFACTURER	2012MY	2013MY	2014MY	2015MY	2016MY
BMW	$180	$320	$540	$710	$860
Chrysler	$550	$800	$940	$1,020	$1,140
Daimler	$110	$200	$330	$440	$540
Ford	$1,180	$1,580	$1,940	$2,330	$3,040
General Motors	$1,260	$1,760	$1,920	$2,550	$3,480
Honda	$320	$570	$760	$750	$850
Hyundai	$120	$200	$270	$400	$460
Kia	$90	$160	$250	$360	$400
Mazda	$120	$190	$260	$330	$400
Mitsubishi	$60	$80	$100	$130	$140
Nissan	$410	$530	$670	$850	$1,080
Porsche	$20	$40	$40	$50	$60
Subaru	$120	$160	$200	$240	$290
Suzuki	$20	$40	$70	$90	$110
Tata	$20	$40	$60	$90	$110
Toyota	$310	$650	$990	$1,280	$1,510
Volkswagen	$240	$510	$740	$980	$1,200
Industry	$4,940	$7,960	$10,340	$12,740	$15,640

Table 6-14 Annual Sales & Costs for Cars & Trucks Relative to the Cost of Complying with the 2011 CAFE Standards (Monetary Values in 2007 dollars)

YEAR	CAR SALES	TRUCK SALES	CAR COSTS ($MILLIONS)	TRUCK COSTS ($MILLIONS)	TOTAL COSTS ($MILLIONS)
2012	9,123,197	5,798,588	$3,120	$1,820	$4,940
2013	9,797,738	6,038,484	$4,970	$2,990	$7,960
2014	10,231,974	5,947,819	$6,460	$3,880	$10,340
2015	10,627,055	5,826,579	$7,960	$4,780	$12,740
2016	10,832,348	5,669,683	$9,410	$6,230	$15,640
2017	10,694,686	5,490,258	$9,290	$6,030	$15,320
2018	10,688,658	5,281,918	$9,290	$5,800	$15,090
2019	10,930,973	5,191,411	$9,500	$5,700	$15,200
2020	11,387,037	5,154,530	$9,900	$5,660	$15,560
2021	11,411,597	5,048,217	$9,920	$5,540	$15,460
2022	11,406,245	4,938,711	$9,320	$5,100	$14,420
2023	11,512,039	4,900,413	$9,400	$5,060	$14,460
2024	11,744,448	4,938,251	$9,590	$5,100	$14,690
2025	11,997,261	4,968,893	$9,800	$5,130	$14,930
2026	12,196,567	4,995,378	$9,960	$5,160	$15,120
2027	12,379,457	5,018,975	$10,110	$5,180	$15,290
2028	12,554,527	5,025,873	$10,260	$5,190	$15,450
2029	12,711,837	5,027,891	$10,380	$5,190	$15,570
2030	12,888,819	5,068,246	$10,530	$5,230	$15,760
2031	13,022,913	5,068,435	$10,640	$5,230	$15,870
2032	13,193,076	5,078,420	$10,780	$5,240	$16,020
2033	13,386,235	5,109,052	$10,940	$5,270	$16,210
2034	13,601,889	5,135,430	$11,110	$5,300	$16,410
2035	13,814,706	5,151,342	$11,290	$5,320	$16,610
2036	13,937,501	5,197,131	$11,390	$5,370	$16,760
2037	14,061,386	5,243,327	$11,490	$5,410	$16,900
2038	14,186,373	5,289,933	$11,590	$5,460	$17,050
2039	14,312,471	5,336,953	$11,690	$5,510	$17,200
2040	14,439,690	5,384,392	$11,800	$5,560	$17,360
2041	14,568,040	5,432,252	$11,900	$5,610	$17,510
2042	14,697,530	5,480,537	$12,010	$5,660	$17,670
2043	14,828,171	5,529,252	$12,110	$5,710	$17,820
2044	14,959,974	5,578,399	$12,220	$5,760	$17,980
2045	15,092,948	5,627,984	$12,330	$5,810	$18,140
2046	15,227,104	5,678,009	$12,440	$5,860	$18,300
2047	15,362,453	5,728,479	$12,550	$5,910	$18,460
2048	15,499,005	5,779,398	$12,660	$5,970	$18,630
2049	15,636,770	5,830,769	$12,770	$6,020	$18,790
2050	15,775,760	5,882,596	$12,890	$6,070	$18,960
NPV, 3%			$226,730	$119,200	$345,940
NPV, 7%			$124,010	$67,850	$191,860

6.2 Cost per Ton of Emissions Reduced

We have calculated the cost per ton of GHG (CO_2 equivalent, or CO_2e) reductions associated with this GHG rule using the costs shown in Table 6-14 and the emissions reductions described in Chapter 5. The cost per metric ton of GHG emissions reductions in the years 2020, 2030, 2040, and 2050 is calculated using the annual vehicle compliance costs and emission reductions for each of those years. The value in 2050 represents the long-term cost per ton of the emissions reduced. EPA has also calculated the cost per metric ton of GHG emission reductions including the savings associated with reduced fuel consumption (see section 6.3 below). This latter calculation does not include the other benefits associated with this rule such as those associated with criteria pollutant reductions or energy security benefits as discussed in Chapter 8 of this RIA. By including the fuel savings in the cost estimates, the cost per ton is less than $0, since the estimated value of fuel savings outweighs the vehicle program costs. With regard to the CH4 and N_2O standards, since these standards would be emissions caps designed to ensure that manufacturers do not backslide from current levels, the costs associated with the standards were not estimated (since the standards would not require any change from current practices nor is it estimated they would result in emissions reductions[F]).

The results for CO_2e costs per ton under the final rule are shown in Table 6-15.

Table 6-15 Annual Cost Per Metric Ton of CO_2e Reduced, in $2007 dollars

Year	Vehicle Compliance Cost [a] ($Millions)	Fuel Savings [b] ($Millions)	CO_2-equivalent Reduction (Million metric tons)	Cost per Ton – Vehicle Program only	Cost per Ton – Vehicle Program with Fuel Savings
2020	$15,600	-$35,700	160	$100	-$130
2030	$15,800	-$79,800	310	$50	-$210
2040	$17,400	-$119,300	400	$40	-$250
2050	$19,000	-$171,200	510	$40	-$300

[a] Costs here include vehicle compliance costs and do not include any fuel savings
[b] Fuel savings calculated using pre-tax fuel prices.

6.3 Fuel Consumption Impacts

In this section, EPA presents the impact of the final rule 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 rule.

The new CO_2 standards will result in significant improvements in the fuel efficiency of affected vehicles. Drivers of those vehicles will see corresponding savings associated with

[F] Including those costs would have very little impact on the costs presented here for new vehicle technology.

reduced expenditures for fuel. EPA has estimated the impacts on fuel consumption for both the tailpipe CO_2 standards and the A/C credit program. To do this, fuel consumption is calculated using both current CO_2 emission levels and the new CO_2 standards. The difference between these estimates represents the net savings from the new CO_2 standards.

The expected impacts on fuel consumption are shown in Table 6-16. The gallons shown in the tables reflect impacts from the new CO_2 standards, including the A/C credit program, and include increased consumption resulting from the rebound effect. Using these fuel consumption estimates, the monetized fuel savings associated with the new CO_2 standards can be calculated. To do this, the reduced fuel consumption in each year is multiplied by the corresponding estimated average fuel price in that year, using the reference case taken from the AEO 2010 Early Release. AEO is the government consensus estimate used by NHTSA and many other government agencies to estimate the projected price of fuel. The calculation has been done using both the pre-tax and the post-tax fuel prices. The latter of these is what consumers actually pay for the fuel and, therefore, the post-tax fuel savings are those savings that consumers will realize. The pre-tax fuel savings represent the savings to society.

Table 6-16 Annual Fuel Consumption Impacts of the Vehicle Standards and A/C Credit Programs

(Monetary values in 2007 dollars)

YEAR	GALLONS (MILLIONS)	FUEL PRICE EXCLUDING TAXES ($/GALLON)	FUEL PRICE INCLUDING TAXES ($/GALLON)	PRE-TAX FUEL SAVINGS ($MILLIONS)	POST-TAX FUEL SAVINGS ($MILLIONS)
2012	500	$2.08	$2.61	$1,100	$1,400
2013	1,300	$2.21	$2.84	$2,900	$3,800
2014	2,300	$2.45	$2.95	$5,700	$6,900
2015	3,800	$2.56	$3.00	$9,600	$11,300
2016	5,700	$2.61	$3.07	$14,800	$17,400
2017	7,500	$2.68	$3.13	$20,100	$23,500
2018	9,200	$2.75	$3.19	$25,400	$29,400
2019	10,900	$2.80	$3.22	$30,600	$35,200
2020	12,600	$2.84	$3.27	$35,700	$41,100
2021	14,200	$2.89	$3.29	$40,900	$46,700
2022	15,600	$2.92	$3.34	$45,600	$52,200
2023	17,100	$2.96	$3.37	$50,500	$57,400
2024	18,400	$2.99	$3.38	$55,100	$62,200
2025	19,700	$3.01	$3.42	$59,200	$67,300
2026	20,800	$3.05	$3.46	$63,600	$72,100
2027	22,000	$3.09	$3.49	$67,900	$76,600
2028	22,900	$3.13	$3.54	$71,800	$81,200
2029	23,900	$3.18	$3.59	$76,000	$85,600
2030	24,700	$3.23	$3.60	$79,800	$89,100
2031	25,600	$3.25	$3.64	$83,100	$93,200
2032	26,400	$3.29	$3.69	$86,800	$97,300

2033	27,200	$3.34	$3.72	$90,700	$101,100
2034	27,900	$3.37	$3.77	$94,200	$105,200
2035	28,700	$3.42	$3.83	$98,200	$109,900
2036	29,500	$3.48	$3.87	$102,700	$114,100
2037	30,300	$3.53	$3.91	$106,700	$118,400
2038	31,000	$3.57	$3.95	$110,800	$122,700
2039	31,800	$3.61	$3.99	$115,000	$127,100
2040	32,600	$3.66	$4.04	$119,300	$131,700
2041	33,400	$3.70	$4.08	$123,800	$136,400
2042	34,300	$3.75	$4.12	$128,400	$141,200
2043	35,100	$3.79	$4.17	$133,200	$146,300
2044	36,000	$3.84	$4.21	$138,100	$151,400
2045	36,800	$3.89	$4.26	$143,200	$156,800
2046	37,700	$3.93	$4.30	$148,400	$162,300
2047	38,700	$3.98	$4.35	$153,900	$168,100
2048	39,600	$4.03	$4.39	$159,500	$173,900
2049	40,500	$4.08	$4.44	$165,300	$180,000
2050	41,500	$4.12	$4.49	$171,200	$186,300
NPV, 3%				$1,545,600	$1,723,900
NPV, 7%				$672,600	$755,700

As shown in Table 6-16, we are projecting that consumers will realize very large fuel savings as a result of the new CO_2 standards. There are several ways to view this value. Some, as demonstrated below in Chapter 8 of this 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 of how consumers in fact make their decisions on how much fuel economy to purchase, they will necessarily gain these fuel savings. Another view says that consumers do not necessarily value fuel savings as equal to the results of this calculation, notwithstanding actual dollars accruing to them. 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 RIA.

If the analysis is limited to the five model years 2012-2016—in other words, to the fuel consumption savings during the vehicle 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	$2,000				$3,400
2014	$1,400	$2,200	$2,900			$6,500
2015	$1,500	$2,200	$3,000	$4,300		$10,900
2016	$1,400	$2,100	$2,900	$4,300	$6,000	$16,700
2017	$1,400	$2,100	$2,900	$4,200	$5,900	$16,600
2018	$1,300	$2,000	$2,800	$4,200	$5,900	$16,300
2019	$1,300	$2,000	$2,700	$4,100	$5,800	$15,800
2020	$1,200	$1,800	$2,600	$3,900	$5,600	$15,200
2021	$1,100	$1,700	$2,500	$3,800	$5,400	$14,500
2022	$1,000	$1,600	$2,300	$3,500	$5,100	$13,600
2023	$900	$1,500	$2,200	$3,300	$4,900	$12,800
2024	$800	$1,300	$2,000	$3,100	$4,600	$11,800
2025	$700	$1,100	$1,800	$2,800	$4,200	$10,600
2026	$500	$1,000	$1,500	$2,500	$3,900	$9,400
2027	$400	$800	$1,300	$2,200	$3,500	$8,200
2028	$400	$700	$1,100	$1,800	$3,000	$6,900
2029	$300	$500	$900	$1,500	$2,500	$5,800
2030	$200	$400	$700	$1,200	$2,100	$4,700
2031	$200	$400	$600	$1,000	$1,700	$3,900
2032	$200	$300	$500	$800	$1,400	$3,200
2033	$100	$200	$400	$700	$1,100	$2,600
2034	$100	$200	$300	$600	$900	$2,100
2035	$100	$200	$300	$500	$800	$1,700
2036	$100	$100	$200	$400	$600	$1,500
2037	$100	$100	$200	$300	$500	$1,200
2038	$0	$100	$200	$300	$400	$1,000
2039	$0	$100	$100	$200	$400	$900
2040	$0	$100	$100	$200	$300	$700
2041	$0	$100	$100	$100	$300	$600
2042	$0	$100	$100	$100	$200	$500
2043	$0	$0	$100	$100	$200	$400
2044	$0	$0	$100	$100	$200	$400
2045	$0	$0	$100	$100	$100	$300
2046	$0	$0	$0	$100	$100	$300
2047	$0	$0	$0	$100	$100	$300
2048	$0	$0	$0	$100	$100	$200
2049	$0	$0	$0	$100	$100	$200
2050	$0	$0	$0	$0	$100	$100
NPV, 3%	$15,600	$23,300	$31,600	$45,300	$62,500	$178,300
NPV, 7%	$12,100	$18,100	$24,600	$35,400	$48,800	$139,000

6.4 Vehicle Program Cost Summary

The vehicle program costs consist of the vehicle compliance costs relative to the cost of complying with the 2011 CAFE standards, and the fuel savings 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 Savings Using Post-Tax Fuel Prices ($Millions of 2007 dollars)

YEAR	VEHICLE COMPLIANCE COSTS	FUEL SAVINGS)	TOTAL
2012	$4,900	-$1,400	$3,500
2013	$8,000	-$3,800	$4,200
2014	$10,300	-$6,900	$3,400
2015	$12,700	-$11,300	$1,400
2016	$15,600	-$17,400	-$1,800
2017	$15,300	-$23,500	-$8,200
2018	$15,100	-$29,400	-$14,300
2019	$15,200	-$35,200	-$20,000
2020	$15,600	-$41,100	-$25,500
2021	$15,500	-$46,700	-$31,200
2022	$14,400	-$52,200	-$37,800
2023	$14,500	-$57,400	-$42,900
2024	$14,700	-$62,200	-$47,500
2025	$14,900	-$67,300	-$52,400
2026	$15,100	-$72,100	-$57,000
2027	$15,300	-$76,600	-$61,300
2028	$15,500	-$81,200	-$65,700
2029	$15,600	-$85,600	-$70,000
2030	$15,800	-$89,100	-$73,300
2031	$15,900	-$93,200	-$77,300
2032	$16,000	-$97,300	-$81,300
2033	$16,200	-$101,100	-$84,900
2034	$16,400	-$105,200	-$88,800
2035	$16,600	-$109,900	-$93,300
2036	$16,800	-$114,100	-$97,300
2037	$16,900	-$118,400	-$101,500
2038	$17,100	-$122,700	-$105,600
2039	$17,200	-$127,100	-$109,900
2040	$17,400	-$131,700	-$114,300
2041	$17,500	-$136,400	-$118,900
2042	$17,700	-$141,200	-$123,500
2043	$17,800	-$146,300	-$128,500
2044	$18,000	-$151,400	-$133,400
2045	$18,100	-$156,800	-$138,700
2046	$18,300	-$162,300	-$144,000
2047	$18,500	-$168,100	-$149,600
2048	$18,600	-$173,900	-$155,300
2049	$18,800	-$180,000	-$161,200
2050	$19,000	-$186,300	-$167,300
NPV, 3%	$345,900	-$1,723,900	-$1,378,000
NPV, 7%	$191,900	-$755,700	-$563,800

References

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

[1] EPA-420-R-09-020, EPA docket number EPA-HQ-OAR-2009-0472-11282; peer review report dated November 6, 2009, is at EPA-HQ-OAR-2009-0472-11285.

[2] "Binning of FEV Costs to GDI, Turbo-charging, and Engine Downsizing," memorandum to Docket EPA-HQ-OAR-2009-0472, from Michael Olechiw, U.S. EPA, dated March 25, 2010.

[3] U.S. EPA. Baseline and Reference Fleet File, as documented in TSD chapter 1. August 2009.

[4] US EPA 2010. 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 standards, but the standards would affect emissions of these pollutants and precursors.

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 (UFPs) 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 numerous 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 chemicals 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.[1]

7.1.1.1.2 Particulate Matter Health Effects

This section provides a summary of the health effects associated with exposure to ambient concentrations of PM.[A] The information in this section is based on the information and conclusions in the Integrated Science Assessment (ISA) for Particulate Matter (December 2009) prepared by EPA's Office of Research and Development (ORD).[B]

The ISA concludes that ambient concentrations of PM are associated with a number of adverse health effects.[C] The ISA characterizes the weight of evidence for different health effects associated with three PM size ranges: $PM_{2.5}$, $PM_{10\text{-}2.5}$, and UFPs. The discussion below highlights the ISA's conclusions pertaining to these three size fractions of PM, considering variations in both short-term and long-term exposure periods.

7.1.1.1.2.1 Effects Associated with $PM_{2.5}$

Short-term Exposure

The ISA concludes that cardiovascular effects and all-cause cardiovascular- and respiratory-related mortality are causally associated with short-term exposure to $PM_{2.5}$.[2] It also concludes that respiratory effects are likely to be causally associated with short-term exposure to $PM_{2.5}$, including respiratory emergency department (ED) visits and hospital admissions for chronic obstructive pulmonary disease (COPD), respiratory infections, and asthma; and exacerbation of respiratory symptoms in asthmatic children.

Long-term Exposure

The ISA concludes that there are causal associations between long-term exposure to $PM_{2.5}$ and cardiovascular effects, such as the development/progression of cardiovascular disease (CVD), and premature mortality, particularly from cardiopulmonary causes.[3] It also

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[A] 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.
[B] The ISA is available at http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=216546
[C] The ISA evaluates the health evidence associated with different health effects, assigning one of five "weight of evidence" determination: causal relationship, likely to be a causal relationship, suggestive of a causal relationship, inadequate to infer a causal relationship, and not likely to be a causal relationship. For definitions of these levels of evidence, please refer to Section 1.5 of the ISA. The following text summarizes only those health effects with at least a "suggestive" weight of evidence determination.

concludes that long-term exposure to $PM_{2.5}$ is likely to be causally associated with respiratory effects, such as reduced lung function growth, increased respiratory symptoms, and asthma development. The ISA characterizes the evidence as suggestive of a causal relationship for associations between long-term $PM_{2.5}$ exposure and reproductive and developmental outcomes, such as low birth weight and infant mortality. It also characterizes the evidence as suggestive of a causal relationship between $PM_{2.5}$ and cancer incidence, mutagenicity, and genotoxicity.

7.1.1.1.2.2 Effects Associated with $PM_{10-2.5}$

The ISA summarizes evidence related to short-term exposure to $PM_{10-2.5}$. $PM_{10-2.5}$ is the fraction of PM_{10} particles that is larger than $PM_{2.5}$.[4] The ISA concludes that available evidence is suggestive of a causal relationship between short-term exposures to $PM_{10-2.5}$ and cardiovascular effects, such as hospitalizations for ischemic heart disease. It also concludes that the available evidence is suggestive of a causal relationship between short-term exposures to $PM_{10-2.5}$ and respiratory effects, including respiratory-related ED visits and hospitalizations and pulmonary inflammation. The ISA also concludes that the available literature suggests a causal relationship between short-term exposures to $PM_{10-2.5}$ and mortality. Data are inadequate to draw conclusions regarding health effects associated with long-term exposure to $PM_{10-2.5}$.[5]

7.1.1.1.2.3 Effects Associated with Ultrafine Particles

The ISA concludes that the evidence is suggestive of a causal relationship between short-term exposures to UFPs and cardiovascular effects, including changes in heart rhythm and vasomotor function (the ability of blood vessels to expand and contract).[6]

The ISA also concludes that there is suggestive evidence of a causal relationship between short-term UFP exposure and respiratory effects. The types of respiratory effects examined in epidemiologic studies include respiratory symptoms and asthma hospital admissions, the results of which are not entirely consistent. There is evidence from toxicological and controlled human exposure studies that exposure to UFPs may increase lung inflammation and produce small asymptomatic changes in lung function. Data are inadequate to draw conclusions regarding health effects associated with long-term exposure to UFPs.[7]

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.[D] These health effects are well documented and are critically assessed in the EPA ozone air quality criteria document (ozone AQCD) and EPA staff paper.[8,9] We are relying on the data and conclusions in the ozone AQCD and staff paper, regarding the health effects associated

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[D] 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.

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.[10] People who appear to be more susceptible to effects associated with exposure to ozone include children, asthmatics and the elderly. Those with greater exposures to ozone, for instance due to time spent outdoors (e.g., children and outdoor workers), are also of concern.

Based on a large number of scientific studies, EPA has identified several key health effects associated with exposure to levels of ozone found today in many areas of the country. Short-term (1 to 3 hours) and prolonged exposures (6 to 8 hours) to ambient ozone concentrations have been linked to lung function decrements, respiratory symptoms, increased hospital admissions and emergency room visits for respiratory problems.[11, 12, 13, 14, 15, 16] Repeated exposure to ozone can increase susceptibility to respiratory infection and lung inflammation and can aggravate preexisting respiratory diseases, such as asthma.[17, 18, 19, 20, 21] 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.[22, 23, 24, 25]

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.[26] 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.[27] 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.[28, 29, 30, 31, 32, 33, 34, 35] 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.[36, 37, 38, 39]

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), 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 SO_2

This section provides an overview of the health effects associated with SO_2. Additional information on the health effects of SO_2 can be found in the EPA Integrated Science Assessment for Sulfur Oxides.[40] Following an extensive evaluation of health evidence from epidemiologic and laboratory studies, the U.S. EPA has concluded that there is a causal relationship between respiratory health effects and short-term exposure to SO_2. The immediate effect of SO_2 on the respiratory system in humans is bronchoconstriction. Asthmatics are more sensitive to the effects of SO_2 likely resulting from preexisting inflammation associated with this disease. In laboratory studies involving controlled human exposures to SO_2, respiratory effects have consistently been observed following 5-10 min exposures at SO_2 concentrations $\geq$ 0.4 ppm in asthmatics engaged in moderate to heavy levels of exercise, with more limited evidence of respiratory effects among exercising asthmatics exposed to concentrations as low as 0.2-0.3 ppm. A clear concentration-response relationship has been demonstrated in these studies following exposures to SO_2 at concentrations between 0.2 and 1.0 ppm, both in terms of increasing severity of respiratory symptoms and decrements in lung function, as well as the percentage of asthmatics adversely affected.

In epidemiologic studies, respiratory effects have been observed in areas where the mean 24-hour SO_2 levels range from 1 to 30 ppb, with maximum 1 to 24-hour average SO_2 values ranging from 12 to 75 ppb. Important new multicity studies and several other studies have found an association between 24-hour average ambient SO_2 concentrations and respiratory symptoms in children, particularly those with asthma. Generally consistent associations also have been observed between ambient SO_2 concentrations and emergency department visits and hospitalizations for all respiratory causes, particularly among children and older adults ($\geq$ 65 years), and for asthma. A limited subset of epidemiologic studies have examined potential confounding by copollutants using multipollutant regression models. These analyses indicate that although copollutant adjustment has varying degrees of influence on the SO_2 effect estimates, the effect of SO_2 on respiratory health outcomes appears to be generally robust and independent of the effects of gaseous and particulate copollutants, suggesting that the observed effects of SO_2 on respiratory endpoints occur independent of the effects of other ambient air pollutants.

Consistent associations between short-term exposure to SO_2 and mortality have been observed in epidemiologic studies, with larger effect estimates reported for respiratory mortality than for cardiovascular mortality. While this finding is consistent with the demonstrated effects of SO_2 on respiratory morbidity, uncertainty remains with respect to the interpretation of these associations due to potential confounding by various copollutants. The U.S. EPA has therefore concluded that the overall evidence is suggestive of a causal relationship between short-term exposure to SO_2 and mortality. Significant associations between short-term exposure to SO_2 and emergency department visits and hospital admissions for cardiovascular diseases have also been reported. However, these findings have been inconsistent across studies and do not provide adequate evidence to infer a causal relationship between SO_2 exposure and cardiovascular morbidity.

7.1.1.3.3 Health Effects of NO_2

Information on the health effects of NO_2 can be found in the EPA Integrated Science Assessment (ISA) for Nitrogen Oxides.[41] The EPA has concluded that the findings of epidemiologic, controlled human exposure, and animal toxicological studies provide evidence that is sufficient to infer a likely causal relationship between respiratory effects and short-term NO_2 exposure. The ISA concludes that the strongest evidence for such a relationship comes from epidemiologic studies of respiratory effects including symptoms, emergency department visits, and hospital admissions. The ISA also draws two broad conclusions regarding airway responsiveness following NO_2 exposure. First, the ISA concludes that NO_2 exposure may enhance the sensitivity to allergen-induced decrements in lung function and increase the allergen-induced airway inflammatory response following 30-minute exposures of asthmatics to NO_2 concentrations as low as 0.26 ppm. In addition, small but significant increases in non-specific airway hyperresponsiveness were reported following 1-hour exposures of asthmatics to 0.1 ppm NO_2. 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

Information on the health effects of carbon monoxide (CO) can be found in the EPA Integrated Science Assessment (ISA) for Carbon Monoxide.[42] The ISA concludes that ambient concentrations of CO are associated with a number of adverse health effects.[E] This section provides a summary of the health effects associated with exposure to ambient concentrations of CO.[F]

Human clinical studies of subjects with coronary artery disease show a decrease in the time to onset of exercise-induced angina (chest pain) and electrocardiogram changes following CO exposure. In addition, epidemiologic studies show associations between short-term CO exposure and cardiovascular morbidity, particularly increased emergency room visits and hospital admissions for coronary heart disease (including ischemic heart disease, myocardial infarction, and angina). Some epidemiologic evidence is also available for increased hospital admissions and emergency room visits for congestive heart failure and cardiovascular disease as a whole. The ISA concludes that a causal relationship is likely between short-term exposures to CO and cardiovascular morbidity. It also concludes that available data are inadequate to conclude that a causal relationship exists between long-term exposures to CO and cardiovascular morbidity.

Animal studies show various neurological effects with in-utero CO exposure. Controlled human exposure studies report inconsistent neural and behavioral effects following low-level CO exposures. The ISA concludes the evidence is suggestive of a causal relationship with both short- and long-term exposure to CO and central nervous system effects.

A number of epidemiologic and animal toxicological studies cited in the ISA have evaluated associations between preterm birth and cardiac birth defects and CO exposure. The epidemiologic studies provide limited evidence of a CO-induced effect on pre-term births and

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[E] The ISA evaluates the health evidence associated with different health effects, assigning one of five “weight of evidence” determination: causal relationship, likely to be a causal relationship, suggestive of a causal relationship, inadequate to infer a causal relationship, and not likely to be a causal relationship. For definitions of these levels of evidence, please refer to Section 1.6 of the ISA.

[F] Personal exposure includes contributions from many sources, and in many different environments. Total personal exposure to CO includes both ambient and nonambient components; and both components may contribute to adverse health effects.

birth defects, with weak evidence for a decrease in birth weight. Animal toxicological studies have found associations between perinatal CO exposure and decrements in birth weight, as well as other developmental outcomes. The ISA concludes these studies are suggestive of a causal relationship between long-term exposures to CO and developmental effects and birth outcomes.

Epidemiologic studies provide evidence of effects on respiratory morbidity such as changes in pulmonary function, respiratory symptoms, and hospital admissions associated with ambient CO concentrations. A limited number of epidemiologic studies considered copollutants such as ozone, SO_2, and PM in two-pollutant models and found that CO risk estimates were generally robust, although this limited evidence makes it difficult to disentangle effects attributed to CO itself from those of the larger complex air pollution mixture. Controlled human exposure studies have not extensively evaluated the effect of CO on respiratory morbidity. Animal studies at levels of 50-100 ppm CO show preliminary evidence of altered pulmonary vascular remodeling and oxidative injury. The ISA concludes that the evidence is suggestive of a causal relationship between short-term CO exposure and respiratory morbidity, and inadequate to conclude that a causal relationship exists between long-term exposure and respiratory morbidity.

Finally, the ISA concludes that the epidemiologic evidence is suggestive of a causal relationship between short-term exposures to CO and mortality. Epidemiologic studies provide evidence of an association between short-term exposure to CO and mortality, but limited evidence is available to evaluate cause-specific mortality outcomes associated with CO exposure. In addition, the attenuation of CO risk estimates which was often observed in copollutant models contributes to the uncertainty as to whether CO is acting alone or as an indicator for other combustion-related pollutants. The ISA also concludes that there is not likely to be a causal relationship between relevant long-term exposures to CO and mortality.

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.[43] 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. [44]

Noncancer health effects can result from chronic,[G] subchronic,[H] or acute[I] 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

[G] 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).
[H] Defined in the IRIS database as exposure to a substance spanning approximately 10% of the lifetime of an organism.
[I] Defined in the IRIS database as exposure by the oral, dermal, or inhalation route for 24 hours or less.

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.[45,46]

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.[47] 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.[48,49,50] 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.[51,52]

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.[53,54] The most sensitive noncancer effect observed in humans, based on current data, is the depression of the absolute lymphocyte count in blood.[55,56] 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.[57,58,59,60] EPA's IRIS program has not yet evaluated these new data.

7.1.1.5.2 1,3-Butadiene

EPA has characterized 1,3-butadiene as carcinogenic to humans by inhalation.[61,62] 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.[63,64] 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.[65]

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.[66] 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.[67,68] 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.[69] 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.[70] 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.[71]

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.[72,73,74] 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.[75,76,77,78] These findings are not supportive of interpreting the CIIT model results as providing a conservative (health protective) estimate of human risk.[79] 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.[80]

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."[81] 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.[82,83]

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.[84] 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.[85,86] 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.[87] In short-term (4 week) rat studies, degeneration of olfactory epithelium was observed at various concentration levels of acetaldehyde exposure.[88,89] 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.[90] 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.[91] The IARC determined in 1995 that acrolein was not classifiable as to its carcinogenicity in humans.[92]

Acrolein is extremely acrid and irritating to humans when inhaled, with acute exposure resulting in upper respiratory tract irritation, mucus hypersecretion and congestion. The intense irritancy of this carbonyl has been demonstrated during controlled tests in human subjects, who suffer intolerable eye and nasal mucosal sensory reactions within minutes of exposure.[93] These data and additional studies regarding acute effects of human exposure to acrolein are summarized in EPA's 2003 IRIS Human Health Assessment for acrolein.[94] Evidence available from studies in humans indicate that levels as low as 0.09 ppm (0.21 mg/m^3) for five minutes may elicit subjective complaints of eye irritation with increasing concentrations leading to more extensive eye, nose and respiratory symptoms.[95] Lesions to the lungs and upper respiratory tract of rats, rabbits, and hamsters have been observed after subchronic exposure to acrolein.[96] Acute exposure effects in animal studies report bronchial hyper-responsiveness.[97] In a recent study, the acute respiratory irritant effects of exposure to 1.1 ppm acrolein were more pronounced in mice with allergic airway disease by comparison to non-diseased mice which also showed decreases in respiratory rate.[98] Based on these animal data and demonstration of similar effects in humans (i.e., reduction in respiratory rate), individuals with compromised respiratory function (e.g., emphysema, asthma) are expected to be at increased risk of developing adverse responses to strong respiratory irritants such as acrolein.

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.[99,100] 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.[101] The draft reassessment completed external peer review.[102] Based on external peer review comments received, additional analyses are being undertaken. This external review draft does not represent official agency opinion and was released solely for the purposes of external peer review and public comment. The National Toxicology Program listed naphthalene as "reasonably anticipated to be a human carcinogen" in 2004 on the basis of bioassays reporting clear evidence of carcinogenicity in rats and some evidence of carcinogenicity in mice.[103] 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.[104]

Naphthalene also causes a number of chronic non-cancer effects in animals, including abnormal cell changes and growth in respiratory and nasal tissues.[105]

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 this final rule. Mobile source air toxic compounds that would potentially be impacted include ethylbenzene, propionaldehyde, toluene, and xylene. Information regarding the health effects of these compounds can be found in EPA's IRIS database.[J]

7.1.1.6 Exposure and Health Effects Associated with Traffic

Populations who live, work, or attend school near major roads experience elevated exposure concentrations to a wide range of air pollutants, as well as higher risks for a number of adverse health effects. While the previous sections of this RIA have focused on the health effects associated with individual criteria pollutants or air toxics, this section discusses the mixture of different exposures near major roadways, rather than the effects of any single pollutant. As such, this section emphasizes traffic-related air pollution, in general, as the relevant indicator of exposure rather than any particular pollutant.

Concentrations of many traffic-generated air pollutants are elevated for up to 300-500 meters downwind of roads with high traffic volumes.[106] Numerous sources on roads contribute to elevated roadside concentrations, including exhaust and evaporative emissions, and resuspension of road dust and tire and brake wear. Concentrations of several criteria and hazardous air pollutants are elevated near major roads. Furthermore, different semi-volatile organic compounds and chemical components of particulate matter, including elemental carbon, organic material, and trace metals, have been reported at higher concentrations near major roads.

Populations near major roads experience greater risk of certain adverse health effects. The Health Effects Institute published a report on the health effects of traffic-related air pollution.[107] It concluded that evidence is "sufficient to infer the presence of a causal association" between traffic exposure and exacerbation of childhood asthma symptoms. The HEI report also concludes that the evidence is either "sufficient" or "suggestive but not sufficient" for a causal association between traffic exposure and new childhood asthma cases. A review of asthma studies by Salam et al. (2008) reaches similar conclusions.[108] The HEI report also concludes that there is "suggestive" evidence for pulmonary function deficits associated with traffic exposure, but concluded that there is "inadequate and insufficient"

[J] U.S. EPA Integrated Risk Information System (IRIS) database is available at: www.epa.gov/iris evidence for causal associations with respiratory health care utilization, adult-onset asthma, COPD symptoms, and allergy. A review by Holguin (2008) notes that the effects of traffic on asthma may be modified by nutrition status, medication use, and genetic factors.[109]

The HEI report also concludes that evidence is "suggestive" of a causal association between traffic exposure and all-cause and cardiovascular mortality. There is also evidence of an association between traffic-related air pollutants and cardiovascular effects such as changes in heart rhythm, heart attack, and cardiovascular disease. The HEI report characterizes this evidence as "suggestive" of a causal association, and an independent epidemiological literature review by Adar and Kaufman (2007) concludes that there is "consistent evidence" linking traffic-related pollution and adverse cardiovascular health outcomes.[110]

Some studies have reported associations between traffic exposure and other health effects, such as birth outcomes (e.g., low birth weight) and childhood cancer. The HEI report concludes that there is currently "inadequate and insufficient" evidence for a causal association between these effects and traffic exposure. A review by Raaschou-Nielsen and Reynolds (2006) concluded that evidence of an association between childhood cancer and traffic-related air pollutants is weak, but noted the inability to draw firm conclusions based on limited evidence.[111]

There is a large population in the U.S. living in close proximity of major roads. According to the Census Bureau's American Housing Survey for 2007, approximately 20 million residences in the U.S., 15.6% of all homes, are located within 300 feet (91 m) of a highway with 4+ lanes, a railroad, or an airport.[112] Therefore, at current population of approximately 309 million, assuming that population and housing similarly distributed, there are over 48 million people in the U.S. living near such sources. The HEI report also notes that in two North American cities, Los Angeles and Toronto, over 40% of each city's population live within 500 meters of a highway or 100 meters of a major road. It also notes that about 33% of each city's population resides within 50 meters of major roads. Together, the evidence suggests that a large U.S. population lives in areas with elevated traffic-related air pollution.

People living near roads are often socioeconomically disadvantaged. According to the 2007 American Housing Survey, a renter-occupied property is over twice as likely as an owner-occupied property to be located near a highway with 4+ lanes, railroad or airport. In the same survey, the median household income of rental housing occupants was less than half that of owner-occupants ($28,921/$59,886). Numerous studies in individual urban areas report higher levels of traffic-related air pollutants in areas with high minority or poor populations.[113,114,115]

Students may also be exposed in situations where schools are located near major roads. In a study of nine metropolitan areas across the U.S., Appatova et al. (2008) found that on average greater than 33% of schools were located within 400 m of an Interstate, US, or state highway, while 12% were located within 100 m.[116] The study also found that among the metropolitan areas studied, schools in the Eastern U.S. were more often sited near major roadways than schools in the Western U.S.

Demographic studies of students in schools near major roadways suggest that this population is more likely than the general student population to be of non-white race or Hispanic ethnicity, and more often live in low socioeconomic status locations. [117,118,119] There is some inconsistency in the evidence, which may be due to different local development patterns and measures of traffic and geographic scale used in the studies.[116]

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 emissions of primary $PM_{2.5}$ and secondary $PM_{2.5}$ precursors such as NO_X. Airborne particles degrade visibility by scattering and absorbing light. Good visibility increases the quality of life where individuals live and work, and where they engage in recreational activities.

EPA is pursuing a two-part strategy to address visibility. First, 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, and has set secondary $PM_{2.5}$ standards.[K] The secondary $PM_{2.5}$ standards act in conjunction with the regional haze program. The regional haze rule (64 FR 35714) was put in place in July 1999 to protect the visibility in mandatory class I federal areas. There are 156 national parks, forests and wilderness areas categorized as mandatory class I federal areas (62 FR 38680-81, July 18, 1997).[L] Visibility can be said to be impaired in both $PM_{2.5}$ nonattainment areas and mandatory class I federal areas. Figure 7-1 shows the location of the 156 mandatory class I federal areas.

[K] The existing annual primary and secondary PM2.5 standards have been remanded and are being addressed in the currently ongoing PM NAAQS review.

[L] These areas are defined in CAA section 162 as those national parks exceeding 6,000 acres, wilderness areas and memorial parks exceeding 5,000 acres, and all international parks which were in existence on August 7, 1977.

Figure 7-1 Mandatory Class I Areas in the U.S.

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. In addition to this indirect method of assessing light extinction, there are optical measurements which directly measure light extinction or its components. Such measurements are taken principally with either a transmissometer, which measures total light extinction, or by combining the PM light scattering measured by integrating nephelometers with the PM light absorption measured by an aethalometer. 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. Visibility is typically worse in the summer months and the rural East generally has higher levels of impairment than remote sites in the West. Figures 9-9 through 9-11 in the PM ISA detail the percent contributions to particulate light extinction for ammonium nitrate and sulfate, EC and OC, and coarse mass and fine soil, by season.[120]

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.[121] 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".[122] Like carbon dioxide (CO_2) and other gaseous substances, ozone enters plant tissues primarily through apertures (stomata) in leaves in a process called "uptake".[123] 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.[124,125] If enough tissue becomes damaged from these effects, a plant's capacity to fix carbon to form carbohydrates, which are the primary form of energy used by plants is reduced,[126] 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.[127,128]

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)[129,130,131] 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.[132]

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.[133,134] 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.[135,136]

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.[137] 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.[138,139,140] 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."[141] In addition, economic studies have shown reduced economic benefits as a result of predicted reductions in crop yields associated with observed ozone levels.[142,143,144]

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.[145] 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.[146] 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.[147]

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.[148,149] 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.[150, 151] 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 indicator 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.[152, 153]

The highest percentages of observed high and severe foliar injury, those which are most likely to be associated with tree or ecosystem-level responses, are primarily found in the Mid-Atlantic and Southeast regions. In EPA Region 3 (which comprises the States of Pennsylvania, West Virginia, Virginia, Delaware, Maryland and Washington D.C.), 12% of ozone-sensitive plants showed signs of high or severe foliar damage, and in Regions 2 (States of New York, New Jersey), and 4 (States of North Carolina, South Carolina, Kentucky, Tennessee, Georgia, Florida, Alabama, and Mississippi) the values were 10% and 7%, respectively. The sum of high and severe ozone injury ranged from 2% to 4% in EPA Region 1 (the six New England States), Region 7 (States of Missouri, Iowa, Nebraska and Kansas), and Region 9 (States of California, Nevada, Hawaii and Arizona). The percentage of sites showing some ozone damage was about 45% in each of these EPA Regions.

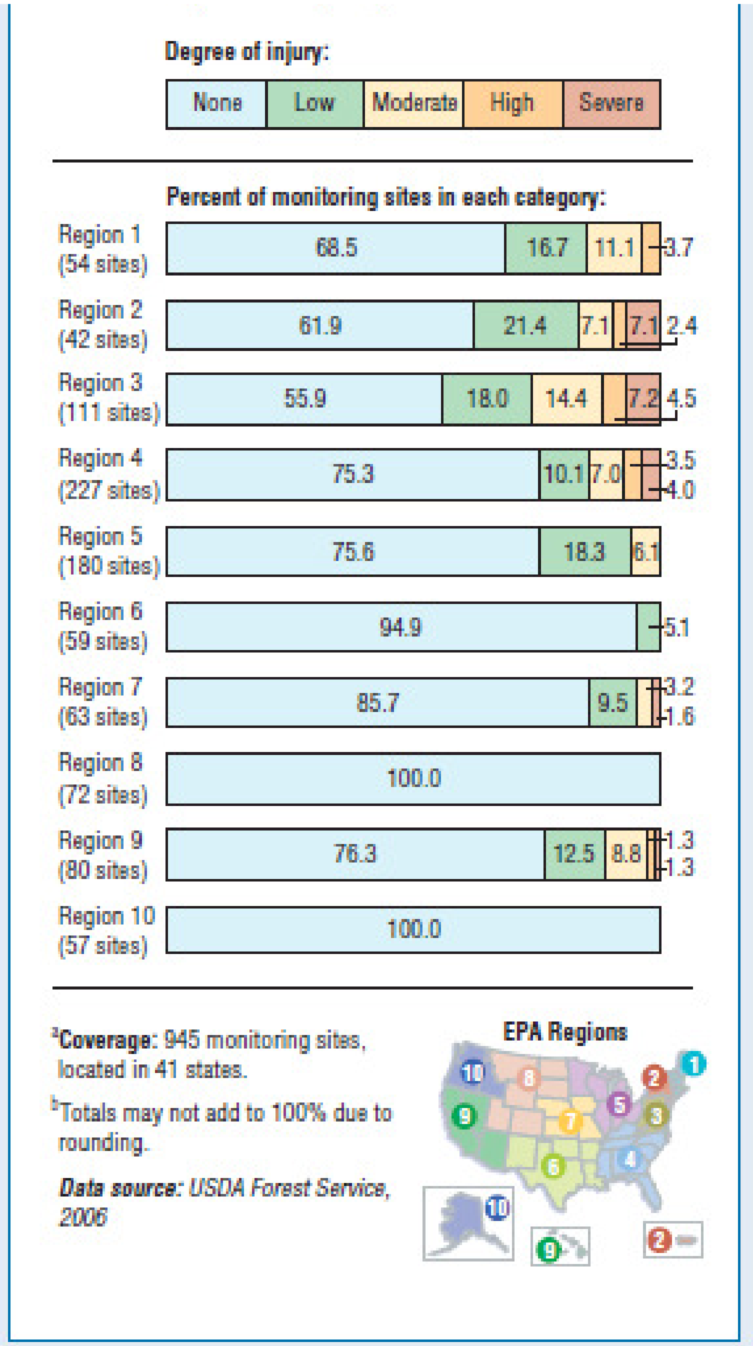

Figure 7-2 Ozone Injury to Forest Plants in U.S. by EPA Regions, 2002[ab]

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.[154] Ozone may have other adverse impacts on plants (e.g., reduced productivity) that do not show signs of visible foliar injury.[155]

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.[156]

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. [157]

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). The following characterizations of the nature of these environmental effects are based on information contained in the 2009 PM ISA and the 2005 PM Staff Paper.[158,159]

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 acidification, nutrient enrichment, and eutrophication of aquatic ecosystems.[160]

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.[161] 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.[162] Lichens are sensitive indicators of nitrogen deposition effects to terrestrial ecosystems and the lichen studies in the Columbia River Gorge clearly show that ecological effects from air pollution are occurring.

Some of the most significant detrimental effects associated with excess nitrogen deposition are those associated with a condition known as nitrogen saturation. Nitrogen saturation is the condition in which nitrogen inputs from atmospheric deposition and other sources exceed the biological requirements of the ecosystem. The effects associated with nitrogen saturation include: (1) decreased productivity, increased mortality, and/or shifts in plant community composition, often leading to decreased biodiversity in many natural habitats wherever atmospheric reactive nitrogen deposition increases significantly above background and critical thresholds are exceeded; (2) leaching of excess nitrate and associated base cations from soils into streams, lakes, and rivers, and mobilization of soil aluminum; and (3) fluctuation of ecosystem processes such as nutrient and energy cycles through changes in the functioning and species composition of beneficial soil organisms.[163]

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.[164]

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 impacting forest growth.[165] Investigation of trace metals near roadways and industrial facilities indicate that a substantial load of heavy metals can accumulate on vegetative surfaces. Copper, zinc, and nickel have been documented to cause direct toxicity to vegetation under field conditions. Little research has been conducted on the effects associated with mixtures of contaminants found in ambient PM. While metals typically exhibit low solubility, limiting their bioavailability and direct toxicity, chemical transformations of metal compounds occur in the environment, particularly in the presence of acidic or other oxidizing species. These chemical changes influence the mobility and toxicity of metals in the environment. Once taken up into plant tissue, a metal compound can undergo chemical changes, exert toxic effects on the plant itself, accumulate and be passed along to herbivores or can re-enter the soil and further cycle in the environment. Although there has been no direct evidence of a physiological association between tree injury and heavy metal exposures, heavy metals have been implicated because of similarities between metal deposition patterns and forest decline. This hypothesized relationship/correlation was further explored in high elevation forests in the northeastern U.S. These studies measured levels of a group of intracellular compounds found in plants that bind with metals and are produced by plants as a response to sublethal concentrations of heavy metals. These studies indicated a systematic and significant increase in concentrations of these compounds associated with the extent of tree injury. These data strongly imply that metal stress causes tree injury and contributes to forest decline in the northeastern United States.[166] Contamination of plant leaves by heavy metals can lead to elevated soil levels. Trace metals absorbed into the plant frequently bind to the leaf tissue, and then are lost when the leaf drops. As the fallen leaves decompose, the heavy metals are transferred into the soil.[167,168] Upon entering the soil environment, PM pollutants can alter ecological processes of energy flow and nutrient cycling, inhibit nutrient uptake, change ecosystem structure, and affect ecosystem biodiversity. Many of the most important effects occur in the soil. The soil environment is one of the most dynamic sites of biological interaction in nature. It is inhabited by microbial communities of bacteria, fungi, and actinomycetes. These organisms are essential participants in the nutrient cycles that make elements available for plant uptake. Changes in the soil environment that influence the role of the bacteria and fungi in nutrient cycling determine plant and ultimately ecosystem response.[169]

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.[170,171] Over fifty percent of the mercury in the Chesapeake Bay has been attributed to atmospheric deposition.[172] Overall, the National Science and Technology Council identifies atmospheric deposition as the primary source of mercury to aquatic systems.[173] 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.[174,175] 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.[176] 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.[177] 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.[178]

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.[179,180] Analyses of PAH deposition in Chesapeake and Galveston Bay indicate that dry deposition and gas exchange from the atmosphere to the surface water predominate.[181,182] 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.[183] 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.[184] 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.[185] 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.[186]

Cousins et al. estimate that more than ninety percent of semi-volatile organic compound (SVOC) emissions in the United Kingdom deposit on soil.[187] An analysis of PAH concentrations near a Czechoslovakian roadway indicated that concentrations were thirty times greater than background.[188]

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.[189] In laboratory experiments, a wide range of tolerance to VOCs has been observed.[190] 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.[191]

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.[192,193,194] 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

This section presents the methodology and results of EPA's air quality modeling to determine the projected impact of the vehicle standards finalized in this rule on ambient concentrations of criteria and air toxic pollutants. Section 7.1 above describes the health and environmental effects associated with the criteria and air toxic pollutants that are impacted by this rule, and Section 7.3 describes the methodology for calculating monetized benefits due to reductions in adverse health effects associated with $PM_{2.5}$ and ozone.

7.2.1 Air Quality Modeling Methodology

Air quality models use mathematical and numerical techniques to simulate the physical and chemical processes that affect air pollutants as they disperse and react in the atmosphere. Based on inputs of meteorological data and source information, these models are designed to characterize primary pollutants that are emitted directly into the atmosphere and secondary pollutants that are formed as a result of complex chemical reactions within the atmosphere. Photochemical air quality models have become widely recognized and routinely utilized tools for regulatory analysis by assessing the effectiveness of control strategies. These models are applied at multiple spatial scales - local, regional, national, and global. This section provides detailed information on the photochemical model used for our air quality analysis (the Community Multi-scale Air Quality (CMAQ) model), atmospheric reactions and the role of chemical mechanisms in modeling, and model uncertainties and limitations. Further discussion of the modeling methodology is included in the Air Quality Modeling Technical Support Document (AQM TSD) found in the docket for this rule. Results of the air quality modeling are presented in Section 7.2.2.

7.2.1.1 Modeling Methodology

A national-scale air quality modeling analysis was performed to estimate future year annual $PM_{2.5}$ concentrations, 24-hour $PM_{2.5}$ concentrations, 8-hour ozone concentrations, air toxics concentrations, and nitrogen and sulfur deposition levels for future years. The 2005-based CMAQ modeling platform was used as the basis for the air quality modeling of the future reference case and the future control scenario for this final rule. This platform represents a structured system of connected modeling-related tools and data that provide a consistent and transparent basis for assessing the air quality response to projected changes in emissions. The base year of data used to construct this platform includes emissions and meteorology for 2005. The platform was developed by the U.S. EPA's Office of Air Quality Planning and Standards in collaboration with the Office of Research and Development and is intended to support a variety of regulatory and research model applications and analyses.

The CMAQ modeling system is a non-proprietary, publicly available, peer-reviewed, state-of-the-science, three-dimensional, grid-based Eulerian air quality grid model designed to estimate the formation and fate of oxidant precursors, primary and secondary PM concentrations, acid deposition, and air toxics, over regional and urban spatial scales for given input sets of meteorological conditions and emissions.[195,196,197] The CMAQ model version 4.7 was most recently peer-reviewed in February of 2009 for the U.S. EPA.[M] The CMAQ model

[M] Report on the peer-review is still being finalized. Draft available upon request from Director S.T.Rao, Atmospheric Modeling and Analysis Division; rao.st@epa.gov; 919-541-4541. Allen, D., Burns, D., Chock, D., Kumar, N., Lamb, B., Moran, M. (February 2009 Draft Version). Report on the Peer Review of the Atmospheric Modeling and Analysis Division, NERL/ORD/EPA. U.S. EPA, Research Triangle Park, NC.

is a well-known and well-respected tool and has been used in numerous national and international applications.[198,199,200] This 2005 multi-pollutant modeling platform used CMAQ version 4.7.1[N] with a minor internal change made by the U.S. EPA CMAQ model developers intended to speed model runtimes when only a small subset of toxics species are of interest.

CMAQ includes many science modules that simulate the emission, production, decay, deposition and transport of organic and inorganic gas-phase and particle-phase pollutants in the atmosphere. We used CMAQ v4.7.1 which reflects updates to version 4.7 to improve the underlying science. These include aqueous chemistry mass conservation improvements, improved vertical convective mixing and lowered CB05 mechanism unit yields for acrolein from 1,3-butadiene tracer reactions which were updated to be consistent with laboratory measurements. Section 7.2.1.2.2 of this RIA discusses the chemical mechanism and SOA formation.

7.2.1.1.1 Model Domain and Configuration

The CMAQ modeling domain encompasses all of the lower 48 States and portions of Canada and Mexico. The modeling domain is made up of a large continental U.S. 36 kilometer (km) grid and two 12 km grids (an Eastern US and a Western US domain), as shown in Figure 7-3. The modeling domain contains 14 vertical layers with the top of the modeling domain at about 16,200 meters, or 100 millibars (mb).

[N] CMAQ version 4.7 was released on December, 2008. It is available from the Community Modeling and Analysis System (CMAS) as well as previous peer-review reports at: http://www.cmascenter.org.

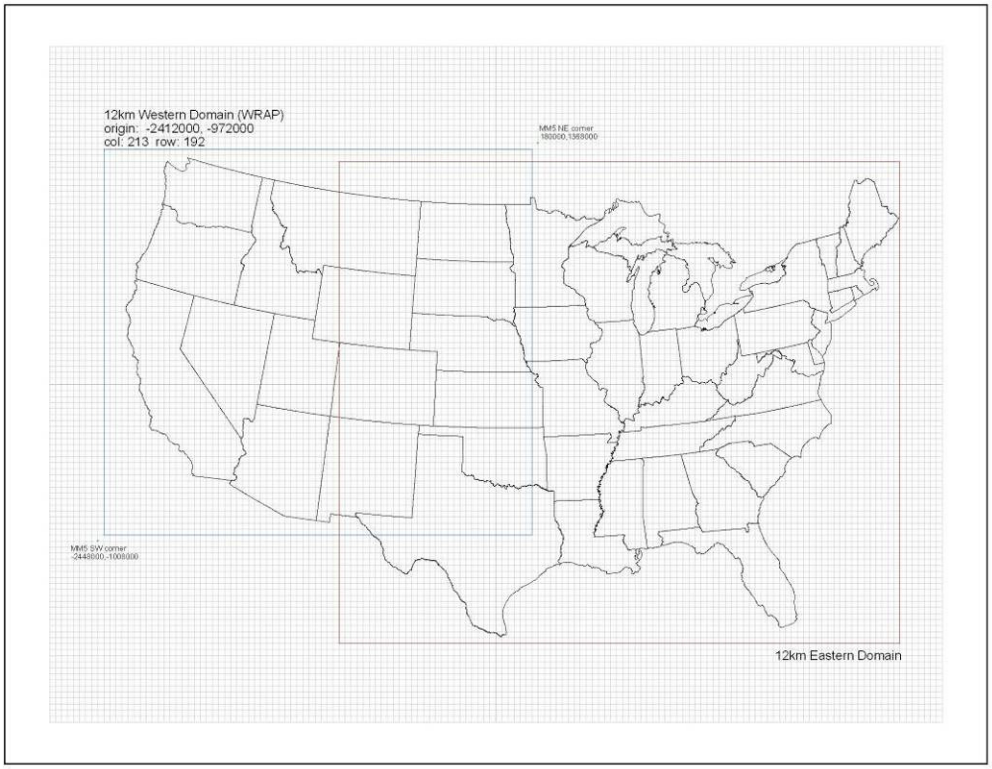

Figure 7-3 Map of the CMAQ Modeling Domain

7.2.1.1.2 Model Inputs

The key inputs to the CMAQ model include emissions from anthropogenic and biogenic sources, meteorological data, and initial and boundary conditions. The CMAQ meteorological input files were derived from simulations of the Pennsylvania State University/National Center for Atmospheric Research Mesoscale Model[201] for the entire year of 2005 over model domains that are slightly larger than those shown in Figure 7-3. 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.[202] The meteorology for the national 36 km grid and the two 12 km grids were developed by EPA and are described in more detail within the AQM TSD. The meteorological outputs from MM5 were processed to create model-ready inputs for CMAQ using the Meteorology-Chemistry Interface Processor (MCIP) version 3.4, for example: horizontal wind components (i.e., speed and direction), temperature, moisture, vertical diffusion rates, and rainfall rates for each grid cell in each vertical layer.[203]

The lateral boundary and initial species concentrations are provided by a three-dimensional global atmospheric chemistry model, the GEOS-CHEM model.[204] The global GEOS-CHEM model simulates atmospheric chemical and physical processes driven by assimilated meteorological observations from the NASA's Goddard Earth Observing System (GEOS). This model was run for 2005 with a grid resolution of 2 degree x 2.5 degree (latitude-longitude) and 20 vertical layers. The predictions were used to provide one-way dynamic boundary conditions at three-hour intervals and an initial concentration field for the 36 km CMAQ simulations. The future base conditions from the 36 km coarse grid modeling were used as the initial/boundary state for all subsequent 12 km finer grid modeling.

The emissions inputs used for the 2005 base year and each of the future year base cases and control scenarios analyzed for this rule are summarized in Chapter 5 of this RIA.

7.2.1.1.3 CMAQ Evaluation

An operational model performance evaluation for ozone, $PM_{2.5}$ and its related speciated components (e.g., sulfate, nitrate, elemental carbon, organic carbon, etc.), nitrate and sulfate deposition, and specific air toxics (formaldehyde, acetaldehyde, benzene, 1,3-butadiene, and acrolein) was conducted using 2005 state/local monitoring data in order to estimate the ability of the CMAQ modeling system to replicate base year concentrations. Model performance statistics were calculated for observed/predicted pairs of daily/monthly/seasonal/annual concentrations. Statistics were generated for the following geographic groupings: domain wide, Eastern vs. Western (divided along the 100th meridian), and each Regional Planning Organization (RPO) region.[O] The "acceptability" of model performance was judged by comparing our results to those found in recent regional $PM_{2.5}$ model applications for other, non-EPA studies.[P] Overall, the performance for the 2005 modeling platform is within the range or close to that of these other applications. The performance of the CMAQ modeling was evaluated over a 2005 base case. The model was able to reproduce historical concentrations of ozone and $PM_{2.5}$ over land with low bias and error results. Model predictions of annual formaldehyde, acetaldehyde and benzene showed relatively small bias and error results when compared to observations. The model yielded larger bias and error results for 1,3 butadiene and acrolein based on limited monitoring sites. A more detailed summary of the 2005 CMAQ model performance evaluation is available within the AQM TSD found in the docket of this rule.

[O] Regional Planning Organization regions include: Mid-Atlantic/Northeast Visibility Union (MANE-VU), Midwest Regional Planning Organization – Lake Michigan Air Directors Consortium (MWRPO-LADCO), Visibility Improvement State and Tribal Association of the Southeast (VISTAS), Central States Regional Air Partnership (CENRAP), and Western Regional Air Partnership (WRAP).

[P] These other modeling studies represent a wide range of modeling analyses which cover various models, model configurations, domains, years and/or episodes, chemical mechanisms, and aerosol modules.

7.2.1.1.4 Model Simulation Scenarios

As part of our analysis for this rulemaking, the CMAQ modeling system was used to calculate daily and annual $PM_{2.5}$ concentrations, 8-hour ozone concentrations, annual and seasonal (summer and winter) air toxics concentrations, and annual nitrogen and sulfur deposition total levels for each of the following emissions scenarios:

- 2005 base year
- 2030 reference case projection
- 2030 control case projection

The emission inventories used in the air quality and benefits modeling are different from the final rule inventories due to the considerable length of time required to conduct the modeling. However, the air quality modeling inventories are generally consistent with the final emission inventories, so the air quality modeling adequately reflects the effects of the rule. The emission inventories used for air quality modeling are discussed in Section 5.8 of this RIA. The emissions modeling TSD, found in the docket for this rule (EPA-HQ-OAR-2009-0472), contains a detailed discussion of the emissions inputs used in our air quality modeling.

We use the predictions from the model in a relative sense by combining the 2005 base-year predictions with predictions from each future-year scenario and applying these modeled ratios to ambient air quality observations to estimate daily and annual $PM_{2.5}$ concentrations, and 8-hour ozone concentrations for each of the 2030 scenarios. The ambient air quality observations are average conditions, on a site-by-site basis, for a period centered around the model base year (i.e., 2003-2007).

The projected daily and annual $PM_{2.5}$ design values were calculated using the Speciated Modeled Attainment Test (SMAT) approach. The SMAT uses a Federal Reference Method (FRM) mass construction methodology that results in reduced nitrates (relative to the amount measured by routine speciation networks), higher mass associated with sulfates (reflecting water included in FRM measurements), and a measure of organic carbonaceous mass that is derived from the difference between measured $PM_{2.5}$ and its non-carbon components. This characterization of $PM_{2.5}$ mass also reflects crustal material and other minor constituents. The resulting characterization provides a complete mass balance. It does not have any unknown mass that is sometimes presented as the difference between measured $PM_{2.5}$ mass and the characterized chemical components derived from routine speciation measurements. However, the assumption that all mass difference is organic carbon has not been validated in many areas of the U.S. The SMAT methodology uses the following $PM_{2.5}$ species components: sulfates, nitrates, ammonium, organic carbon mass, elemental carbon, crustal, water, and blank mass (a fixed value of 0.5 $\mu g/m^3$). More complete details of the

SMAT procedures can be found in the report "Procedures for Estimating Future $PM_{2.5}$ Values for the CAIR Final Rule by Application of the (Revised) Speciated Modeled Attainment Test (SMAT)".[205] For this latest analysis, several datasets and techniques were updated. These changes are fully described within the technical support document for the Small SI Engine Rule modeling AQM TSD.[206] The projected 8-hour ozone design values were calculated using the approach identified in EPA's guidance on air quality modeling attainment demonstrations.[207]

Additionally, we conducted an analysis to compare the absolute and percent differences between the 2030 control case and the 2030 reference cases for annual and seasonal ethanol and five air toxics of interest (formaldehyde, acetaldehyde, benzene, 1,3-butadiene, and acrolein), as well as annual nitrate and sulfate deposition. These data were not compared in a relative sense due to the limited observational data available.

7.2.1.2 Chemical Mechanisms in Modeling

This rule presents inventories for NO_X, VOC, CO, $PM_{2.5}$, SO_2, NH_3, and five air toxics: benzene, 1,3-butadiene, formaldehyde, acetaldehyde, and acrolein. The five air toxics are explicit model species in the CMAQv4.7 model with carbon bond 5 (CB05) mechanisms.[208] In addition to direct emissions, photochemical processes mechanisms are responsible for formation of some of these compounds in the atmosphere from precursor emissions. For some pollutants such as PM, formaldehyde, and acetaldehyde, many photochemical processes are involved. CMAQ therefore also requires inventories for a large number of other air toxics and precursor pollutants. Methods used to develop the air quality inventories can be found in Chapter 5 of the RIA.

In the CB05 mechanism, the chemistry of thousands of different VOCs in the atmosphere are represented by a much smaller number of model species which characterize the general behavior of a subset of chemical bond types; this condensation is necessary to allow the use of complex photochemistry in a fully 3-D air quality model.[209]

Complete combustion of ethanol in fuel produces carbon dioxide (CO_2) and water (H_2O). Incomplete combustion results in the production of other air pollutants, such as acetaldehyde and other aldehydes, and the release of unburned ethanol. Ethanol is also present in evaporative emissions. In the atmosphere, ethanol from unburned fuel and evaporative emissions can undergo photodegradation to form aldehydes (acetaldehyde and formaldehyde) and peroxyacetyl nitrate (PAN), and also plays a role in ground-level ozone formation. Mechanisms for these reactions are included in CMAQ. Additionally, other aromatic hydrocarbons (AHC) and hydrocarbons are considered because any increase in acetyl peroxy radicals due to ethanol increases might be counterbalanced by a decrease in radicals resulting from decreases in AHC and other hydrocarbons.

CMAQ includes 63 inorganic reactions to account for the cycling of all relevant oxidized nitrogen species and cycling of radicals, including the termination of NO_2 and formation of nitric acid (HNO_3) without PAN formation.[Q]

$NO_2 + \cdot OH + M \rightarrow HNO_3 + M$ k = 1.19 x 10^{-11} $cm^3 molecule^{-1} s^{-1}$ [210]

The CB05 mechanism also includes more than 90 organic reactions that include alternate pathways for the formation of acetyl peroxy radical, such as by reaction of methylglyoxal, which is also formed from reactions of AHC. Alternate reactions of acetyl peroxy radical, such as oxidation of NO to form NO_2, which again leads to ozone formation, are also included.

Atmospheric reactions and chemical mechanisms involving several key formation pathways are discussed in more detail in the following sections.

7.2.1.2.1 Acetaldehyde

Acetaldehyde is the main photodegradation product of ethanol, as well as other precursor hydrocarbons. Acetaldehyde is also a product of fuel combustion. In the atmosphere, acetaldehyde can react with the OH radical and O_2 to form the acetyl peroxy radical [$CH_3C(O)OO\cdot$].[R] This radical species can then further react with nitric oxide (NO), to produce formaldehyde (HCHO), or with nitrogen dioxide (NO_2), to produce PAN [$CH_3C(O)OONO_2$]. An overview of these reactions and the corresponding reaction rates are provided below.[S]

$\mathbf{CH_3CHO} + \cdot OH \rightarrow CH_3C\cdot O + H_2O$ k = 1.5 x 10^{-11} $cm^3 molecule^{-1} s^{-1}$ [211]

$CH_3C\cdot O + O_2 + M \rightarrow \mathbf{CH_3C(O)OO\cdot} + M$

$\mathbf{CH_3C(O)OO\cdot} + \boldsymbol{NO} \rightarrow CH_3C(O)O\cdot + \boldsymbol{NO_2}$ k = 2.0 x 10^{-11} $cm^3 molecule^{-1} s^{-1}$ [212]

$CH_3C(O)O\cdot \rightarrow \cdot CH_3 + CO_2$

$\cdot CH_3 + O_2 + M \rightarrow CH_3OO\cdot + M$

$CH_3OO\cdot + NO \rightarrow CH_3O\cdot + NO_2$

[Q] All rate coefficients in this RIA are listed at 298 K and, if applicable, 1 bar of air.
[R] Acetaldehyde is not the only source of acetyl peroxy radicals in the atmosphere. For example, dicarbonyl compounds (methylglyoxal, biacetyl, and others) also form acetyl radicals, which can further react to form peroxyacetyl nitrate (PAN).
[S] All rate coefficients in this RIA are listed at 298 K and, if applicable, 1 bar of air.

$CH_3O\cdot + O_2 \rightarrow$ **HCHO** $+ HO_2$

$CH_3C(O)OO\cdot$ $+ NO_2 + M \rightarrow$ **$CH_3C(O)OONO_2$** $+ M$ $k = 1.0 \times 10^{-11}\ cm^3 molecule^{-1} s^{-1}$ [213]

Acetaldehyde can also photolyze (hν), which predominantly produces $\cdot CH_3$ and HCO:

CH_3CHO $+ h\nu \rightarrow \cdot CH_3 + HCO$ $\lambda = 240\text{-}380$ nm [214]

As mentioned above, $\cdot CH_3$ is oxidized in the atmosphere to produce formaldehyde (HCHO). Formaldehyde is also a product of hydrocarbon combustion. In the atmosphere, formaldehyde undergoes photolysis and reaction with the OH radical, NO_3 radical, and ozone, and the resulting lifetimes are ~4 hours, 1.2 days, 83 days, and >4.5 years, respectively.[T] Formaldehyde is removed mainly by photolysis whereas the higher aldehydes, those with two or more carbons such as acetaldehyde, react predominantly with OH radicals. The photolysis of formaldehyde is a source of additional radicals, and as shown above, these radicals can react with NO_2 to form PAN in the atmosphere.

HCHO $+ h\nu \rightarrow H + HCO$ $\lambda = 240\text{-}360$ nm [215]

CB05 mechanisms for acetaldehyde formation warrant a detailed discussion given the increase in vehicle and engine exhaust emissions for this pollutant and ethanol, which can form acetaldehyde in the air. Acetaldehyde is represented explicitly in the CB05 chemical mechanism[216,217] by the ALD2 model species, which can be both formed from other VOCs and can decay via reactions with oxidants and radicals. The reaction rates for acetaldehyde, as well as for the inorganic reactions that produce and cycle radicals, and the representative reactions of other VOCs have all been updated to be consistent with recommendations in the literature.[218]

The decay reactions of acetaldehyde are fewer in number and can be characterized well because they are explicit representations. Acetaldehyde can photolyze in the presence of sunlight or react with molecular oxygen ($O^3(P)$), hydroxyl radical (OH), or nitrate radicals. Of these reactions, both photolysis and reaction with OH are the most important reactions determining loss of acetaldehyde. The reaction rates are based on expert recommendations,[219] and the photolysis rate is from IUPAC recommendations.

In CMAQ v4.7, the acetaldehyde that is formed from photochemical reactions is tracked separately from that which is due to direct emission and transport of direct emissions. In CB05, there are 25 different reactions that form acetaldehyde in molar yields ranging from

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[T] Lifetime calculated using the following: for photolysis, with overhead sun (at noontime during the summer); for OH radical reactions, a 12-hour daytime average of 2.0×10^6 molecule cm^{-3}; for NO_3 radical reactions, a 12-hour nighttime average of 5×10^8 molecule cm^{-3}; and for ozone, a 24-hour average of 7×10^{11} molecule cm^{-3}.

0.02 (ozone reacting with lumped products from isoprene oxidation) to 2.0 (cross reaction of acylperoxy radicals, CXO3). The specific parent VOCs that contribute the most to acetaldehyde concentrations vary spatially and temporally depending on characteristics of the ambient air, but alkenes in particular are found to play a large role. The IOLE model species, which represents internal carbon-carbon double bonds, has high emissions and relatively high yields of acetaldehyde. The OLE model species, representing terminal carbon double bonds, also plays a role because it has high emissions although lower acetaldehyde yields. Production from peroxyproprional nitrate and other peroxyacylnitrates (PANX) and aldehydes with 3 or more carbon atoms also play an important role. Thus, the amount of acetaldehyde (and formaldehyde as well) formed in the ambient air as well as emitted in the exhaust (the latter being accounted for in emission inventories) is affected by changes in these precursor compounds due to the addition of ethanol to fuels (e.g., decreases in alkenes would cause some decrease of acetaldehyde, and to a larger extent, formaldehyde).

The reaction of ethanol (CH_3CH_2OH) with OH is slower than some other important reactions but can be an important source of acetaldehyde if the emissions are large. Based on kinetic data for molecular reactions, the only important chemical loss process for ethanol (and other alcohols) is reaction with the hydroxyl radical (·OH).[220] This reaction produces acetaldehyde (CH_3CHO) with a 90% yield.[221] The lifetime of ethanol in the atmosphere can be calculated from the rate coefficient, k, and due to reaction with the OH radical, occurs on the order of a day in polluted urban areas or several days in unpolluted areas.[U]

$\mathbf{CH_3CH_2OH} + \cdot OH \rightarrow CH_3C\cdot HOH + H_2O$ $\qquad k = 3.2 \times 10^{-12}\ cm^3 molecule^{-1} s^{-1}$ [222]

$CH_3C\cdot HOH + O_2 \rightarrow \mathbf{CH_3CHO} + HO_2$

In CB05, reaction of one molecule of ethanol yields 0.90 molecules of acetaldehyde. It assumes the majority of the reaction occurs through H-atom abstraction of the more weakly-bonded methylene group, which reacts with oxygen to form acetaldehyde and hydroperoxy radical (HO2), and the remainder of the reaction occurs at the –CH3 and -OH groups, creating formaldehyde (HCHO), oxidizing NO to NO2 (represented by model species XO2) and creating glycoaldehyde, which is represented as ALDX:

CH3CHOH + OH → HO2 + 0.90 CH3CHO + 0.05 ALDX + 0.10 HCHO + 0.10 XO2

7.2.1.2.2 Secondary Organic Aerosols

Secondary organic aerosol (SOA) chemistry research described below has led to implementation of new pathways for secondary organic aerosol (SOA) in CMAQ 4.7, based on recommendations of Edney et al. and the recent work of Carlton et al.[223, 224] In previous

[U] All rate coefficients in this RIA are listed at 298 K and, if applicable, 1 bar of air.

versions of the CMAQ model, all SOA was treated as semi-volatile, whereas in CMAQ v4.7, non-volatile SOA are simulated as well, including SOA originating from aromatic oxidation under low-NO_X conditions.

7.2.1.2.2.1 SOA Research

SOA results when products of atmospheric transformation or photooxidation of a volatile organic compound (VOC) form or partition to the particle phase. Current research suggests SOA contributes significantly to ambient organic aerosol (OA) concentrations, and in Southeast and Midwest States may make up more than 50% (although the contribution varies from area to area) of the organic fraction of $PM_{2.5}$ during the summer (but less in the winter).[225,226] A wide range of laboratory studies conducted over the past twenty years show that anthropogenic aromatic hydrocarbons and long-chained alkanes, along with biogenic isoprene, monoterpenes, and sesquiterpenes, contribute to SOA formation.[227,228,229,230,231] Anthropogenic SOA is a small portion of all SOA; most is biogenic and varies with season. Based on these laboratory results, SOA chemical mechanisms have been developed and integrated into air quality models such as the CMAQ model and have been used to predict OA concentrations.[232]

Over the past 10 years, ambient OA concentrations have been routinely measured in the U.S. and some of these data have been used to determine, by employing source/receptor methods, the contributions of the major OA sources, including biomass burning and vehicular gasoline and diesel exhaust. Since mobile sources are a significant source of VOC emissions, currently accounting for approximately 50% of anthropogenic VOC,[233] mobile sources are also an important source of SOA.

Toluene is an important contributor to anthropogenic SOA. Other aromatic compounds contribute as well, but the extent of their contribution has not yet been quantified. Mobile sources are the most significant contributor to ambient toluene concentrations as shown by analyses done for the 2002 National Air Toxics Assessment (NATA)[234] and the Mobile Source Air Toxics (MSAT) Rule.[235] 2002 NATA indicates that onroad and nonroad mobile sources accounted for 70% (2.24 $\mu g/m^3$) of the total average nationwide ambient concentration of toluene (3.24 $\mu g/m^3$), when the contribution of the estimated "background" is apportioned among source sectors.

The amount of toluene in gasoline influences the amount of toluene emitted in vehicle exhaust and evaporative emissions, although, like benzene, some toluene is formed in the combustion process. In turn, levels of toluene and other aromatics in gasoline are potentially influenced by the amount of ethanol blended into the fuel. Due to the high octane quality of ethanol, it greatly reduces the need for and levels of other high-octane components such as aromatics including toluene (which is the major aromatic compound in gasoline). Since toluene contributes to SOA and the toluene level of gasoline is decreasing, it is important to assess the effect of these reductions on ambient PM.

It is unlikely that ethanol would directly form SOA or affect SOA formation indirectly through changes in the radical populations from increasing ethanol exhausts. Nevertheless, scientists at the U.S. EPA's Office of Research and Development's National Exposure Research Laboratory recently directed experiments to investigate ethanol's SOA forming potential.[236] The experiments were conducted under conditions where peroxy radical reactions would predominate (irradiations performed in the absence of NO_X and OH produced from the photolysis of hydrogen peroxide). This was the most likely scenario under which SOA formation could occur, since a highly oxygenated C4 organic would be potentially made. As expected, no SOA was produced. From these experiments, the upper limit for the aerosol yield would have been less than 0.01% based on scanning mobility particle sizer (SMPS) data. Given the expected negative result based on these initial smog chamber experiments, these data were not published.

In general, a review of the literature shows limited data on SOA concentrations, largely due to the lack of analytical methods for identifying and determining the concentrations of the highly polar organic compounds that make up SOA. The most widely applied method of estimating total ambient SOA concentrations is the EC tracer method using ambient data which estimates of the OC/EC ratio in primary source emissions.[237,238] SOA concentrations have also been estimated using OM (organic mass) to OC (organic carbon) ratios, which can indicate that SOA formation has occurred, or by subtracting the source/receptor-based total primary organic aerosol (POA) from the measured OC concentration.[239] Such methods, however, may not be quantitatively accurate and provide no information on the contribution of individual biogenic and anthropogenic SOA sources, which is critical information needed to assess the impact of specific sources and the associated health risk. These methods assume that OM containing additional mass from oxidation of OC comes about largely (or solely) from SOA formation. In particular, the contributions of anthropogenic SOA sources, including those of aromatic precursors, are required to determine exposures and risks associated with replacing fossil fuels with biofuels.

Upon release into the atmosphere, numerous VOC compounds can react with free radicals in the atmosphere to form SOA. While this has been investigated in the laboratory, there is relatively little information available on the specific chemical composition of SOA compounds themselves from specific VOC precursors. This absence of compositional data from the precursors has largely prevented the identification of aromatically-derived SOA in ambient samples which, in turn, has prevented observation-based measurements of the aromatic and other SOA contributions to ambient PM levels.

As a first step in determining the ambient SOA concentrations, EPA has developed a tracer-based method to estimate such concentrations.[240,241] The method is based on using mass fractions of SOA tracer compounds, measured in smog chamber-generated SOA samples, to convert ambient concentrations of SOA tracer compounds to ambient SOA concentrations. This method consists of irradiating the SOA precursor of interest in a smog chamber in the presence of NO_x, collecting the SOA produced on filters, and then analyzing the samples for highly polar compounds using advanced analytical chemistry methods. Employing this method, candidate tracers have been identified for several VOC compounds which are emitted in significant quantities and known to produce SOA in the atmosphere. Some of these SOA-forming compounds include toluene, a variety of monoterpenes, isoprene, and β-caryophyllene, the latter three of which are emitted by vegetation and are more significant sources of SOA than toluene. Smog chamber work can also be used to investigate SOA chemical formation mechanisms.[242,243,244,245]

Although these concentrations are only estimates, due to the assumption that the mass fractions of the smog chamber SOA samples using these tracers are equal to those in the ambient atmosphere, there are presently no other means available for estimating the SOA concentrations originating from individual SOA precursors. Among the tracer compounds observed in ambient $PM_{2.5}$ samples are two tracer compounds that have been identified in smog chamber aromatic SOA samples.[246] To date, these aromatic tracer compounds have been identified, in the laboratory, for toluene and *m*-xylene SOA. Additional work is underway by the EPA to determine whether these tracers are also formed by benzene and other alkylbenzenes (including *o*-xylene, *p*-xylene, 1,2,4-trimethylbenzene, and ethylbenzene).

One caveat regarding this work is that a large number of VOCs emitted into the atmosphere, which have the potential to form SOA, have not yet been studied in this way. It is possible that these unstudied compounds produce SOA species which are being used as tracers for other VOCs. This means that the present work could overestimate the amount of SOA formed in the atmosphere by the VOCs studied to date. This approach may also estimate entire hydrocarbon classes (e.g., all methylsubstituted-monoaromatics or all monoterpenes) and not individual precursor hydrocarbons. Thus the tracers could be broadly representative and not indicative of individual precursors. This is still unknown. Also, anthropogenic precursors play a role in formation of atmospheric radicals and aerosol acidity, and these factors influence SOA formation from biogenic hydrocarbons. This anthropogenic and biogenic interaction, important to EPA and others, needs further study. The issue of SOA formation from aromatic precursors is an important one to which EPA and others are paying significant attention. For benzene, smog chamber studies show that benzene forms SOA possibly through reactions with NO_x. Early smog chamber work suggests benzene might be relatively inert in forming SOA, although this study may not be conclusive.[247] However, more recent work shows that benzene does form SOA in smog chambers.[248,249] This new smog chamber work shows that benzene can be oxidized in the presence of NO_X to form SOA with maximum mass of SOA being 8-25% of the mass of benzene. As mentioned above, work is needed to determine if a tracer compound can be found for benzene SOA which might indicate how much of ambient SOA comes from benzene.

The aromatic tracer compounds and their mass fractions have also been used to estimate monthly ambient aromatic SOA concentrations from March 2004 to February 2005 in five U.S. Midwestern cities.[250] The annual tracer-based SOA concentration estimates were

0.15, 0.18, 0.13, 0.15, and 0.19 μg carbon/m^3 for Bondville, IL, East St. Louis, IL, Northbrook, IL, Cincinnati, OH and Detroit, MI, respectively, with the highest concentrations occurring in the summer. On average, the aromatic SOA concentrations made up 17 % of the total SOA concentration. Thus, this work suggests that we are finding ambient PM levels on an annual basis of about 0.15 μg/m^3 associated with present toluene levels in the ambient air in these Midwest cities. Based on preliminary analysis of recent laboratory experiments, it appears the toluene tracer could also be formed during photooxidation of some of the xylenes.[251]

Over the past decade a variety of modeling studies have been conducted to predict ambient SOA levels, with most studies focusing on the contributions of biogenic monoterpenes and anthropogenic aromatic hydrocarbons. More recently, modelers have begun to include the contribution of the isoprene SOA to ambient OC concentrations.[252] In general, the studies have been limited to comparing the sum of the POA and SOA concentrations with ambient OC concentrations. The general consensus in the atmospheric chemistry community appears to be that monoterpene contributions, which are clearly significant, and the somewhat smaller aromatic contributions, are insufficient to account for observed ambient SOA levels.[253] Part of this gap has been filled recently by SOA predictions for isoprene. Furthermore, the identification in ambient SOA of a tracer compound for the sesquiterpene β-caryophyllene,[254] coupled with the high sesquiterpene SOA yields measured in the laboratory,[255] suggests this class of hydrocarbons should be included in SOA chemical mechanisms. In addition, recent data on SOA formation from aromatic hydrocarbons suggest their contributions, while much smaller than biogenic hydrocarbons, could be larger than previously thought.[256,257]

7.2.1.2.3 Ozone

As mentioned above, the addition of ethanol to fuels has been shown to contribute to PAN formation and this is one way for it to contribute therefore to ground-level ozone formation. PAN is a reservoir and carrier of NO_X and is the product of acetyl radicals reacting with NO_2 in the atmosphere. One source of PAN is the photooxidation of acetaldehyde (Section 7.2.1.2.1), but any hydrocarbon having a methyl group has the potential for forming acetyl radicals and therefore PAN.[V] PAN can undergo thermal decomposition with a lifetime of approximately 1 hour at 298K or 148 days at 250K.[W]

$$\mathbf{CH_3C(O)OONO_2} + M \rightarrow CH_3C(O)OO\cdot + \mathbf{NO_2} + M \qquad k = 3.3 \times 10^{-4}\ s^{-1}$$ [258]

[V] Many aromatic hydrocarbons, particularly those present in high percentages in gasoline (toluene, m-, o-, p-xylene, and 1,3,5-, 1,2,4-trimethylbenzene), form methylglyoxal and biacetyl, which are also strong generators of acetyl radicals (Smith, D.F., T.E. Kleindienst, C.D. McIver (1999) Primary product distribution from the reaction of OH with m-, p-xylene and 1,2,4- and 1,3,5-Trimethylbenzene. J. Atmos. Chem., 34: 339- 364.).
[W] All rate coefficients in this RIA are listed at 298 K and, if applicable, 1 bar of air.

The reaction above shows how NO_2 is released in the thermal decomposition of PAN. NO_2 can also be formed in photodegradation reactions where NO is converted to NO_2 (see OH radical reaction of acetaldehyde in Section 3.4.1.2.1). In both cases, NO_2 further photolyzes to produce ozone (O_3).

$\mathbf{NO_2} + h\nu \rightarrow NO + O(^3P)$ $\lambda = 300\text{-}800$ nm [259]

$O(^3P) + O_2 + M \rightarrow \mathbf{O_3} + M$

The temperature sensitivity of PAN allows it to be stable enough at low temperatures to be transported long distances before decomposing to release NO_2. NO_2 can then participate in ozone formation in regions remote from the original NO_X source.[260] A discussion of CB05 mechanisms for ozone formation can be found in Yarwood et al. (2005).[261]

7.2.1.3 Modeling Uncertainties and Limitations

All the results presented below must be interpreted with the understanding that there are uncertainties in inventories, atmospheric processes in CMAQ, and other aspects of the modeling process. While it is beyond the scope of this Regulatory Impact Analysis to include a comprehensive discussion of all limitations and uncertainties associated with air quality modeling, several sources of uncertainty that impact analyses for this rule are addressed.

A key source of uncertainty is the photochemical mechanisms in CMAQ 4.7. Pollutants such as ozone, PM, acetaldehyde, formaldehyde, acrolein, and 1,3-butadiene can be formed secondarily through atmospheric chemical processes. Since secondarily formed pollutants can result from many different reaction pathways, there are uncertainties associated with each pathway. Simplifications of chemistry must be made in order to handle reactions of thousands of chemicals in the atmosphere. Mechanisms for formation of ozone, PM, acetaldehyde and peroxyacetyl nitrate (PAN) are discussed in Section 7.2.1.2.

For PM, there are a number of uncertainties associated with SOA formation that should be addressed explicitly. As mentioned in Section 7.2.1.2.2, a large number of VOCs emitted into the atmosphere, which have the potential to form SOA, have not yet been studied in detail. In addition, the amount of ambient SOA that comes from benzene is uncertain. Simplifications to the SOA treatment in CMAQ have also been made in order to preserve computational efficiency. These simplifications are described in release notes for CMAQ 4.7 on the Community Modeling and Analysis System (CMAS) website.[262]

7.2.2 Air Quality Modeling Results

As described above, we performed a series of air quality modeling simulations for the continental U.S in order to assess the impacts of the vehicle rule. We looked at impacts on future ambient $PM_{2.5}$, ozone, ethanol and air toxics levels, as well as nitrogen and sulfur deposition levels and visibility impairment. In this section, we present information on current levels of pollution as well as model projected levels of pollution for 2030.

Emissions and air quality modeling decisions are made early in the analytical process. For this reason, the inventories used in the air quality modeling and the benefits modeling, which are presented in Section 5.8, are slightly different than the final vehicle standard inventories presented in Section 5.5. However, the air quality inventories and the final rule inventories are generally consistent, so the air quality modeling adequately reflects the effects of the rule.

7.2.2.1 Particulate Matter ($PM_{2.5}$ and PM_{10})

As described in Section 7.1, PM causes adverse health effects, and the EPA has set national ambient air quality standards (NAAQS) to protect against those health effects. In this section we present information on current and model-projected future PM levels.

7.2.2.1.1 Current Levels of PM

Figure 7-4 and Figure 7-5 show a snapshot of annual and 24-hour $PM_{2.5}$ concentrations in 2008. There are two National Ambient Air Quality Standards (NAAQS) for $PM_{2.5}$: an annual standard (15 $\mu g/m^3$) and a 24-hour standard (35 $\mu g/m^3$). In 2008, the highest annual average $PM_{2.5}$ concentrations were in California, Arizona, and Hawaii and the highest 24-hour $PM_{2.5}$ concentrations were in California and Virginia.

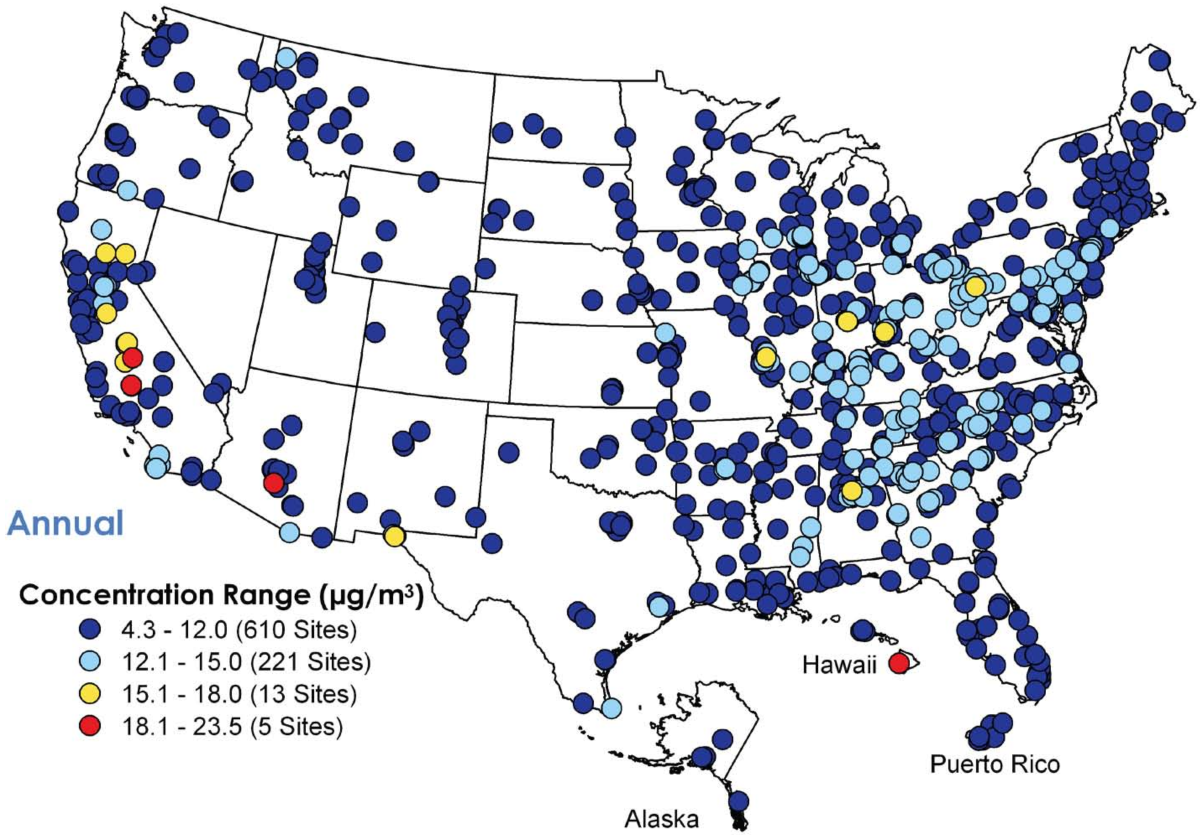

Figure 7-4 Annual Average $PM_{2.5}$ Concentrations in µg/m^3 for 2008[X]

[X] From U.S. EPA, 2010. Our Nation's Air: Status and Trends through 2008. EPA-454/R-09-002. February 2010. Available at: http://www.epa.gov/airtrends/2010/index.html.

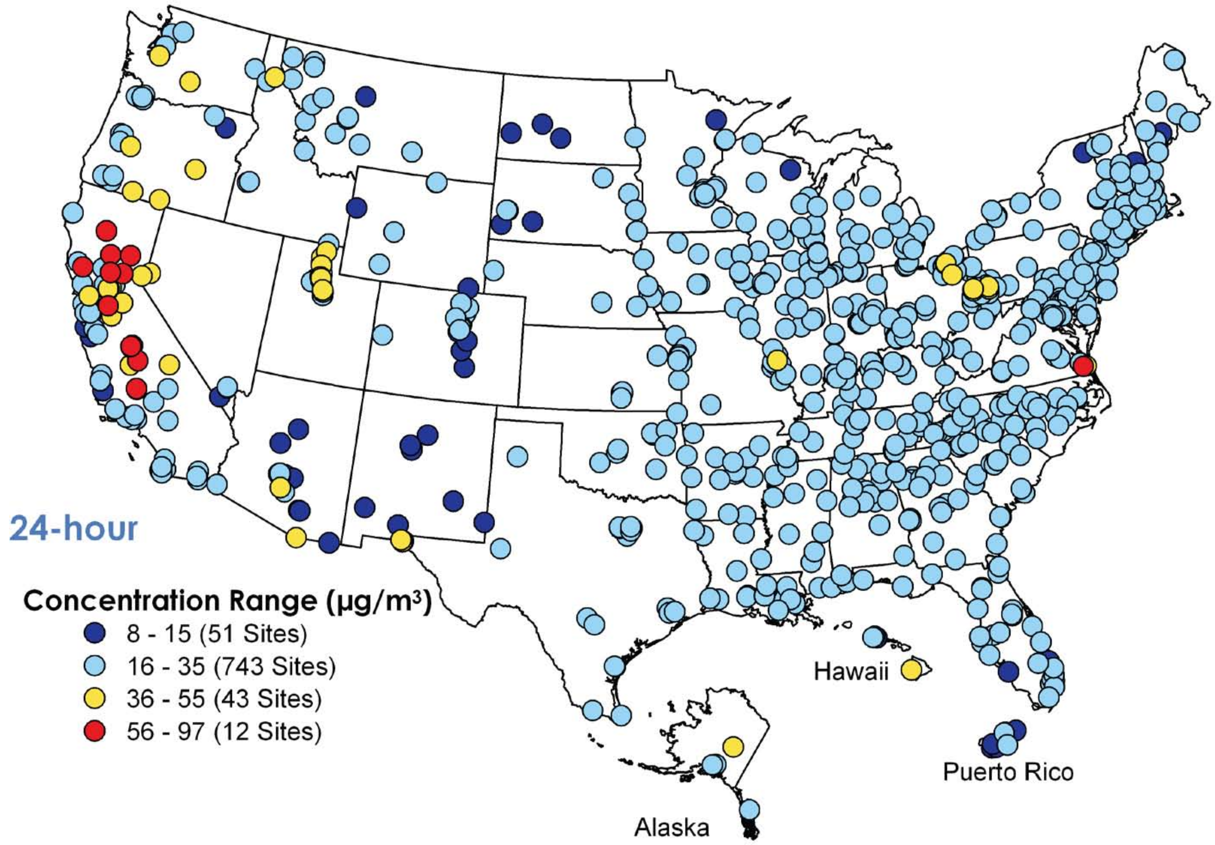

Figure 7-5 24-hour (98th percentile 24- hour concentrations) $PM_{2.5}$ Concentrations in µg/m^3 for 2008[Y]

The most recent revisions to the PM 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).[Z] As of January 6, 2010, approximately 88 million people live in the 39 areas that are designated as nonattainment for the 1997 $PM_{2.5}$ National Ambient Air Quality Standard (NAAQS). These $PM_{2.5}$ nonattainment areas are comprised of 208 full or partial counties. Nonattainment areas for the 1997 $PM_{2.5}$ NAAQS are pictured in Figure 7-6. On October 8, 2009, the EPA issued final nonattainment area designations for the 2006 24-hour $PM_{2.5}$ NAAQS (74 FR 58688, November 13, 2009). These designations include 31 areas composed

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[Y] From U.S. EPA, 2010. Our Nation's Air: Status and Trends through 2008. EPA-454/R-09-002. February 2010. Available at: http://www.epa.gov/airtrends/2010/index.html.

[Z] 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.

of 120 full or partial counties with a population of over 70 million. Nonattainment areas for the 2006 $PM_{2.5}$ NAAQS are pictured in Figure 7-7. In total, there are 54 $PM_{2.5}$ nonattainment areas composed of 243 counties with a population of almost 102 million people.

States with $PM_{2.5}$ nonattainment areas will be required to take action to bring those areas into compliance in the future. Most 1997 $PM_{2.5}$ nonattainment areas will be 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.[263] 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.[264] The vehicle standards finalized here first apply to model year 2012 vehicles.

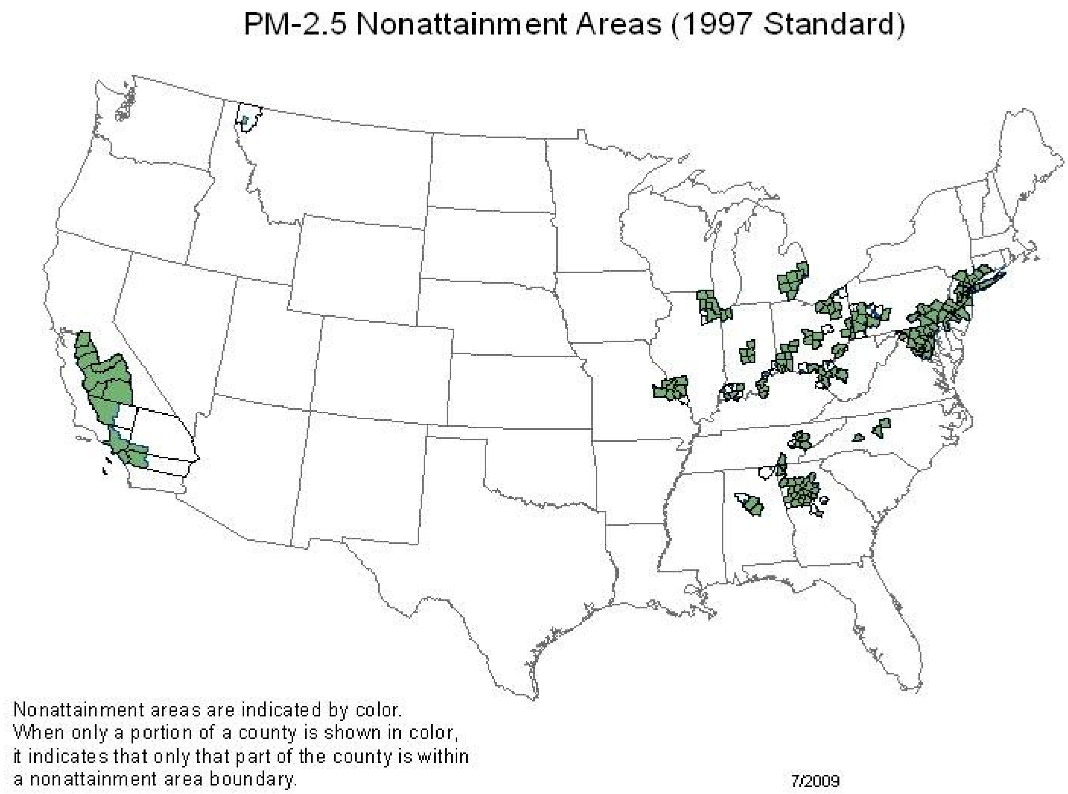

Figure 7-6 1997 $PM_{2.5}$ Nonattainment Areas

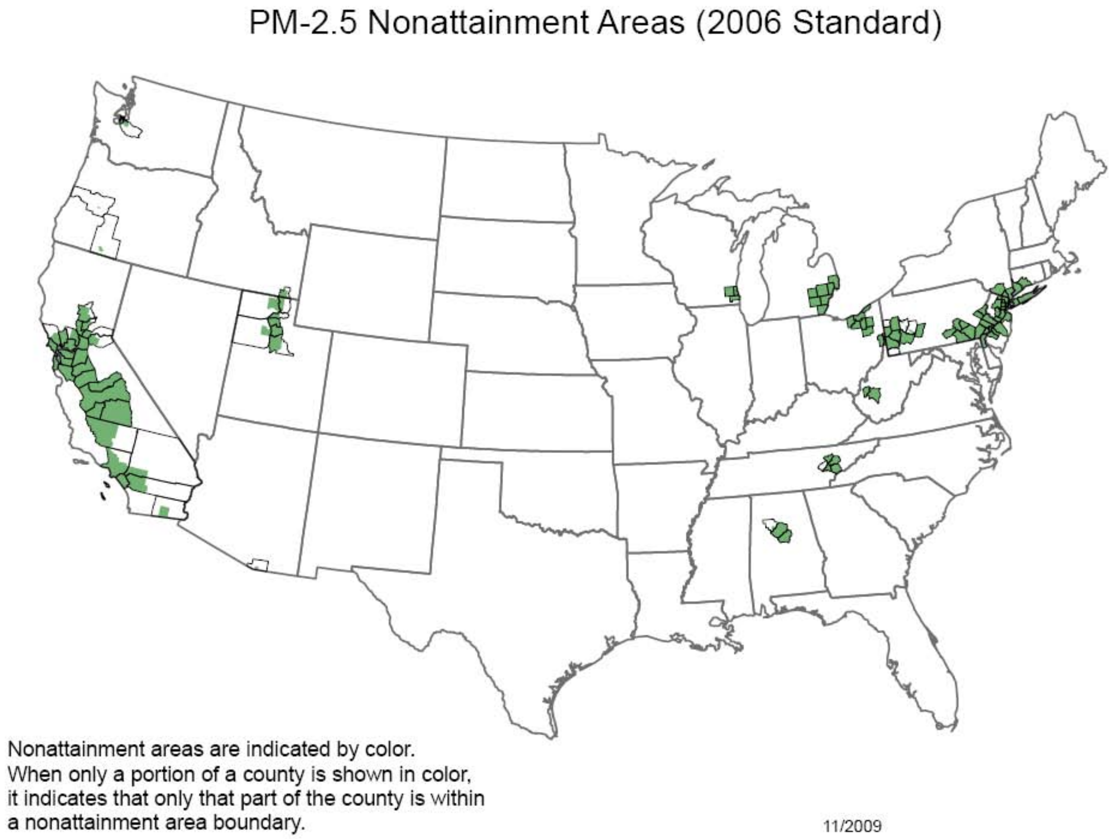

Figure 7-7 2006 $PM_{2.5}$ Nonattainment Areas

As of January 6, 2010, approximately 26 million people live in the 47 areas that are designated as nonattainment for the PM_{10} NAAQS. There are 40 full or partial counties that make up the PM_{10} nonattainment areas. Nonattainment areas for the PM_{10} NAAQS are pictured in Figure 7-8.

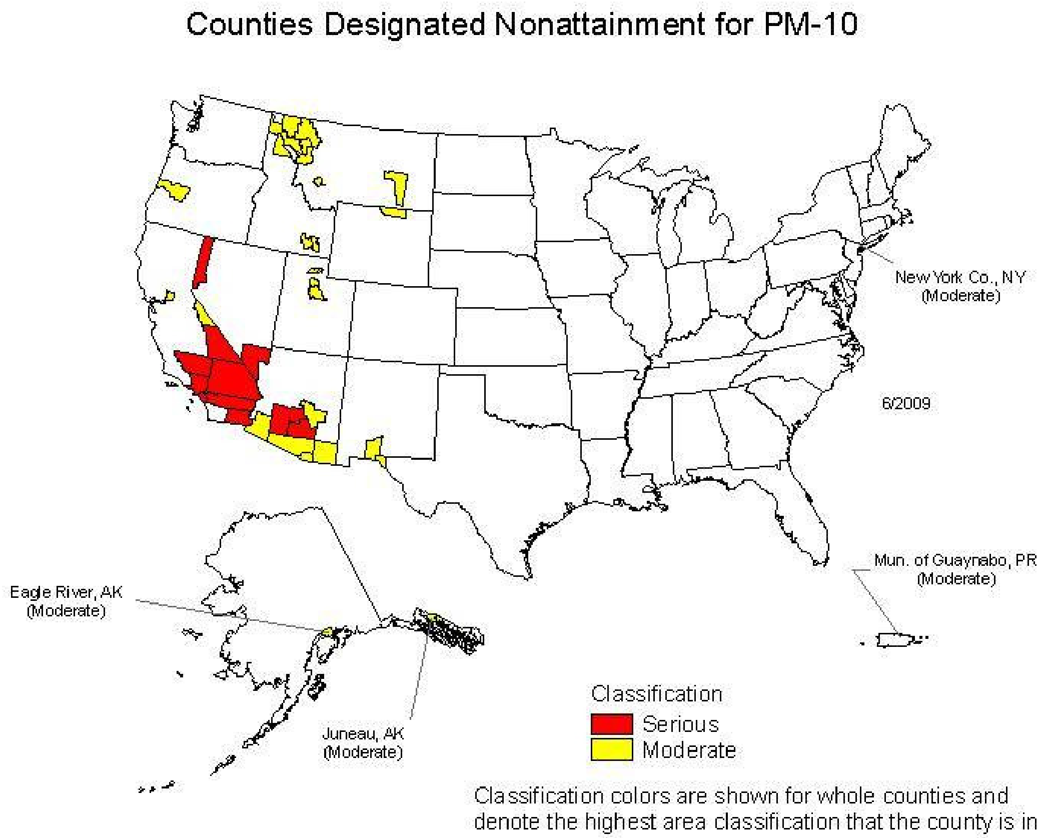

Figure 7-8 PM_{10} Nonattainment Areas

7.2.2.1.2 Projected Levels of $PM_{2.5}$

Generally, our modeling indicates that the vehicle standards will reduce $PM_{2.5}$ concentrations in some localized areas of the country. In the following sections we describe projected $PM_{2.5}$ levels in the future, with and without the vehicle standards. Information on the air quality modeling methodology is contained in Section 7.2.1.1. Additional detail can be found in the air quality modeling technical support document (AQM TSD).

7.2.2.1.2.1 Projected Levels of $PM_{2.5}$ without this Rule

EPA has already adopted many mobile source emission control programs that are expected to reduce ambient PM levels. These control programs include the New Marine Compression-Ignition Engines at or Above 30 Liters per Cylinder rule,[AA] the Marine Spark-Ignition and Small Spark-Ignition Engine rule (73 FR 59034, October 8, 2008), the Locomotive and Marine Compression-Ignition Engine Rule (73 FR 25098, May 6, 2008), the Clean Air Nonroad Diesel rule (69 FR 38957, June 29, 2004), the Heavy Duty Engine and Vehicle Standards and Highway Diesel Fuel Sulfur Control Requirements (66 FR 5002, Jan. 18, 2001) and the Tier 2 Motor Vehicle Emissions Standards and Gasoline Sulfur Control Requirements (65 FR 6698, Feb. 10, 2000). As a result of these and other federal, state and local programs, the number of areas that fail to meet the $PM_{2.5}$ NAAQS in the future is expected to decrease. However, even with the implementation of all current state and federal regulations, there are projected to be counties violating the $PM_{2.5}$ NAAQS well into the future.

The air quality modeling conducted projects that in 2030, with all current controls in effect but excluding the emissions changes expected to occur as a result of the vehicle standards being finalized here, at least 9 counties, with a projected population of nearly 28 million people, may not attain the annual standard of 15 $\mu g/m^3$ and at least 26 counties, with a projected population of over 41 million people, may not attain the 2006 24-hour standard of 35 $\mu g/m^3$. Since the emission changes from this rule go into effect during the period when some areas are still working to attain the $PM_{2.5}$ NAAQS, the projected emission changes will impact state and local agencies in their effort to attain and maintain the $PM_{2.5}$ standard. In the following section we discuss projected nonattainment areas and how they compare to the areas which are projected to experience $PM_{2.5}$ reductions or increases from the vehicle standards.

7.2.2.1.2.2 Projected Annual Average $PM_{2.5}$ Design Values with this Rule

This section summarizes the results of our modeling of annual average $PM_{2.5}$ air quality impacts in the future due to the vehicle standards. Specifically, we compare a 2030 reference scenario, a scenario without the vehicle standards, to a 2030 control scenario which includes the vehicle standards. Our modeling indicates that the majority of the modeled counties will see decreases of less than 0.05 $\mu g/m^3$ in their annual $PM_{2.5}$ design values due to

[AA] This rule was signed on December 18, 2009 but has not yet been published in the Federal Register. The signed version of the rule is available at http://epa.gov/otaq/oceanvessels.htm).

the vehicle standards. Figure 7-9 presents the changes in annual $PM_{2.5}$ design values in 2030.[BB]

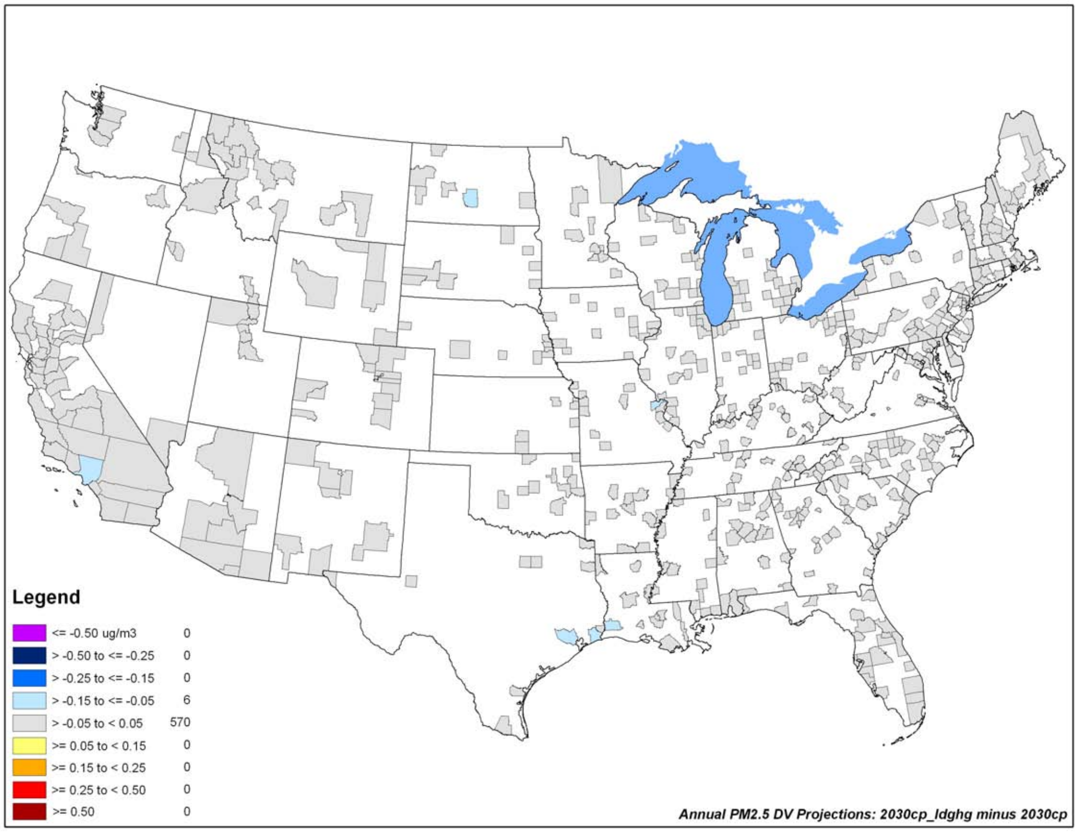

Figure 7-9 Projected Change in 2030 Annual $PM_{2.5}$ Design Values Between the Reference Case and Control Case

As shown in Figure 7-9, six counties will see decreases of more than 0.05 $\mu g/m^3$. These counties are in southern California, central North Dakota, eastern Missouri, southwest Louisiana and the Houston area in Texas. The maximum projected decrease in an annual $PM_{2.5}$ design value is 0.07 $\mu g/m^3$ in Harris County, Texas. The decreases in annual $PM_{2.5}$ design values that we see in some counties are likely due to emission reductions related to lower gasoline production at existing oil refineries; reductions in direct $PM_{2.5}$ emissions and $PM_{2.5}$ precursor emissions (NO_X and SO_X) contribute to reductions in ambient concentrations

[BB] An annual $PM_{2.5}$ design value is the concentration that determines whether a monitoring site meets the annual NAAQS for $PM_{2.5}$. The full details involved in calculating an annual $PM_{2.5}$ design value are given in appendix N of 40 CFR part 50.

of both direct $PM_{2.5}$ and secondarily-formed $PM_{2.5}$. Additional information on the upstream emissions reductions that are projected with this final rule is available in Section 5.5.

There are also a few counties that will see small, no more than 0.01 $\mu g/m^3$, design value increases. These small increases in annual $PM_{2.5}$ design values are likely related to downstream emission increases. Additional information on the downstream emissions increases that are projected with this final rule is also available in Section 5.3.3.5.

There are 9 counties, all in California, that are projected to have annual $PM_{2.5}$ design values above the NAAQS in 2030 with the vehicle standards in place. Table 7-2 below presents the changes in design values for these counties.

Table 7-2 Change in Annual PM2.5 Design Values (µg/m3) for Counties Projected to be Above the Annual PM2.5 NAAQS in 2030

County Name	Change in Annual $PM_{2.5}$ Design Value ($\mu g/m^3$)	Population in 2030[a]
Riverside Co., California	-0.02	2,614,198
San Bernardino Co., California	-0.03	2,784,489
Los Angeles Co., California	-0.06	10,742,722
Kern Co., California	-0.01	981,806
Tulare Co., California	-0.01	528,662
Orange Co., California	-0.03	4,431,070
Kings Co., California	0.00	195,067
Fresno Co., California	0.00	1,196,949
San Diego Co., California	0.00	4,399,983

Note:
[a] Population numbers based on Woods & Poole data. Woods & Poole Economics, Inc. 2001. Population by Single Year of Age CD.

Table 7-3 shows the average change in 2030 annual $PM_{2.5}$ design values for: (1) all counties with 2005 baseline design values, (2) counties with 2005 baseline design values that exceeded the annual $PM_{2.5}$ standard, (3) counties with 2005 baseline design values that did not exceed the standard, but were within 10% of it, (4) counties with 2030 design values that exceeded the annual $PM_{2.5}$ standard, and (5) counties with 2030 design values that did not exceed the standard, but were within 10% of it. Counties within 10% of the standard are intended to reflect counties that although not violating the standards, will also be impacted by changes in $PM_{2.5}$ as they work to ensure long-term maintenance of the annual $PM_{2.5}$ NAAQS. These statistics show either no change or a decrease in annual $PM_{2.5}$ design values in 2030.

On a population-weighted basis, the average modeled future-year annual $PM_{2.5}$ design values are projected to decrease by 0.01 $\mu g/m^3$ due to the vehicle standards. On a population-weighted basis annual $PM_{2.5}$ design values in those counties that are projected to be above the annual $PM_{2.5}$ standard in 2030 will see a slightly larger decrease of 0.03 $\mu g/m^3$ due to the vehicle standards.

Table 7-3 Average Change in Projected Annual PM2.5 Design Values

Average[a]	Number of US Counties	2030 Population[b]	Change in 2030 design value ($\mu g/m^3$)
All			0.00
All, population-weighted	576	247,415,381	-0.01
Counties whose 2005 base year is violating the 1997 annual $PM_{2.5}$ standard			0.00
Counties whose 2005 base year is violating the1997 annual $PM_{2.5}$ standard, population-weighted	70	65,106,709	-0.02
Counties whose 2005 base year is within 10 percent of the1997 annual PM2.5 standard			0.00
Counties whose 2005 base year is within 10 percent of the 1997 annual PM2.5 standard, population-weighted	102	33,008,932	0.00
Counties whose 2030 control case is violating the 1997 annual PM2.5 standard			-0.02
Counties whose 2030 control case is violating the 1997 annual PM2.5 standard, population-weighted	9	27,874,946	-0.03
Counties whose 2030 control case is within 10% of the 1997 annual PM2.5 standard			0.00
Counties whose 2030 control case is within 10% of the 1997 annual PM2.5 standard, population-weighted	5	5,864,401	0.00

Note:
[a] Averages are over counties with 2005 modeled design values
b Population numbers based on Woods & Poole data. Woods & Poole Economics, Inc. 2001. Population by Single Year of Age CD.

7.2.2.1.2.3 Projected 24-hour Average $PM_{2.5}$ Design Values with this Rule

This section summarizes the results of our modeling of 24-hour $PM_{2.5}$ air quality impacts in the future due to the vehicle standards. Specifically, we compare a 2030 reference scenario, a scenario without the vehicle standards, to a 2030 control scenario which includes the vehicle standards. Our modeling indicates that the majority of the modeled counties will see changes of between -0.05 µg/m^3 and +0.05 µg/m^3 in their 24-hour $PM_{2.5}$ design values. Figure 7-10 presents the changes in 24-hour $PM_{2.5}$ design values in 2030.[CC]

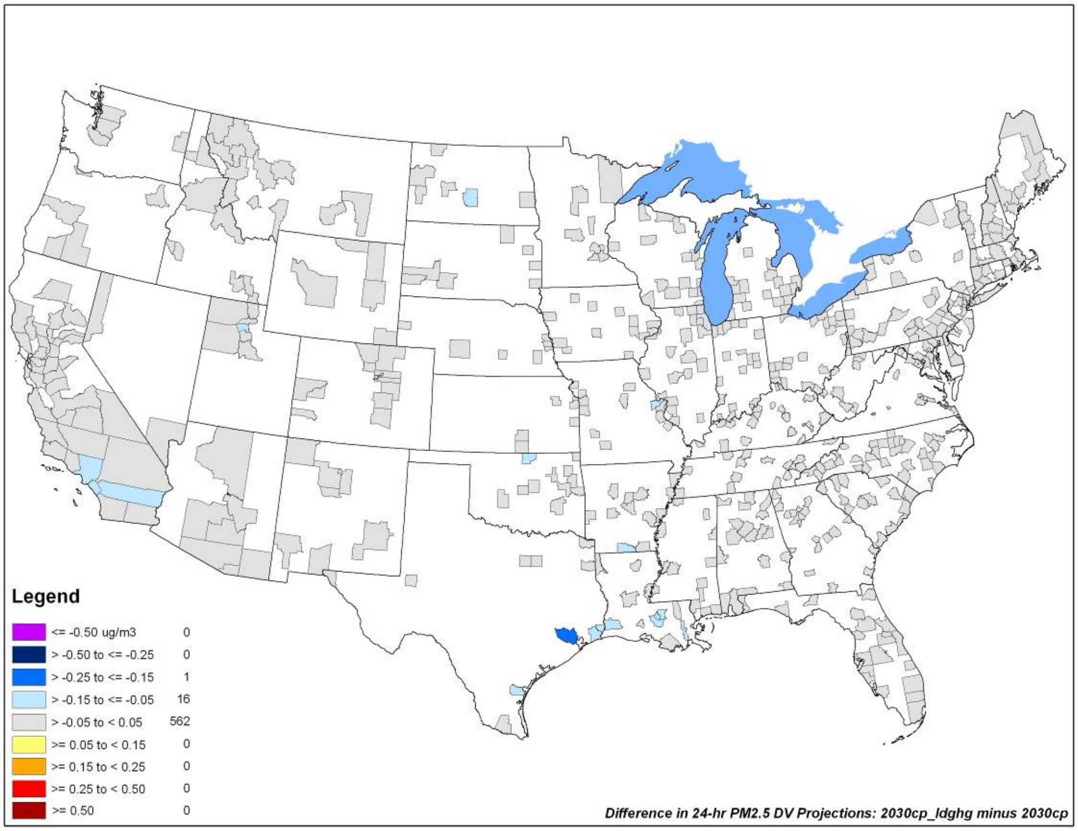

Figure 7-10 Projected Change in 2030 24-hour $PM_{2.5}$ Design Values Between the Reference Case and the Control Case

As shown in Figure 7-10, 17 counties will see decreases of more than 0.05 µg/m^3. These counties are in southern California, northern Utah, central North Dakota, eastern Missouri, southern Arkansas, northern Oklahoma, southwest Louisiana and the Houston area in Texas. The maximum projected decrease in a 24-hour $PM_{2.5}$ design value is 0.21 µg/m^3 in Harris County, Texas. The decreases in 24-hour $PM_{2.5}$ design values that we see in some counties are likely due to emission reductions related to lower gasoline production at existing

[CC] A 24-hour $PM_{2.5}$ design value is the concentration that determines whether a monitoring site meets the 24-hour NAAQS for $PM_{2.5}$. The full details involved in calculating a 24-hour $PM_{2.5}$ design value are given in appendix N of 40 CFR part 50.

oil refineries; reductions in direct $PM_{2.5}$ emissions and $PM_{2.5}$ precursor emissions (NO_X and SO_X) contribute to reductions in ambient concentrations of both direct $PM_{2.5}$ and secondarily-formed $PM_{2.5}$. Additional information on the upstream emissions reductions that are projected with this final rule is available in Section 5.5.

There are also some counties that will see small, less than 0.05 $\mu g/m^3$, design value increases. These small increases in 24-hour $PM_{2.5}$ design values are likely related to downstream emissions increases.

There are 26 counties, mainly in California, that are projected to have 24-hour $PM_{2.5}$ design values above the NAAQS in 2030 with the vehicle standards in place. Table 7-4 below presents the changes in design values for these counties.

Table 7-4 Change in 24-hour $PM_{2.5}$ Design Values ($\mu g/m^3$) for Counties Projected to be Above the 24-hour $PM_{2.5}$ NAAQS in 2030

County Name	Change in 24-hour $PM_{2.5}$ Design Value ($\mu g/m^3$)	Population in 2030[a]
Riverside Co., California	-0.05	2,614,198
Kern Co., California	-0.02	981,806
Allegheny Co., Pennsylvania	0.04	1,234,931
Fresno Co., California	-0.01	1,196,950
San Bernardino Co., California	-0.02	2,784,490
Los Angeles Co., California	-0.10	10,742,722
Kings Co., California	-0.01	195,067
Tulare Co., California	0.00	528,663
Lane Co., Oregon	0.00	460,993
Sacramento Co., California	-0.01	1,856,971
Cache Co., Utah	0.01	141,446
Salt Lake Co., Utah	-0.02	1,431,946
Orange Co., California	-0.09	4,431,071
Butte Co., California	0.00	287,236
Stanislaus Co., California	-0.01	688,246
Klamath Co., Oregon	0.00	77,200
Utah Co., Utah	0.04	661,456
Lincoln Co., Montana	0.00	20,454
Pierce Co., Washington	0.03	1,082,579
Santa Clara Co., California	-0.01	2,320,199
Merced Co., California	0.00	313,334
Imperial Co., California	0.00	174,175
Wayne Co., Michigan	-0.01	1,838,270
San Diego Co., California	-0.02	4,399,983
Milwaukee Co., Wisconsin	0.00	927,986
Brooke Co., West Virginia	0.00	24,095

Note:
[a] Population numbers based on Woods & Poole data. Woods & Poole Economics, Inc. 2001. Population by Single Year of Age CD.

Table 7-5 shows the average change in 2030 24-hour $PM_{2.5}$ design values for: (1) all counties with 2005 baseline design values, (2) counties with 2005 baseline design values that exceeded the 24-hour $PM_{2.5}$ standard, (3) counties with 2005 baseline design values that did not exceed the standard, but were within 10% of it, (4) counties with 2030 design values that exceeded the 24-hour $PM_{2.5}$ standard, and (5) counties with 2030 design values that did not exceed the standard, but were within 10% of it. Counties within 10% of the standard are intended to reflect counties that although not violating the standards, will also be impacted by changes in $PM_{2.5}$ as they work to ensure long-term maintenance of the 24-hour $PM_{2.5}$ NAAQS. On a population-weighted basis, the average modeled future-year 24-hour $PM_{2.5}$ design values are projected to decrease by 0.01 $\mu g/m^3$ due to the vehicle standards. On a population-weighted basis 24-hour $PM_{2.5}$ design values in those counties that are projected to be above the 24-hour $PM_{2.5}$ standard in 2030 will see a slightly larger decrease of 0.05 $\mu g/m^3$.

Table 7-5 Average Change in Projected 24-hour $PM_{2.5}$ Design Values

Average[a]	Number of US Counties	2030 Population[b]	Change in 2030 design value ($\mu g/m^3$)
All			0.00
All, population-weighted	579	247,228,608	-0.01
Counties whose 2005 base year is violating the 2006 24-hour $PM_{2.5}$ standard			0.00
Counties whose 2005 base year is violating the 2006 24-hour $PM2_{.5}$ standard, population-weighted	105	86,013,770	-0.02
Counties whose 2005 base year is within 10 percent of the 2006 24-hour PM2.5 standard			0.00
Counties whose 2005 base year is within 10 percent of the 2006 24-hour PM2.5 standard, population-weighted	139	53,848,276	0.00
Counties whose 2030 control case is violating the 2006 24-hour PM2.5 standard			-0.01
Counties whose 2030 control case is violating the 2006 24-hour PM2.5 standard, population-weighted	26	41,416,465	-0.05
Counties whose 2030 control case is within 10% of the 2006 24-hour PM2.5 standard			0.00
Counties whose 2030 control case is within 10% of the 2006 24-hour PM2.5 standard, population-weighted	24	18,526,165	0.01

Note:
[a] Averages are over counties with 2005 modeled design values
[b] Population numbers based on Woods & Poole data. Woods & Poole Economics, Inc. 2001. Population by Single Year of Age CD.

7.2.2.2 Ozone

As described in Section 7.1, ozone causes adverse health effects, and the EPA has set national ambient air quality standards (NAAQS) to protect against those health effects. In this section, we present information on current and model-projected future ozone levels.

7.2.2.2.1 Current Levels of Ozone

Figure 7-11 shows a snapshot of ozone concentrations in 2007. The highest ozone concentrations were located in California. Thirty-two percent of the sites were above 0.075 ppm, the level of the 2008 standard.

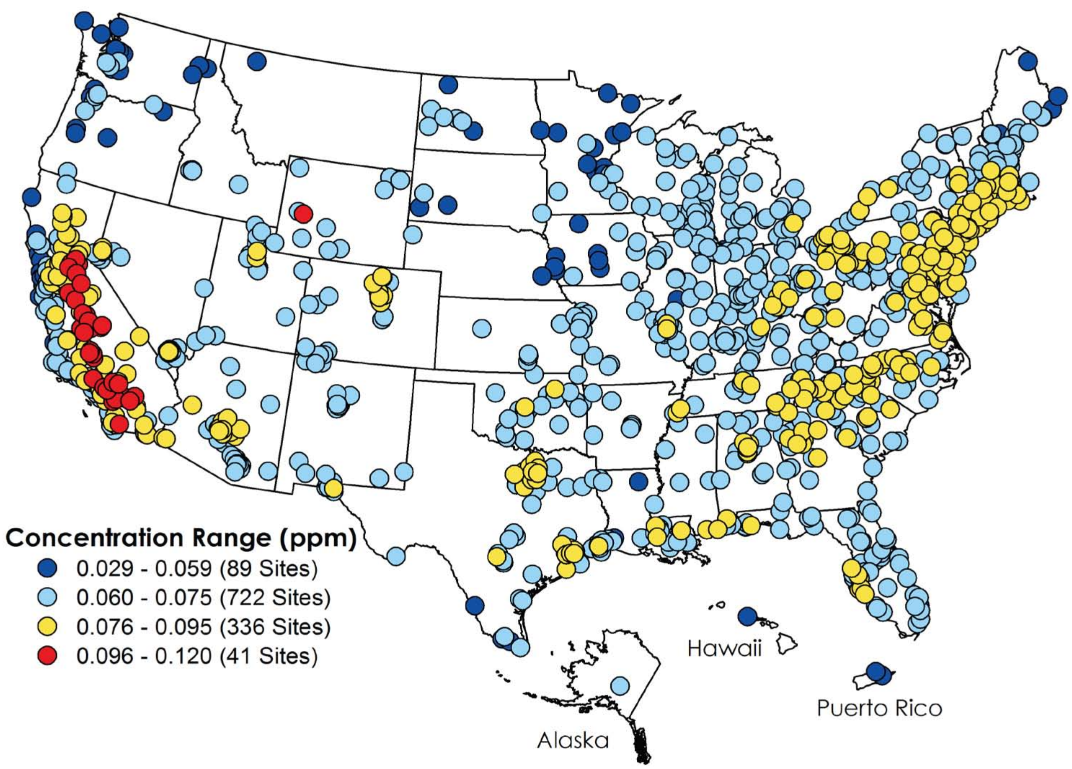

Figure 7-11 Ozone Concentrations (fourth highest daily maximum 8-hour concentration) in ppm for 2008[DD]

[DD] From U.S. EPA, 2010. Our Nation's Air: Status and Trends through 2008. EPA-454/R-09-002. February 2010. Available at: http://www.epa.gov/airtrends/2010/index.html.

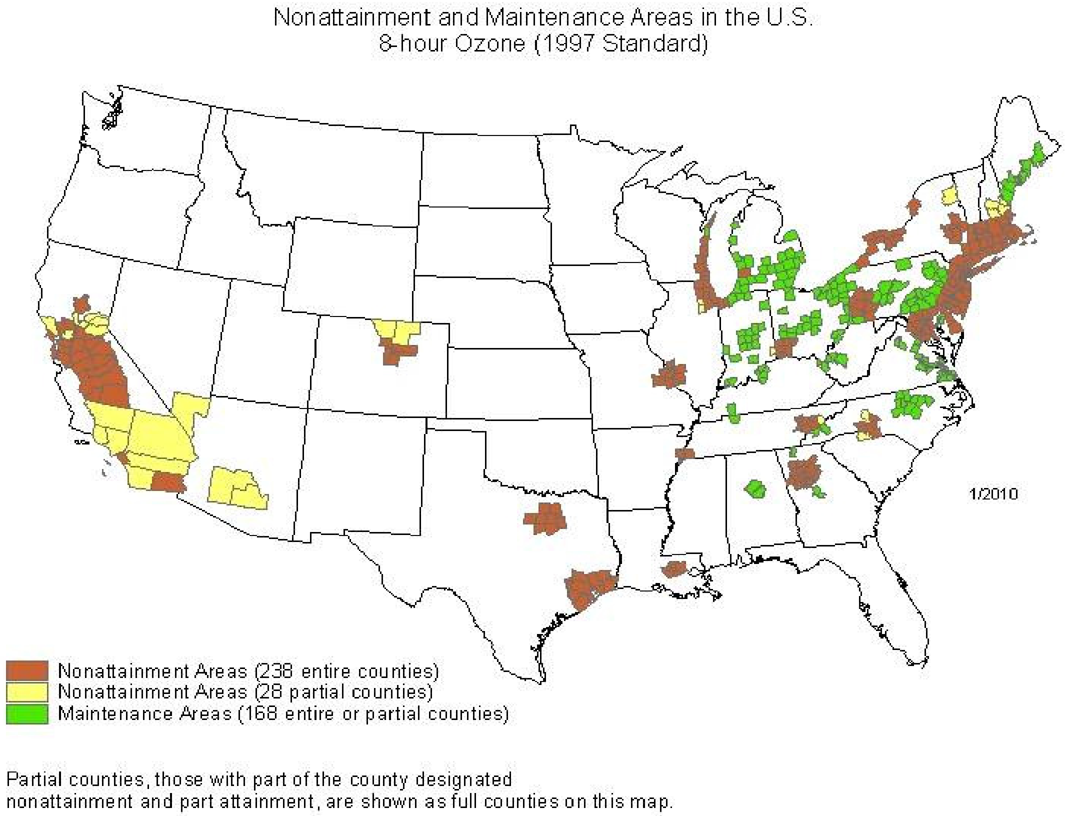

Figure 7-12 1997 Ozone Nonattainment Areas

The primary and secondary national ambient air quality standards (NAAQS) for ozone are 8-hour standards set at 0.075 ppm. The most recent revision to the ozone standards was in 2008; the previous 8-hour ozone standards, set in 1997, had been set at 0.08 ppm. In 2004, the U.S. EPA designated nonattainment areas for the 1997 8-hour ozone NAAQS (69 FR 23858, April 30, 2004). As of January 6, 2010, there are 51 8-hour ozone nonattainment areas for the 1997 ozone NAAQS composed of 266 full or partial counties with a total population of over 122 million. Figure 7-12 presents the 1997 NAAQS ozone nonattainment areas. On January 6, 2010, EPA proposed to reconsider the 2008 ozone NAAQS to ensure that they are requisite to protect public health with an ample margin of safety, and requisite to protect public welfare. EPA intends to complete the reconsideration by August 31, 2010. If, as a result of the reconsideration, EPA promulgates different ozone standards, the new 2010 ozone standards would replace the 2008 ozone standards and the requirement to designate areas for the replaced 2008 standards would no longer apply. Because of the significant uncertainty the reconsideration proposal creates regarding the continued applicability of the 2008 ozone NAAQS, EPA has extended the deadline for designating areas for the 2008 NAAQS by one year. This will allow EPA to complete its reconsideration of the 2008 ozone NAAQS before determining whether designations for those standards are necessary.

If EPA promulgates new ozone standards in 2010, EPA intends to accelerate the designations process for the primary standard so that the designations would be effective in August 2011. EPA is considering two alternative schedules for designating areas for a new seasonal secondary standard, an accelerated schedule or a 2-year schedule.

Table 7-6 includes an estimate, based on 2006-08 air quality data, of the counties with design values greater than the 2008 ozone NAAQS.

Table 7-6 Counties with Design Values Greater Than the Ozone NAAQS

	NUMBER OF COUNTIES	POPULATION[A]
1997 Ozone Standard: counties within the 54 areas currently designated as nonattainment (as of 1/6/10)	266	122,343, 799
2008 Ozone Standard: additional counties that would not meet the 2008 NAAQS (based on 2006-2008 air quality data)[b]	156	36,678,478
Total	422	159,022,277

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.

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 be required to maintain it thereafter.[EE] In addition, there will be attainment dates associated with the designation of

[EE] 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 their attainment date June 15, 2024. The San Joaquin Valley Air Basin 8-

nonattainment areas as a result of the reconsideration of the 2008 ozone NAAQS. If the ozone NAAQS reconsideration action is completed on the proposed schedule, the primary NAAQS attainment dates would be in the 2014-2031 time frame. The vehicle standards first apply to model year 2012 vehicles.

7.2.2.2.2 Projected Levels of Ozone

In the following sections, we describe projected ozone levels in the future with and without the vehicle standards. We do not expect this rule to have a meaningful impact on ozone concentrations, given the small magnitude of the ozone impacts and the fact that much of the impact is due to ethanol assumptions that are independent of this rule. Our modeling indicates that there will be increases in ozone design value concentrations in many areas of the country and decreases in ozone design value concentrations in a few areas. However, the increases in ozone design values are not due to the standards finalized in this rule, but are related to our assumptions about the volume of ethanol that will be blended into gasoline. The ethanol volumes will be occurring as a result of the recent Renewable Fuel Standards (RFS2) rule.[265] Information on the air quality modeling methodology is contained in Section 7.2.1.1. Additional detail can be found in the air quality modeling technical support document (AQM TSD).

7.2.2.2.2.1 Projected Levels of Ozone without this Rule

EPA has already adopted many emission control programs that are expected to reduce ambient ozone levels. These control programs include the New Marine Compression-Ignition Engines at or Above 30 Liters per Cylinder rule,[FF] the Marine Spark-Ignition and Small Spark-Ignition Engine rule (73 FR 59034, October 8, 2008), the Locomotive and Marine Rule (73 FR 25098, May 6, 2008), the Clean Air Interstate Rule (70 FR 25162, May 12, 2005), the Clean Air Nonroad Diesel rule (69 FR 38957, June 29, 2004), and the Heavy Duty Engine and Vehicle Standards and Highway Diesel Fuel Sulfur Control Requirements (66 FR 5002, Jan. 18, 2001). As a result of these and other federal, state and local programs, 8-hour ozone levels are expected to improve in the future. However, even with the implementation of all current state and federal regulations, there are projected to be counties violating the ozone NAAQS well into the future.

The air quality modeling projects that in 2030, with all current controls in effect but excluding the emissions changes expected to occur as a result of this final rule, at least 16

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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 their attainment date June 15, 2024.

[FF] This rule was signed on December 18, 2009 but has not yet been published in the Federal Register. The signed version of the rule is available at http://epa.gov/otaq/oceanvessels.htm).

counties, with a projected population of almost 35 million people, may not attain the 2008 8-hour ozone standard of 75 ppb. Since the emission changes from this rule go into effect during the period when some areas are still working to attain the ozone NAAQS, the projected emission changes will impact state and local agencies in their effort to attain and maintain the ozone standard. In the following section we discuss projected nonattainment areas and how they compare to the areas which are projected to experience ozone reductions from the vehicle standards.

7.2.2.2.2.2 Projected Levels of Ozone with this Rule

This section summarizes the results of our modeling of ozone air quality impacts in the future with the vehicle standards. Specifically, we compare a 2030 reference scenario, a scenario without the vehicle standards, to a 2030 control scenario which includes the vehicle standards. We do not expect this rule to have a meaningful impact on ozone concentrations, given the small magnitude of the ozone impacts and the fact that much of the impact is due to ethanol assumptions that are independent of this rule.

Our modeling indicates ozone design value concentrations will increase in many areas of the country and decrease in a few areas. The increases in ozone design values are not due to the standards finalized in this rule, but are related to our assumptions about the volume of ethanol that will be blended into gasoline. The ethanol volumes will be occurring as a result of the recent RFS2 rule. As discussed in Sections 5.3.2 and 5.3.3.5 of this RIA, we attribute decreased fuel consumption and production from this program to gasoline only, while assuming constant ethanol volumes in our reference and control cases. Holding ethanol volumes constant while decreasing gasoline volumes increases the market share of 10% ethanol (E10) in the control case. However, the increased E10 market share is projected to occur regardless of this rule, and the air quality impacts of this effect are included in our analyses for the recent RFS2 rule. As the RFS2 analyses indicate, increasing usage of E10 fuels (when compared with E0 fuels) can increase NO_X emissions and thereby increase ozone concentrations, especially in NO_X-limited areas where relatively small amounts of NO_X enable ozone to form rapidly.[266] Figure 7-13 presents the changes in 8-hour ozone design value concentration in 2030 between the reference case and the control case.[GG]

[GG] An 8-hour ozone design value is the concentration that determines whether a monitoring site meets the 8-hour ozone NAAQS. The full details involved in calculating an 8-hour ozone design value are given in appendix I of 40 CFR part 50.

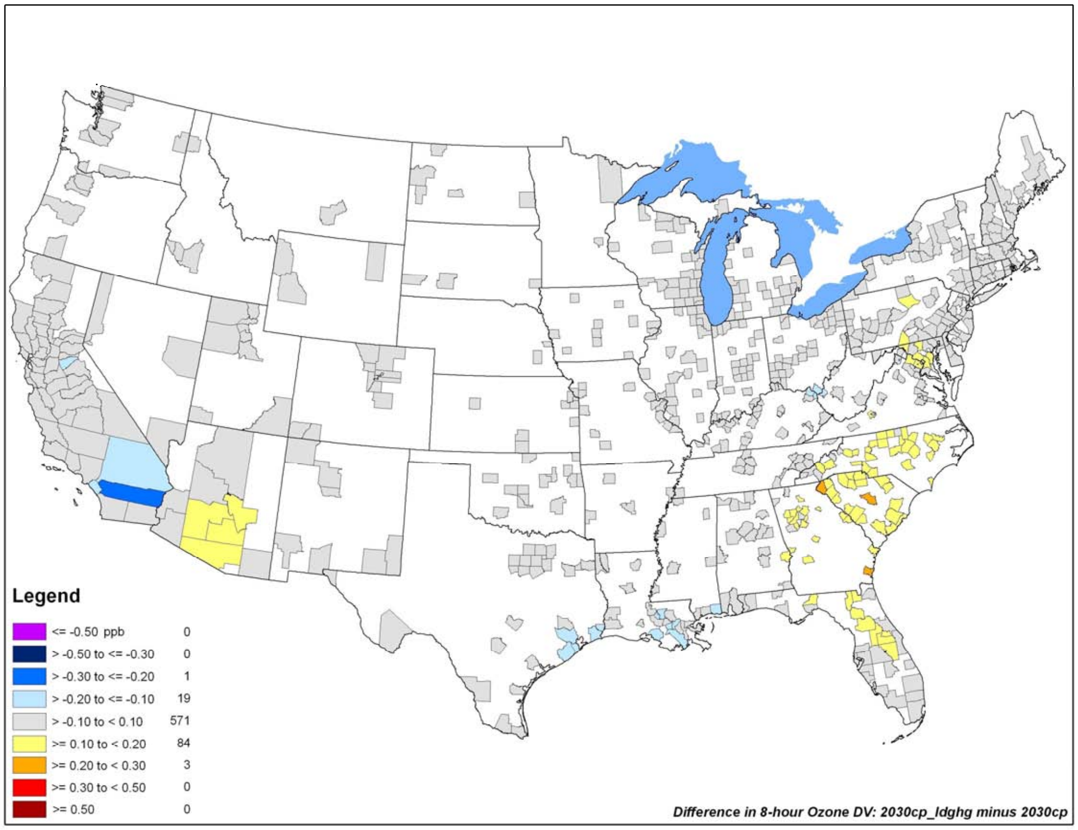

Figure 7-13 Projected Change in 2030 8-hour Ozone Design Values Between the Reference Case and Control Case

As can be seen in Figure 7-13, the majority of the design value increases are less than 0.1 ppb. However, there are some counties that will see 8-hour ozone design value increases above 0.1 ppb; these counties are along the mid-Atlantic coast and in southern Arizona. The maximum projected increase in an 8-hour ozone design value is 0.25 ppb in Richland County, South Carolina. There are also some counties that are projected to see 8-hour ozone design value decreases. The decreases in ambient ozone concentration are likely due to projected upstream emissions decreases in NO_X and VOCs from reduced gasoline production. The counties with ozone design value decreases greater than 0.1 ppb are in California, Texas, Louisiana, Mississippi, Kentucky, Ohio and West Virginia. The maximum decrease projected in an 8-hour ozone design value is 0.22 ppb in Riverside, CA.

There are 16 counties, half of them in California, that are projected to have 8-hour ozone design values above the 2008 NAAQS in 2030 with the vehicle standards in place. Table 7-7 below presents the changes in design values for these counties. Increases in design values in Maryland and Connecticut are a reflection of our ethanol volume assumptions as discussed above (also Sections 5.3.2 and 5.3.3.5) and are not due to the standards finalized in this rule.

Table 7-7 Change in Ozone Design Values (ppb) for Counties Projected to be Above the 2008 Ozone NAAQS in 2030

County Name	Change in 8-hour Ozone Design Value (ppb)	Population in 2030[a]
San Bernardino Co., California	-0.18	60,710,005
Riverside Co., California	-0.22	60,658,001
Los Angeles Co., California	-0.06	60,376,012
Kern Co., California	-0.07	60,295,001
Harris Co., Texas	-0.17	482,010,055
Tulare Co., California	-0.02	61,070,009
Suffolk Co., New York	-0.02	361,030,002
Fresno Co., California	-0.04	60,190,008
Brazoria Co., Texas	-0.15	480,391,004
Orange Co., California	-0.13	60,595,001
Harford Co., Maryland	0.06	240,251,001
Fairfield Co., Connecticut	0.00	90,013,007
East Baton Rouge Co., Louisiana	-0.10	220,330,003
Calaveras Co., California	-0.10	60,090,001
Ventura Co., California	-0.03	61,112,002
New Haven Co., Connecticut	0.04	90,093,002
San Bernardino Co., California	-0.18	60,710,005

Note:
[a] Population numbers based on Woods & Poole data. Woods & Poole Economics, Inc. 2001. Population by Single Year of Age CD.

Table 7-8 shows the average change in 2030 8-hour ozone design values for: (1) all counties with 2005 baseline design values, (2) counties with 2005 baseline design values that exceeded the 2008 ozone standard, (3) counties with 2005 baseline design values that did not exceed the 2008 standard, but were within 10% of it, (4) counties with 2030 design values that exceeded the 2008 ozone standard, and (5) counties with 2030 design values that did not exceed the standard, but were within 10% of it. Counties within 10% of the standard are intended to reflect counties that although not violating the standards, will also be impacted by changes in ozone as they work to ensure long-term maintenance of the ozone NAAQS. Many of these statistics, except for counties with 2030 design values that exceed the 2008 ozone standard, show an increase in 2030. Again, increases in ozone design value concentrations are a reflection of our ethanol volume assumptions, as discussed above (also Sections 5.3.2 and 5.3.3.5), and are not due to the standards finalized in this rule. On a population-weighted basis, the average modeled future-year 8-hour ozone design values are projected to increase by 0.28 ppb in 2030. On a population-weighted basis those counties that are projected to be above the 2008 ozone standard in 2030 will see a decrease of 0.10 ppb due to the vehicle standards.

Table 7-8 Average Change in Projected 8-hour Ozone Design Value

Average[a]	Number of US Counties	2030 Population[b]	Change in 2030 design value (ppb)
All	678	262,264,195	0.03
All, population-weighted			0.01
Counties whose 2005 base year is violating the 2008 8-hour ozone standard	389	192,026,888	0.03
Counties whose 2005 base year is violating the 2008 8-hour ozone standard, population-weighted			0.01
Counties whose 2005 base year is within 10 percent of the 2008 8-hour ozone standard	208	47,276,756	0.03
Counties whose 2005 base year is within 10 percent of the 2008 8-hour ozone standard, population-weighted			0.02
Counties whose 2030 control case is violating the 2008 8-hour ozone standard	16	34,751,421	-0.07
Counties whose 2030 control case is violating the 2008 8-hour ozone standard, population-weighted			-0.10
Counties whose 2030 control case is within 10% of the 2008 8-hour ozone standard	80	61,467,398	0.00
Counties whose 2030 control case is within 10% of the 2008 8-hour ozone standard, population-weighted			0.01

Note:
[a] Averages are over counties with 2005 modeled design values

[b] Population numbers based on Woods & Poole data. Woods & Poole Economics, Inc. 2001. Population by Single Year of Age CD.

Ground-level ozone pollution is formed by the reaction of VOCs and NO_X in the atmosphere in the presence of heat and sunlight. The science of ozone formation, transport, and accumulation is complex.[267] The projected ozone decreases which are seen in the air quality modeling for this final rule are likely a result of the emissions changes due to the vehicle standards combined with the photochemistry involved, the different background concentrations of VOCs and NO_X in different areas of the country, and the different meteorological conditions in different areas of the country.

When VOC levels are relatively high, relatively small amounts of NO_X enable ozone to form rapidly. Under these conditions, VOC reductions have little effect on ozone and while NO_X reductions are highly effective in reducing ozone, NO_X increases lead to increases in ozone. Such conditions are called "NO_X -limited." Because the contribution of VOC emissions from biogenic (natural) sources to local ambient ozone concentrations can be significant, even some areas where man-made VOC emissions are relatively low can be NO_X -limited. Rural areas are usually NO_X -limited, due to the relatively large amounts of biogenic VOC emissions in such areas.

When NO_X levels are relatively high and VOC levels relatively low, NO_X forms inorganic nitrates (i.e., particles) but relatively little ozone. Such conditions are called "VOC-limited." Under these conditions, VOC reductions are effective in reducing ozone, but NO_X reductions can actually increase local ozone under certain circumstances.

7.2.2.3 Air Toxics

7.2.2.3.1 Current Levels of Air Toxics

The majority of Americans continue to be exposed to ambient concentrations of air toxics at levels which have the potential to cause adverse health effects.[268] The levels of air toxics to which people are exposed vary depending on where people live and work and the kinds of activities in which they engage, as discussed in detail in U.S. EPA's most recent Mobile Source Air Toxics Rule.[269] In order to identify and prioritize air toxics, emission source types and locations which are of greatest potential concern, U. S. EPA conducts the National-Scale Air Toxics Assessment (NATA). The most recent NATA was conducted for calendar year 2002, and was released in June 2009.[270] NATA for 2002 includes four steps:

1) Compiling a national emissions inventory of air toxics emissions from outdoor sources

2) Estimating ambient concentrations of air toxics across the United States

3) Estimating population exposures across the United States

4) Characterizing potential public health risk due to inhalation of air toxics including both cancer and noncancer effects

Figure 7-14 and Figure 7-15 depict estimated county-level carcinogenic risk and noncancer respiratory hazard from the assessment. The respiratory hazard is dominated by a single pollutant, acrolein.

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.[271,HH] 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. Over the years, EPA has implemented a number of mobile source and fuel controls which have resulted in VOC reductions, which also reduced benzene and other air toxic emissions.

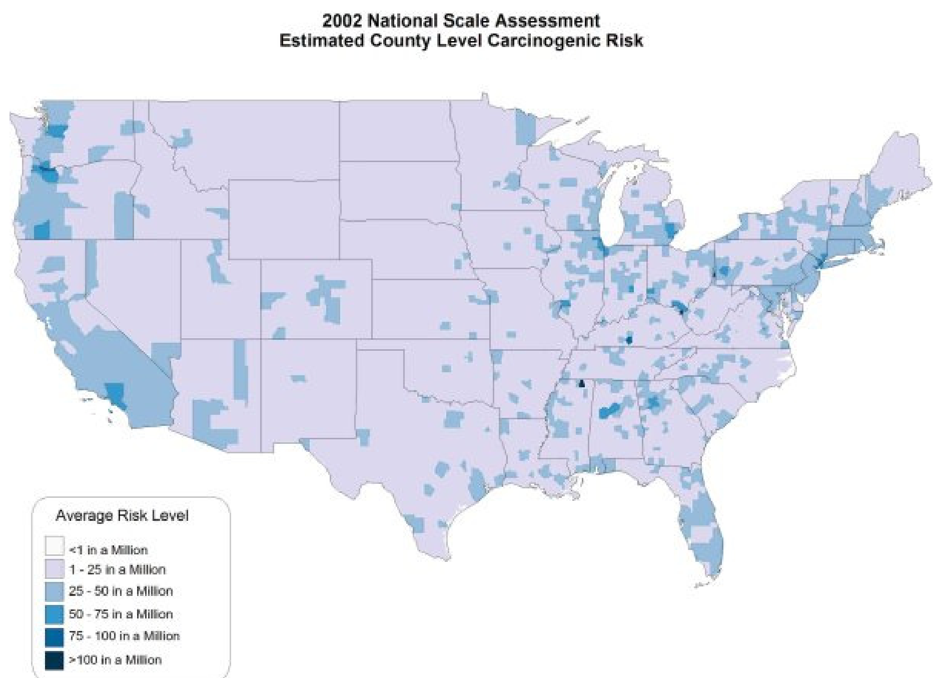

Figure 7-14 County Level Average Carcinogenic Risk, 2002 NATA

[HH] NATA relies on a Guassian plume model, Assessment System for Population Exposure Nationwide (ASPEN), to estimate toxic air pollutant concentrations. Projected air toxics concentrations presented in this rule were modeled with CMAQ 4.7, which has only recently been updated to include air toxics.

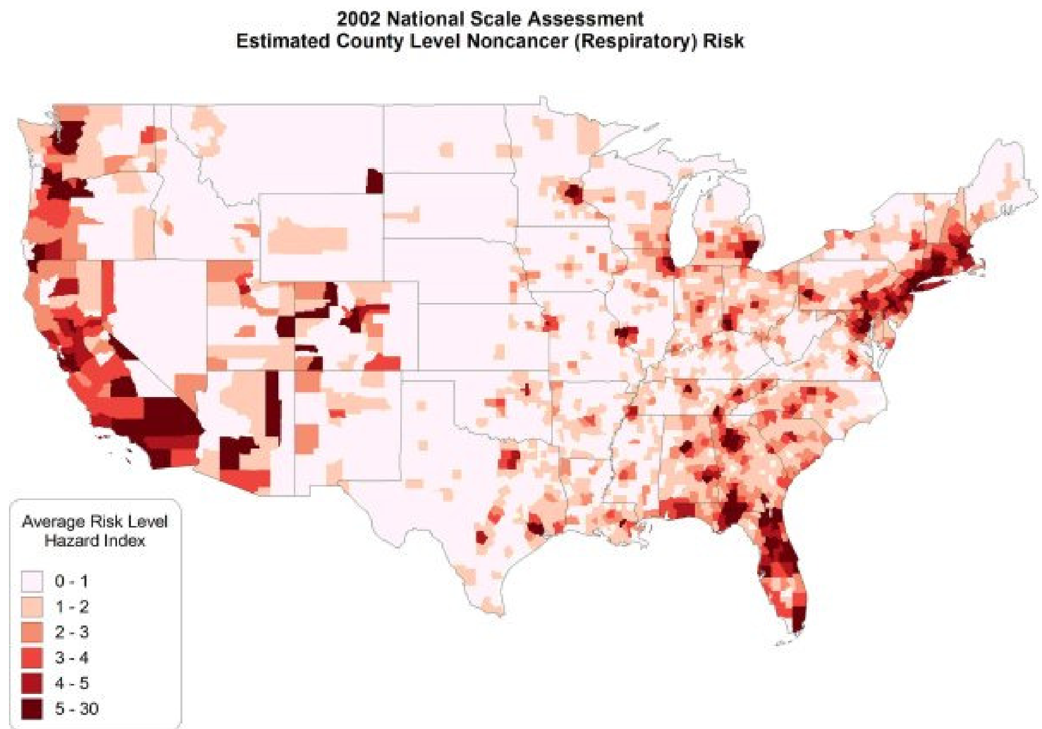

Figure 7-15 County Level Average Noncancer Hazard Index, 2002 NATA

7.2.2.3.2 Projected Levels of Air Toxics

In the following sections, we describe results of our modeling of air toxics levels in the future with the standards finalized in this action. Although there are a large number of compounds which are considered air toxics, we focused on those which were identified as national and regional-scale cancer and noncancer risk drivers in past NATA assessments and were also likely to be significantly impacted by the standards. These compounds include benzene, 1,3-butadiene, formaldehyde, acetaldehyde, and acrolein. Ethanol impacts were also included in our analyses. Information on the air quality modeling methodology is contained in Section 7.2.1. Additional detail such as the seasonal concentration maps for the modeled air toxics can be found in the air quality modeling technical support document (AQM TSD) in the docket for this rule.

It should be noted that EPA has adopted many mobile source emission control programs that are expected to reduce ambient air toxics levels. These control programs include the Heavy-duty Onboard Diagnostic Rule (74 FR 8310, February 24, 2009), Small SI and Marine SI Engine Rule (73 FR 59034, October 8, 2008), Locomotive and Commercial Marine Rule (73 FR 25098, May 6, 2008), Mobile Source Air Toxics Rule (72 FR 8428, February 26, 2007), Clean Air Nonroad Diesel Rule (69 FR 38957, June 29, 2004), Heavy

Duty Engine and Vehicle Standards and Highway Diesel Fuel Sulfur Control Requirements (66 FR 5002, Jan. 18, 2001) and the Tier 2 Motor Vehicle Emissions Standards and Gasoline Sulfur Control Requirements (65 FR 6698, Feb. 10, 2000). As a result of these programs, the ambient concentration of air toxics in the future is expected to decrease. The reference case and control case scenarios include these controls.

Our modeling indicates that the GHG standards have relatively little impact on national average ambient concentrations of the modeled air toxics. Because overall impacts are small, we concluded that assessing exposure to ambient concentrations and conducting a quantitative risk assessment of air toxic impacts was not warranted. However, we did develop population metrics, including the population living in areas with increases or decreases in concentrations of various magnitudes.

Acetaldehyde

Our air quality modeling does not show substantial overall nationwide impacts on ambient concentrations of acetaldehyde as a result of the standards finalized in this rule. Annual percent changes in ambient concentrations of acetaldehyde are less than 1% across the country (Figure 7-16). Decreases in ambient concentrations of acetaldehyde seen in the much of the eastern half of the U.S. and parts of the West are generally less than 0.01 µg/m³ (Figure 7-16).

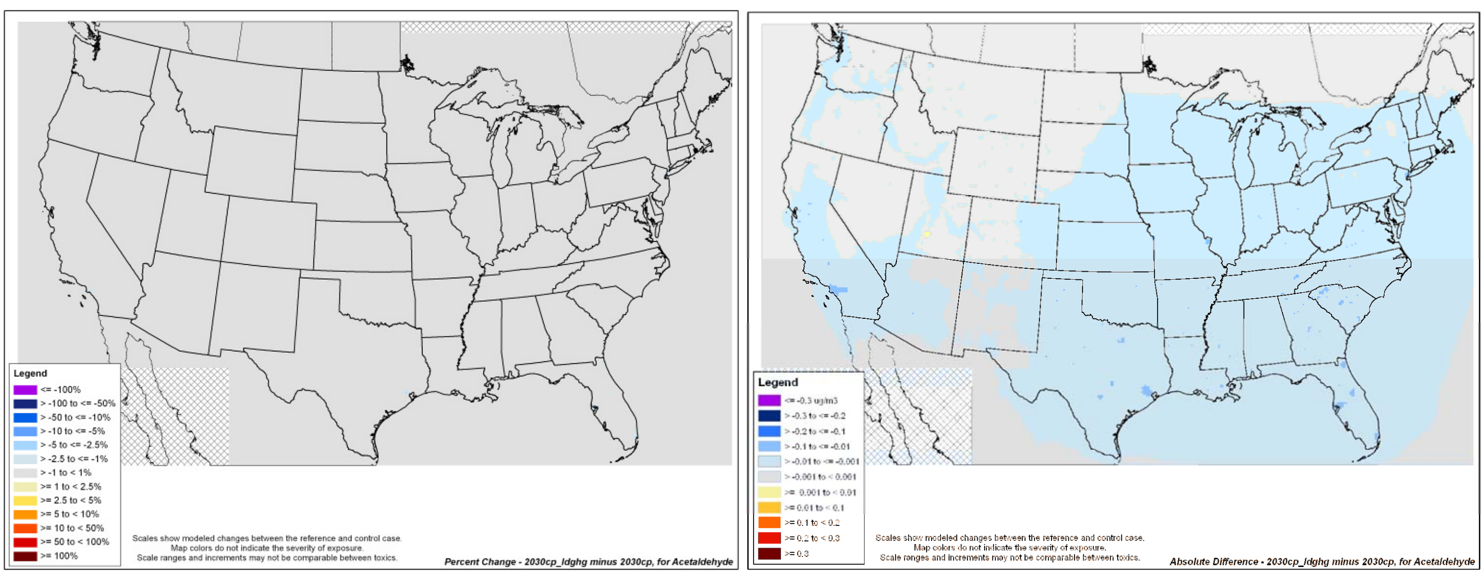

Figure 7-16 Changes in Acetaldehyde Ambient Concentrations Between the Reference Case and the Control Case in 2030: Percent Changes (left) and Absolute Changes in µg/m³ (right)

Formaldehyde

Our modeling projects that the standards finalized in this rule will not have a significant impact on ambient formaldehyde concentrations. As shown in Figure 7-17, annual percent changes in ambient concentrations of formaldehyde are less than 1% across the country, with the exception of a 1 to 5% decrease in a small area of southern Kansas and northern Oklahoma. Figure 7-17 also shows that absolute changes in ambient concentrations of formaldehyde are generally less than 0.1 µg/m³. Increases in ambient formaldehyde concentrations, which range from 0.001 to 0.1 µg/m³, are a reflection of our ethanol volume assumptions as discussed above in Section 7.2.2.2.2.2 (also Sections 5.3.2 and 5.3.3.5) and are not due to the standards finalized in this rule.

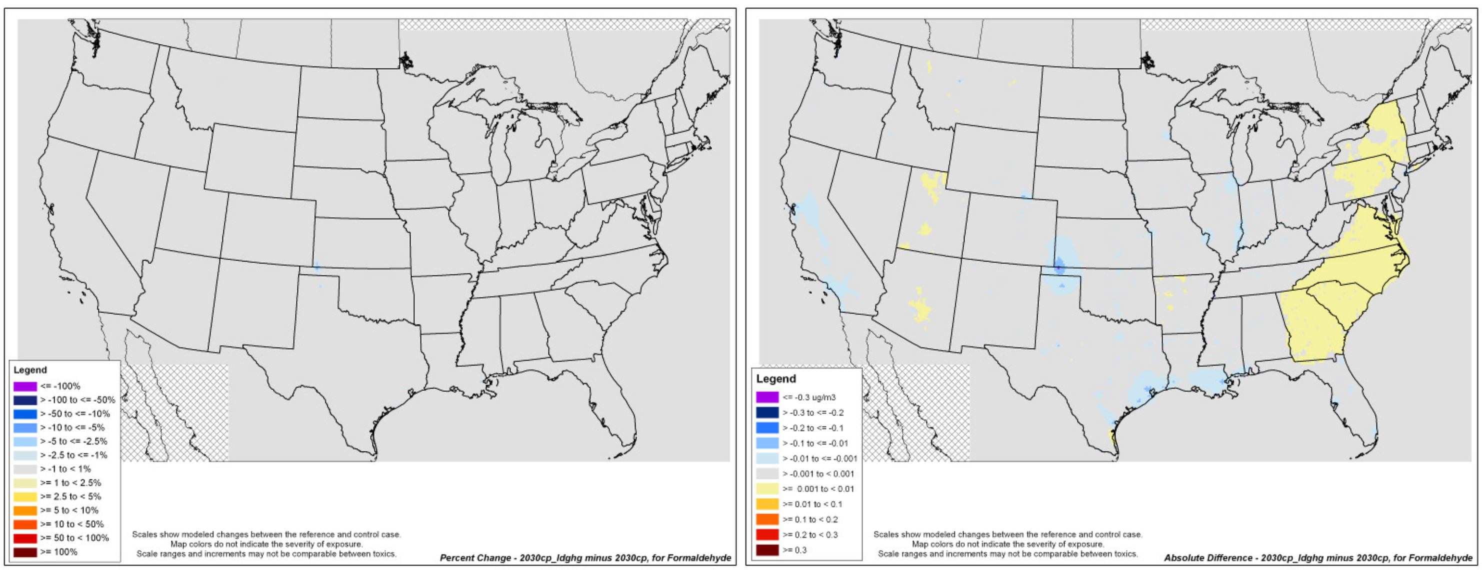

Figure 7-17 Changes in Formaldehyde Ambient Concentrations Between the Reference Case and the Control Case in 2030: Percent Changes (left) and Absolute Changes in µg/m³ (right)

Ethanol

Our air quality modeling results do not show substantial impacts on ambient concentrations of ethanol from the vehicle GHG standards. While Figure 7-18 shows increases in ambient ethanol concentrations ranging between 1 and 50% in some areas of the country, these increases are a reflection of our ethanol volume assumptions as discussed above in Section 7.2.2.2.2.2 (also Sections 5.3.2 and 5.3.3.5) and are not due to the standards finalized in this rule.

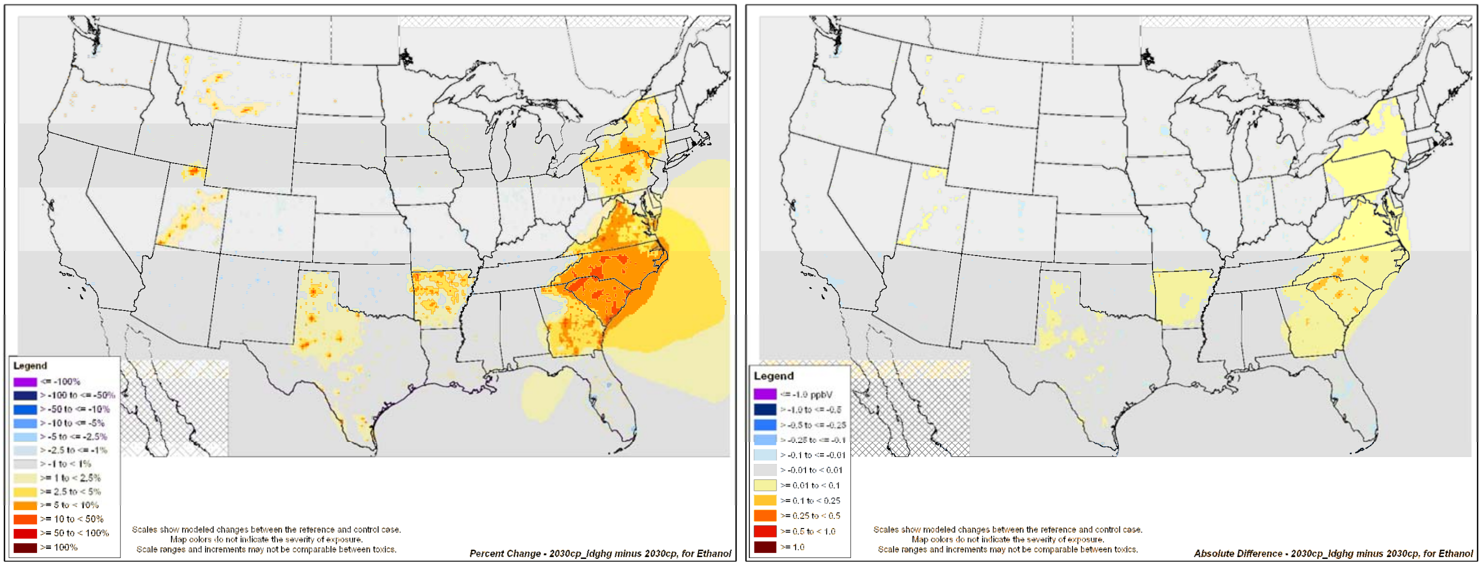

Figure 7-18 Changes in Ethanol Ambient Concentrations Between the Reference Case and the Control Case in 2030: Percent Changes (left) and Absolute Changes in µg/m³ (right)

Benzene

Our modeling projects that the standards finalized in this rule will not have a significant impact on ambient benzene concentrations. Figure 7-19 shows decreases in ambient benzene concentrations ranging between 1 and 10% and between 0.001 and 0.1 µg/m³. Because this rule will reduce consumption and production of gasoline, some of these decreases in benzene concentrations are likely due to the vehicle GHG standards. However, decreases in benzene concentrations may also be a reflection of our ethanol volume assumptions as discussed above for ozone, ethanol and formaldehyde, and are not due to the standards finalized in this rule. For example, the percent change map in Figure 7-19 below shows benzene decreases occurring in the same areas of the country as ozone, ethanol, and formaldehyde increases.

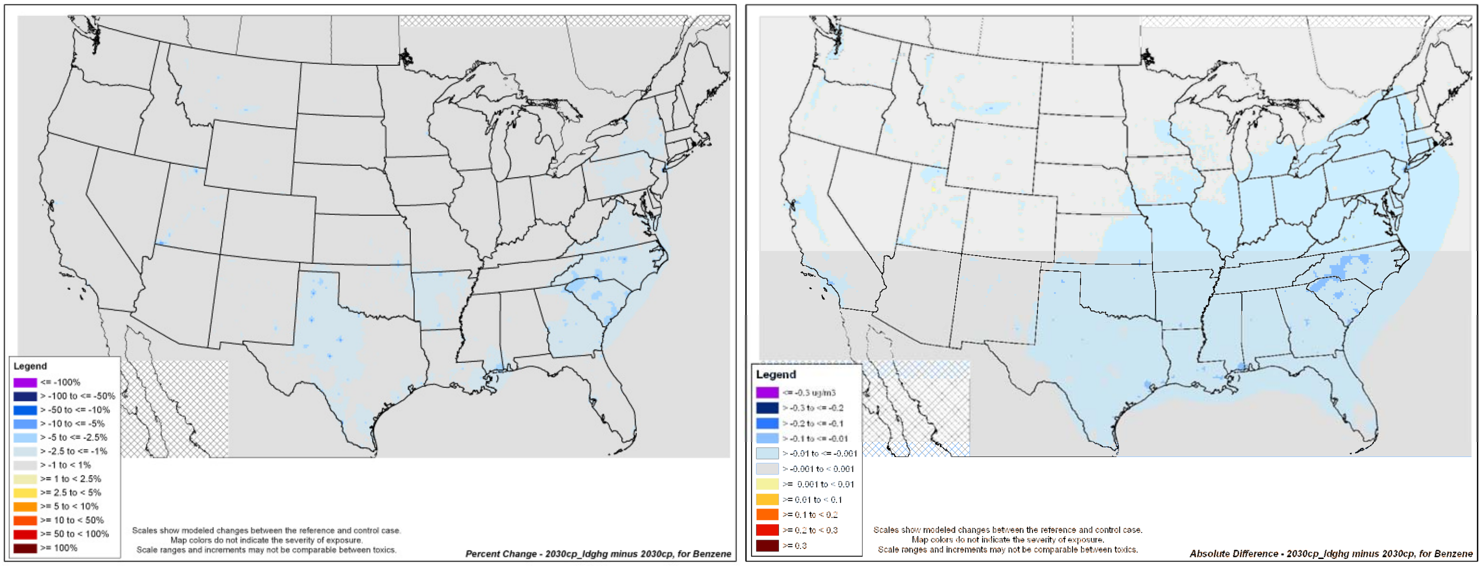

Figure 7-19 Changes in Benzene Ambient Concentrations Between the Reference Case and the Control Case in 2030: Percent Changes (left) and Absolute Changes in µg/m³ (right)

1,3-Butadiene

Our air quality modeling results do not show substantial impacts on ambient concentrations of 1,3-butadiene from the GHG standards. Small decreases ranging from 1 to 10% occur in some southern areas of the country and increases ranging from 1 to over 100% occur in some northern areas and areas with high altitudes (Figure 7-20). Changes in absolute concentrations of ambient 1,3-butadiene are less than 0.001 µg/m³ except in some areas of the Northeast and Utah (Figure 7-20). Annual increases in ambient concentrations of 1,3-butadiene are driven by wintertime rather than summertime changes (seasonal maps can be found in the AQM TSD). These increases appear in rural areas with cold winters and low ambient levels but high contributions of emissions from snowmobiles, and a major reason for this modeled increase may be deficiencies in available emissions test data used to estimate snowmobile 1,3-butadiene emission inventories. These data were based on tests using only three engines, which showed significantly higher 1,3-butadiene emissions with 10% ethanol. However, they may not have been representative of real-world response of snowmobile engines to ethanol. Regardless, these increases are a reflection of our ethanol volume assumptions and are not due to the standards finalized in this rule.

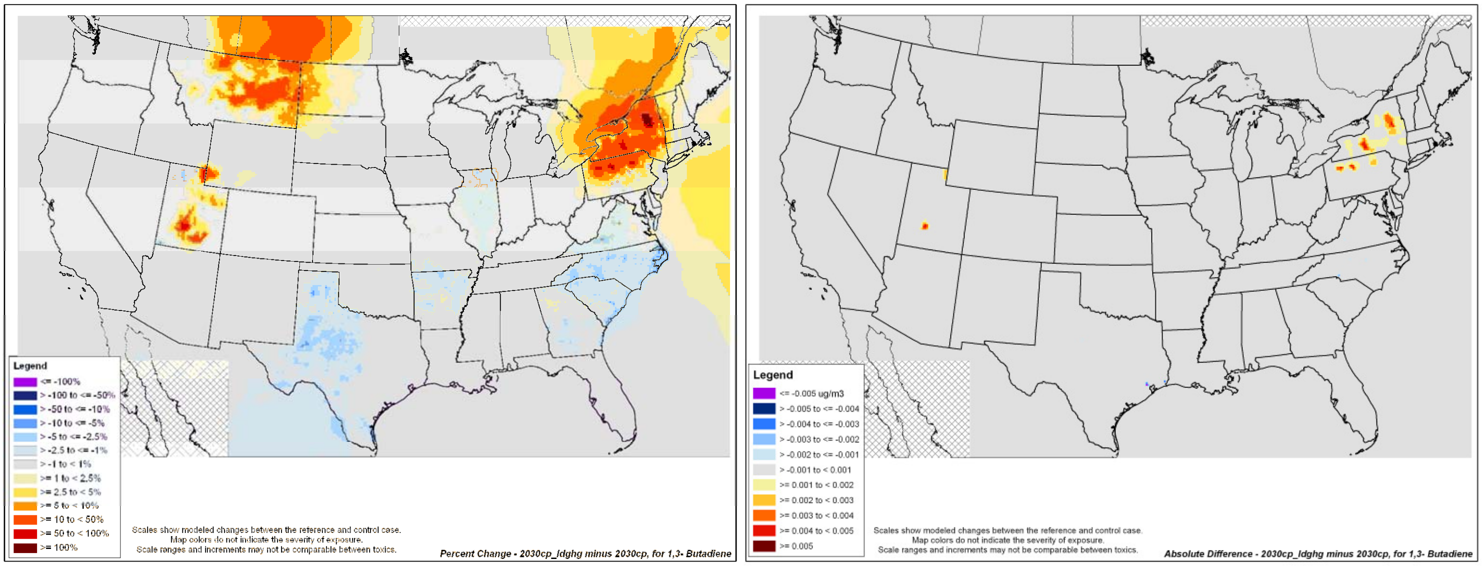

Figure 7-20 Changes in 1,3-Butadiene Ambient Concentrations Between the Reference Case and the Control Case in 2030: Percent Changes (left) and Absolute Changes in µg/m³ (right)

Acrolein

Our air quality modeling results do not show substantial impacts on ambient concentrations of acrolein from the standards finalized in this rule. Small decreases ranging from 1 to 2.5% occur in a few areas of the country and increases ranging from 1 to 100% occur in some northern areas and areas with high altitudes (Figure 7-21). Changes in absolute concentrations of acrolein are less than 0.001 µg/m³ across the country (Figure 7-21). Ambient acrolein increases are driven by wintertime changes (see the AQM TSD for seasonal maps), and occur in the same areas of the country that have wintertime rather than summertime increases in ambient 1,3-butadiene. 1,3-butadiene is a precursor to acrolein, and these increases are likely associated with the same emission inventory uncertainties in areas of high snowmobile usage seen for 1,3-butadiene. As described above, these increases are a reflection of our ethanol volume assumptions and are not due to the standards finalized in this rule.

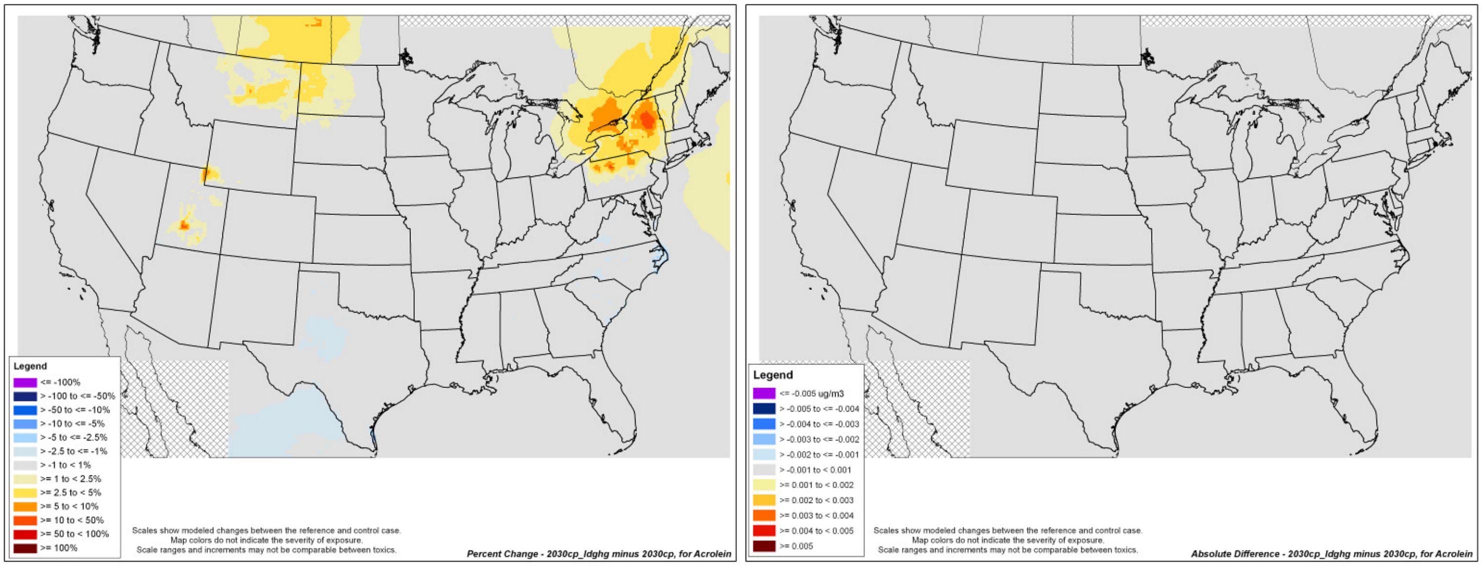

Figure 7-21 Changes in Acrolein Ambient Concentrations Between the Reference Case and the Control Case in 2030: Percent Changes (left) and Absolute Changes in µg/m³ (right)

Population Metrics

To assess the impact of projected changes in air quality with the GHG standards, we developed population metrics that show population experiencing increases and decreases in annual ambient concentrations across the modeled air toxics. Table 7-9 illustrates the percentage of the population impacted by changes of various magnitudes in annual ambient concentrations between the reference case and the control case. As discussed above, increases in ambient ethanol, 1,3-butadiene, and acrolein concentration are due to our ethanol volume assumptions, and are not the result of the GHG vehicle standards.

Table 7-9 Percent of Total Population Impacted by Changes in Annual Ambient Concentrations of Toxic Pollutants Between the Reference and Control Cases in 2030

Percent Change in Annual Ambient Concentration	Acetaldehyde	Acrolein	Benzene	1,3-Butadiene	Ethanol	Formaldehyde
≤-100						
>-100 to ≤-50						
>-50 to ≤-10						
>-10 to ≤-5		0.97%	0.60%	0.64%	0.44%	0.54%
>-5 to ≤-2.5	0.61%	0.18%	4.65%	3.26%	1.84%	0.41%
>-2.5 to ≤-1	5.13%	1.92%	16.22%	8.43%	15.11%	0.27%
> -1 to <1	94.86%	94.82%	78.63%	75.36%	67.59%	99.75%
≥1 to <2.5		2.19%		8.45%	4.92%	
≥2.5 to <5		0.93%		2.25%	2.77%	
≥5 to <10		0.14%		0.82%	3.96%	
≥10 to <50		0.63%		0.78%	3.82%	
≥50 to <100				0.27%		
≥100				0.13%		

7.2.2.4 Deposition of Nitrogen and Sulfur

7.2.2.4.1 Current Levels of Nitrogen and Sulfur Deposition

Over the past two decades, the EPA has undertaken numerous efforts to reduce nitrogen and sulfur deposition across the U.S. Analyses of long-term monitoring data for the U.S. show that deposition of both nitrogen and sulfur compounds has decreased over the last 17 years although many areas continue to be negatively impacted by deposition. Deposition of inorganic nitrogen and sulfur species routinely measured in the U.S. between 2004 and 2006 were as high as 9.6 kilograms of nitrogen per hectare per year (kg N/ha/yr) and 21.3 kilograms of sulfur per hectare per year (kg S/ha/yr). Figure 7-22 and Figure 7-23 show that annual total deposition (the sum of wet and dry deposition) decreased between 1989-1999 and 2004-2006 due to sulfur and NO_X controls on power plants, motor vehicles and fuels in the U.S. The data show that reductions were more substantial for sulfur compounds than for nitrogen compounds. These numbers are generated by the U.S. national monitoring network and they likely underestimate nitrogen deposition because neither ammonia nor organic nitrogen is measured. In the eastern U.S., where data are most abundant, total sulfur deposition decreased by about 44% between 1990 and 2007, while total nitrogen deposition decreased by 25% over the same time frame.[272]

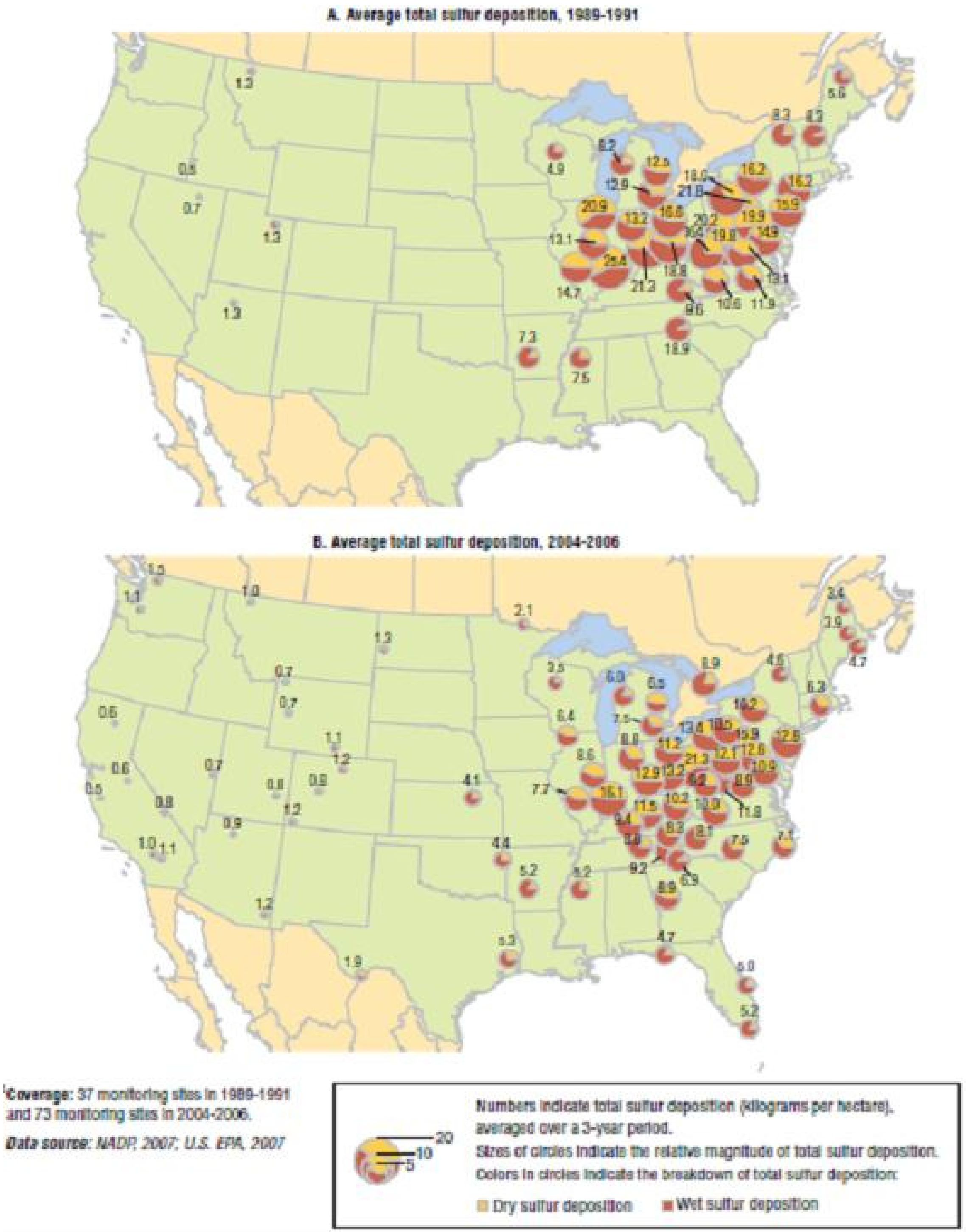

Figure 7-22 Total Sulfur Deposition in the Contiguous U.S., 1989-1991 and 2004 -2006

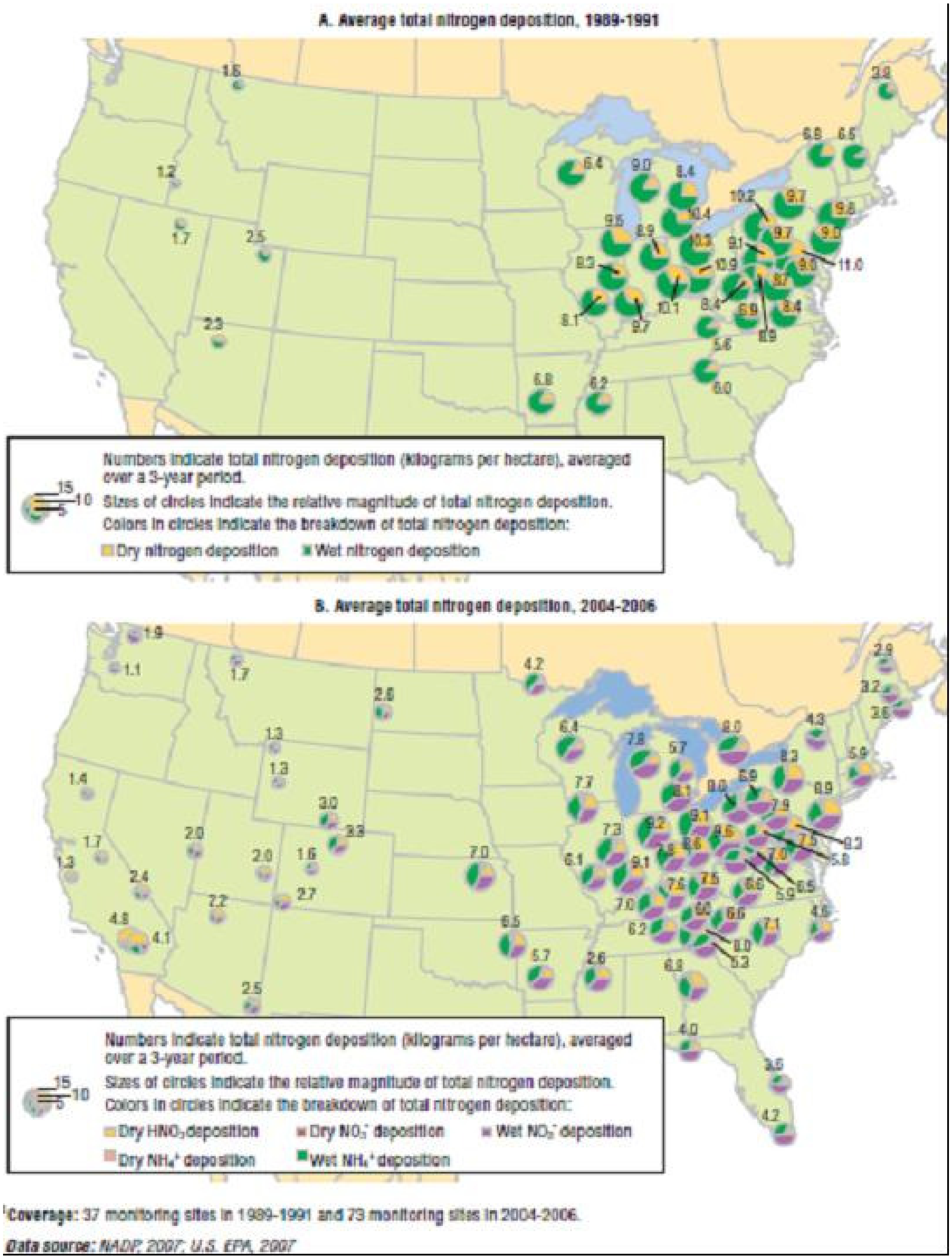

Figure 7-23 Total Nitrogen Deposition in the Contiguous U.S., 1989-1991 and 2004-2006

7.2.2.4.2 Projected Levels of Nitrogen and Sulfur Deposition

Our air quality modeling does not show substantial overall nationwide impacts on the annual total sulfur and nitrogen deposition occurring across the U.S. as a result of the vehicle standards required by this rule. Figure 7-24 shows that for sulfur deposition the vehicle standards will result in annual percent decreases of 0.5% to more than 2% in locations with refineries as a result of the lower output from refineries due to less gasoline usage. These locations include the Texas and Louisiana portions of the Gulf Coast; the Washington D.C. area; Chicago, IL; portions of Oklahoma and northern Texas; Bismarck, North Dakota; Billings, Montana; Casper, Wyoming; Salt Lake City, Utah; Seattle, Washington; and San Francisco, Los Angeles, and San Luis Obispo, California. The remainder of the country will see only minimal changes in sulfur deposition, ranging from decreases of less than 0.5% to increases of less than 0.5%. The impacts of the vehicle standards on nitrogen deposition are minimal, ranging from decreases of up to 0.5% to increases of up to 0.5%.

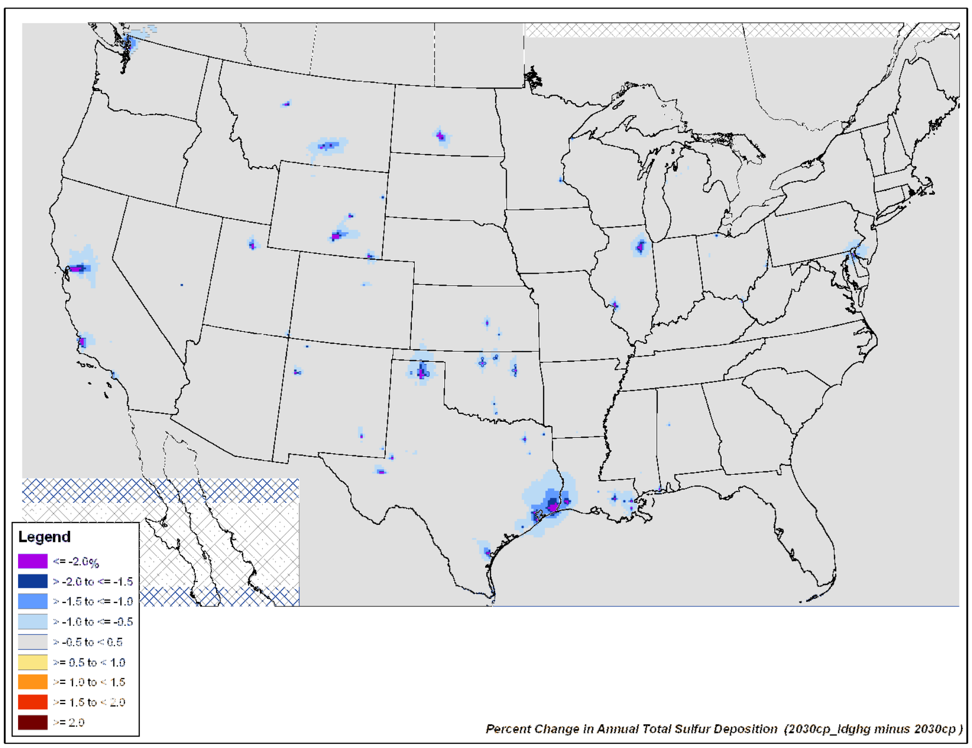

Figure 7-24 Percent Change in Annual Total Sulfur over the U.S. Modeling Domain as a Result of the Required Vehicle Standards

7.2.2.5 Visibility Degradation

7.2.2.5.1 Current Visibility Levels

Recently designated $PM_{2.5}$ nonattainment areas indicate that, as of January 6, 2010, approximately 101 million people live in nonattainment areas for the $PM_{2.5}$ NAAQS. Thus, at least these populations would likely be experiencing visibility impairment, as well as many thousands of individuals who travel to these areas. In addition, while visibility trends have improved in mandatory class I federal areas, the most recent data show that these areas continue to suffer from visibility impairment. In eastern areas, average visual range has decreased from 90 miles to 15-25 miles. In western areas, visual range has decreased from 140 miles to 35-90 miles.[273] In summary, visibility impairment is experienced throughout the U.S., in multi-state regions, urban areas, and remote mandatory class I federal areas.

7.2.2.5.2 Projected Visibility Levels

Air quality modeling conducted for this final rule was used to project visibility conditions in 138 mandatory class I federal areas across the U.S. in 2030. The results show that all the modeled areas will continue to have annual average deciview levels above background in 2030.[II] The results also indicate that the majority of the modeled mandatory class I federal areas will see no change in their visibility, but some mandatory class I federal areas will see improvements in visibility due to the vehicle standards and a few mandatory class I federal areas will see visibility decreases. The average visibility at all modeled mandatory class I federal areas on the 20% worst days is projected to improve by 0.002 deciviews, or 0.01%, in 2030. The greatest improvement in visibilities will be seen in Bosque de Apache (New Mexico) and the San Gorgonio Wilderness (near Los Angeles, California). Bosque de Apache will see a 0.15% improvement (0.02 DV) and the San Gorgonio Wilderness will see a 0.10% improvement (0.02 DV) in 2030 due to the vehicle standards. The following six areas will see a degradation of 0.01 DV in 2030 as a result of the vehicle standards: Hells Canyon Wilderness (Oregon), 0.06% degradation; Kalmiopsis Wilderness (Oregon), 0.06% degradation; Strawberry Mountain Wilderness (Oregon), 0.06% degradation; Petrified Forest National Park (Arizona), 0.08% degradation; Rocky Mountain National Park (Colorado), 0.08% degradation; and Three Sisters Wilderness (Oregon), 0.06% degradation. Table 7-10 contains the full visibility results from 2030 for the 138 analyzed areas.

[II] The level of visibility impairment in an area is based on the light-extinction coefficient and a unitless visibility index, called a "deciview", which is used in the valuation of visibility. The deciview metric provides a scale for perceived visual changes over the entire range of conditions, from clear to hazy. Under many scenic conditions, the average person can generally perceive a change of one deciview. The higher the deciview value, the worse the visibility. Thus, an improvement in visibility is a decrease in deciview value.

Table 7-10 Visibility Levels in Deciviews for Individual U.S. Class I Areas on the 20% Worst Days for Several Scenarios

CLASS 1 AREA (20% WORST DAYS)	STATE	2005 BASELINE VISIBILITY	2030 BASE	2030 CONT-ROL	NATURAL BACKGROUND
Sipsey Wilderness	AL	29.62	23.41	23.41	11.39
Caney Creek Wilderness	AR	26.78	22.52	22.51	11.33
Upper Buffalo Wilderness	AR	27.09	23.06	23.05	11.28
Chiricahua NM	AZ	13.33	13.28	13.28	6.92
Chiricahua Wilderness	AZ	13.33	13.27	13.27	6.91
Galiuro Wilderness	AZ	13.33	13.20	13.20	6.88
Grand Canyon NP	AZ	11.85	11.58	11.58	6.95
Mazatzal Wilderness	AZ	13.80	13.10	13.10	6.91
Mount Baldy Wilderness	AZ	11.27	11.10	11.10	6.95
Petrified Forest NP	AZ	13.73	13.31	13.32	6.97
Pine Mountain Wilderness	AZ	13.80	13.12	13.12	6.92
Saguaro NM	AZ	14.53	14.04	14.04	6.84
Sierra Ancha Wilderness	AZ	14.37	13.82	13.82	6.92
Superstition Wilderness	AZ	14.01	13.46	13.46	6.88
Sycamore Canyon Wilderness	AZ	15.34	15.04	15.04	6.96
Agua Tibia Wilderness	CA	23.09	24.56	24.55	7.17
Ansel Adams Wilderness (Minarets)	CA	14.90	14.78	14.77	7.12
Caribou Wilderness	CA	14.19	13.98	13.97	7.29
Cucamonga Wilderness	CA	19.35	18.23	18.22	7.17
Desolation Wilderness	CA	12.52	12.54	12.54	7.13
Emigrant Wilderness	CA	17.37	17.21	17.20	7.14
Hoover Wilderness	CA	11.92	11.85	11.85	7.12

John Muir Wilderness	CA	14.90	14.81	14.80	7.14
Joshua Tree NM	CA	19.40	18.68	18.68	7.08
Kaiser Wilderness	CA	14.90	14.71	14.71	7.13
Kings Canyon NP	CA	23.41	22.81	22.80	7.13
Lassen Volcanic NP	CA	14.19	14.00	14.00	7.31
Lava Beds NM	CA	14.77	14.31	14.31	7.49
Mokelumne Wilderness	CA	12.52	12.50	12.49	7.14
Pinnacles NM	CA	18.22	18.10	18.09	7.34
Point Reyes NS	CA	22.89	22.98	22.98	7.39
Redwood NP	CA	18.66	19.22	19.22	7.81
San Gabriel Wilderness	CA	19.35	18.06	18.05	7.17
San Gorgonio Wilderness	CA	21.80	20.23	20.21	7.10
San Jacinto Wilderness	CA	21.80	20.12	20.11	7.12
San Rafael Wilderness	CA	19.04	18.94	18.93	7.28
Sequoia NP	CA	23.41	22.64	22.64	7.13
South Warner Wilderness	CA	14.77	14.58	14.58	7.32
Thousand Lakes Wilderness	CA	14.19	14.00	14.00	7.32
Ventana Wilderness	CA	18.22	18.58	18.58	7.32
Yosemite NP	CA	17.37	17.24	17.24	7.14
Black Canyon of the Gunnison NM	CO	10.18	9.82	9.82	7.06
Eagles Nest Wilderness	CO	9.38	9.19	9.19	7.08
Flat Tops Wilderness	CO	9.38	9.27	9.27	7.07
Great Sand Dunes NM	CO	12.49	12.29	12.28	7.10
La Garita Wilderness	CO	10.18	10.00	10.00	7.06
Maroon Bells-Snowmass Wilderness	CO	9.38	9.23	9.23	7.07

Mesa Verde NP	CO	12.78	12.44	12.44	7.09
Mount Zirkel Wilderness	CO	10.19	10.08	10.08	7.08
Rawah Wilderness	CO	10.19	9.99	9.99	7.08
Rocky Mountain NP	CO	13.54	13.33	13.34	7.05
Weminuche Wilderness	CO	10.18	9.99	9.99	7.06
West Elk Wilderness	CO	9.38	9.20	9.20	7.07
Everglades NP	FL	22.48	21.34	21.34	11.15
Okefenokee	GA	27.24	23.44	23.44	11.45
Wolf Island	GA	27.24	23.44	23.44	11.42
Craters of the Moon NM	ID	14.19	13.56	13.56	7.13
Sawtooth Wilderness	ID	14.33	14.24	14.24	7.15
Mammoth Cave NP	KY	31.76	25.48	25.48	11.53
Acadia NP	ME	23.19	22.20	22.20	11.45
Moosehorn	ME	21.94	21.03	21.03	11.36
Roosevelt Campobello International Park	ME	21.94	21.03	21.03	11.36
Isle Royale NP	MI	21.33	19.42	19.42	11.22
Seney	MI	24.71	22.45	22.45	11.37
Voyageurs NP	MN	19.82	17.79	17.79	11.09
Hercules-Glades Wilderness	MO	27.15	23.60	23.60	11.27
Anaconda-Pintler Wilderness	MT	13.91	13.72	13.72	7.28
Bob Marshall Wilderness	MT	14.54	14.32	14.32	7.36
Cabinet Mountains Wilderness	MT	14.15	13.81	13.81	7.43
Gates of the Mountains Wilderness	MT	11.67	11.47	11.47	7.22
Glacier NP	MT	19.13	18.55	18.55	7.56

Medicine Lake	MT	17.78	16.81	16.81	7.30
Mission Mountains Wilderness	MT	14.54	14.25	14.25	7.39
Scapegoat Wilderness	MT	14.54	14.30	14.29	7.29
Selway-Bitterroot Wilderness	MT	13.91	13.79	13.79	7.32
UL Bend	MT	14.92	14.63	14.63	7.18
Linville Gorge Wilderness	NC	29.40	23.36	23.36	11.43
Shining Rock Wilderness	NC	28.72	23.04	23.04	11.45
Lostwood	ND	19.50	17.95	17.95	7.33
Theodore Roosevelt NP	ND	17.69	16.29	16.29	7.31
Great Gulf Wilderness	NH	22.13	20.19	20.18	11.31
Presidential Range-Dry River Wilderness	NH	22.13	20.19	20.18	11.33
Brigantine	NJ	29.28	25.88	25.87	11.28
Bandelier NM	NM	11.87	11.29	11.28	7.02
Bosque del Apache	NM	13.89	13.18	13.16	6.97
Gila Wilderness	NM	13.32	13.03	13.03	6.95
Pecos Wilderness	NM	10.10	9.82	9.82	7.04
Salt Creek	NM	18.20	17.21	17.20	6.99
San Pedro Parks Wilderness	NM	10.39	10.06	10.06	7.03
Wheeler Peak Wilderness	NM	10.10	9.70	9.70	7.07
White Mountain Wilderness	NM	13.52	12.94	12.94	6.98
Jarbidge Wilderness	NV	12.13	12.09	12.09	7.10
Wichita Mountains	OK	23.79	20.50	20.49	11.07
Crater Lake NP	OR	14.04	13.76	13.76	7.71
Diamond Peak Wilderness	OR	14.04	13.71	13.71	7.77

Eagle Cap Wilderness	OR	18.25	17.64	17.63	7.34
Gearhart Mountain Wilderness	OR	14.04	13.88	13.88	7.46
Hells Canyon Wilderness	OR	18.73	17.90	17.91	7.32
Kalmiopsis Wilderness	OR	16.31	16.38	16.39	7.71
Mount Hood Wilderness	OR	14.79	14.49	14.49	7.77
Mount Jefferson Wilderness	OR	15.93	15.75	15.75	7.81
Mount Washington Wilderness	OR	15.93	15.72	15.72	7.89
Mountain Lakes Wilderness	OR	14.04	13.75	13.74	7.57
Strawberry Mountain Wilderness	OR	18.25	17.65	17.66	7.49
Three Sisters Wilderness	OR	15.93	15.72	15.73	7.87
Cape Romain	SC	27.14	24.09	24.09	11.36
Badlands NP	SD	16.73	15.52	15.51	7.30
Wind Cave NP	SD	15.96	14.93	14.93	7.24
Great Smoky Mountains NP	TN	30.43	24.30	24.30	11.44
Joyce-Kilmer-Slickrock Wilderness	TN	30.43	24.30	24.30	11.45
Big Bend NP	TX	17.39	16.43	16.42	6.93
Carlsbad Caverns NP	TX	16.98	15.89	15.88	7.02
Guadalupe Mountains NP	TX	16.98	15.89	15.88	7.03
Arches NP	UT	11.04	10.82	10.81	6.99
Bryce Canyon NP	UT	11.73	11.52	11.52	6.99
Canyonlands NP	UT	11.04	10.88	10.88	7.01
Capitol Reef NP	UT	10.63	10.74	10.74	7.03
James River Face Wilderness	VA	29.32	23.18	23.17	11.24
Shenandoah NP	VA	29.66	23.73	23.72	11.25
Lye Brook Wilderness	VT	24.17	20.72	20.72	11.25

Alpine Lake Wilderness	WA	17.35	17.29	17.28	7.86
Glacier Peak Wilderness	WA	13.78	14.06	14.05	7.80
Goat Rocks Wilderness	WA	12.88	12.32	12.32	7.82
Mount Adams Wilderness	WA	12.88	12.33	12.33	7.78
Mount Rainier NP	WA	17.56	17.23	17.22	7.90
North Cascades NP	WA	13.78	14.20	14.19	7.78
Olympic NP	WA	16.14	16.35	16.35	7.88
Pasayten Wilderness	WA	15.39	14.99	14.99	7.77
Dolly Sods Wilderness	WV	29.73	23.14	23.14	11.32
Otter Creek Wilderness	WV	29.73	23.14	23.14	11.33
Bridger Wilderness	WY	10.93	10.80	10.80	7.08
Fitzpatrick Wilderness	WY	10.93	10.80	10.80	7.09
Grand Teton NP	WY	10.94	10.61	10.61	7.09
North Absaroka Wilderness	WY	11.12	10.98	10.98	7.09
Red Rock Lakes	WY	10.94	10.68	10.68	7.14
Teton Wilderness	WY	10.94	10.70	10.70	7.09
Washakie Wilderness	WY	11.12	10.98	10.98	7.09
Yellowstone NP	WY	10.94	10.66	10.66	7.12

7.3 Quantified and Monetized Non-GHG Health and Environmental Impacts

This section presents EPA's analysis of the non-GHG health and environmental impacts that can be expected to occur as a result of the 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 standards are also significant sources of mobile source air pollution such as direct PM, NO_X, VOCs and air toxics. The standards will affect exhaust emissions of these pollutants from vehicles. They will also affect emissions from upstream sources related to changes in fuel consumption.

Changes in ambient ozone, $PM_{2.5}$, and air toxics that will result from the standards are expected to affect human health in the form of premature deaths and other serious human health effects, as well as other important public health and welfare effects.

It is important to quantify the health and environmental impacts associated with the final rule 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.

This section is split into two sub-sections: the first presents the PM- and ozone-related health and environmental impacts associated with final rule in calendar year (CY) 2030; the second presents the PM-related benefits-per-ton values used to monetize the PM-related co-benefits associated with the model year (MY) analysis of the final rule.[JJ]

7.3.1 Quantified and Monetized Non-GHG Human Health Benefits of the 2030 Calendar Year (CY) Analysis

This analysis reflects the impact of the final light-duty GHG rule in 2030 compared to a future-year reference scenario without the rule in place. Overall, we estimate that the final rule will lead to a net decrease in $PM_{2.5}$-related health impacts (see Chapter 7.2.2.2 for more information about the air quality modeling results). While the PM-related air quality impacts are relatively small, the decrease in population-weighted national average $PM_{2.5}$ exposure results in a net decrease in adverse PM-related human health impacts (the decrease in national population weighted annual average $PM_{2.5}$ is 0.0036 μg/m3).

The air quality modeling also projects very small increases in ozone concentrations in many areas (see Chapter 7.2.2.1), but these are driven by the ethanol production volumes mandated by the recently finalized RFS2 rule and are not due to the standards finalized in this rule (see Chapters 5.3.2 and 5.3.3.5 for more information). While the ozone-related impacts are very small, the overall increase in population-weighted national average ozone exposure results in a small increase in ozone-related health impacts (population weighted maximum 8-hour average ozone increases by 0.0104 ppb).

[JJ] EPA typically analyzes rule impacts (emissions, air quality, costs and benefits) in the year in which they occur; for this analysis, we selected 2030 as a representative future year. We refer to this analysis as the "Calendar Year" (CY) analysis. EPA also conducted a separate analysis of the impacts over the model year lifetimes of the 2012 through 2016 model year vehicles. We refer to this analysis as the "Model Year" (MY) analysis. In contrast to the CY analysis, the MY lifetime analysis shows the lifetime impacts of the program on each of these MY fleets over the course of its lifetime.

We base our analysis of the final rule's impact on human health in 2030 on peer-reviewed studies of air quality and human health effects.[274,275] Our benefits methods are also consistent with recent rulemaking analyses such as the proposed Portland Cement National Emissions Standards for Hazardous Air Pollutants (NESHAP) RIA,[276] the final NO_2 NAAQS,[277] and the final Category 3 Marine Engine rule.[278] To model the ozone and PM air quality impacts of the final rule, we used the Community Multiscale Air Quality (CMAQ) model (see Section 7.2.1). The modeled ambient air quality data serves as an input to the Environmental Benefits Mapping and Analysis Program (BenMAP).[KK] BenMAP is a computer program developed by the U.S. EPA that integrates a number of the modeling elements used in previous analyses (e.g., interpolation functions, population projections, health impact functions, valuation functions, analysis and pooling methods) to translate modeled air concentration estimates into health effects incidence estimates and monetized benefits estimates.

The range of total monetized ozone- and PM-related health impacts is presented in Table 7-11. We present total benefits based on the PM- and ozone-related premature mortality function used. The benefits ranges therefore reflect the addition of each estimate of ozone-related premature mortality (each with its own row in Table 7-11) to estimates of PM-related premature mortality. These estimates represent EPA's preferred approach to characterizing a best estimate of benefits. As is the nature of Regulatory Impact Analyses (RIAs), the assumptions and methods used to estimate air quality benefits evolve to reflect the Agency's most current interpretation of the scientific and economic literature.

Table 7-11 Estimated 2030 Monetized PM-and Ozone-Related Health Benefits[a]

2030 Total Ozone and PM Benefits – PM Mortality Derived from American Cancer Society Analysis and Six-Cities Analysis[a]			
Premature Ozone Mortality Function	Reference	Total Benefits (Millions, 2007$, 3% Discount Rate)[b,c,d]	Total Benefits (Millions, 2007$, 7% Discount Rate)[b,c,d]
Multi-city analyses	Bell et al., 2004	Total: $510 - $1,300 PM: $550 - $1,300 Ozone: -$40	Total: $460 - $1,200 PM: $500 - $1,200 Ozone: -$40
	Huang et al., 2005	Total: $490 - $1,300 PM: $550 - $1,300 Ozone: -$64	Total: $440 - $1,200 PM: $500 - $1,200 Ozone: -$64
	Schwartz, 2005	Total: $490 - $1,300 PM: $550 - $1,300 Ozone: -$60	Total: $440 - $1,200 PM: $500 - $1,200 Ozone: -$60
Meta-analyses	Bell et al., 2005	Total: $430 - $1,200 PM: $550 - $1,300 Ozone: -$120	Total: $380 - $1,100 PM: $500 - $1,200 Ozone: -$120

[KK] Information on BenMAP, including downloads of the software, can be found at http://www.epa.gov/ttn/ecas/ benmodels.html.

	Ito et al., 2005	Total: \$380 - \$1,200 PM: \$550 - \$1,300 Ozone: -\$170	Total: \$330 - \$1,000 PM: \$500 - \$1,200 Ozone: -\$170
	Levy et al., 2005	Total: \$380 - \$1,200 PM: \$550 - \$1,300 Ozone: -\$170	Total: \$330 - \$1,000 PM: \$500 - \$1,200 Ozone: -\$170

Notes:
[a] Total includes premature mortality-related and morbidity-related ozone and $PM_{2.5}$ benefits. Range was developed by adding the estimate from the ozone premature mortality function to the estimate of $PM_{2.5}$-related premature mortality derived from either the ACS study (Pope et al., 2002) or the Six-Cities study (Laden et al., 2006).
[b] Note that total benefits presented here do not include a number of unquantified benefits categories. A detailed listing of unquantified health and welfare effects is provided in Table 7-12.
[c] Results reflect the use of both a 3 and 7 percent discount rate, as recommended by EPA's Guidelines for Preparing Economic Analyses and OMB Circular A-4. Results are rounded to two significant digits for ease of presentation and computation.
[d] Negatives indicate a disbenefit, or an increase in health effect incidence.

The benefits in Table 7-11 include all of the human health impacts we are able to quantify and monetize at this time. However, the full complement of human health and welfare effects associated with PM and ozone remain unquantified because of current limitations in methods or available data. We have not quantified a number of known or suspected health effects linked with ozone and PM for which appropriate health impact functions are not available or which do not provide easily interpretable outcomes (e.g., changes in heart rate variability). Additionally, we are unable to quantify a number of known welfare effects, including reduced acid and particulate deposition damage to cultural monuments and other materials, and environmental benefits due to reductions of impacts of eutrophication in coastal areas. These are listed in Table 7-12. As a result, the health benefits quantified in this section are likely underestimates of the total benefits attributable to the final rule.

Table 7-12 Unquantified and Non-Monetized Potential Effects

Pollutant/Effects	Effects Not Included in Analysis - Changes in:
Ozone Health[a]	Chronic respiratory damage[b] Premature aging of the lungs[b] Non-asthma respiratory emergency room visits Exposure to UVb (+/-)[e]
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 (+/-)[e]
PM Health[c]	Premature mortality - short term exposures[d] Low birth weight

	Pulmonary function Chronic respiratory diseases other than chronic bronchitis Non-asthma respiratory emergency room visits Exposure to UVb (+/-)[e]
PM Welfare	Residential and recreational visibility in non-Class I areas Soiling and materials damage Damage to ecosystem functions Exposure to UVb (+/-)[e]
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
HC/Toxics Health[f]	Cancer (benzene, 1,3-butadiene, formaldehyde, acetaldehyde) Anemia (benzene) Disruption of production of blood components (benzene) Reduction in the number of blood platelets (benzene) Excessive bone marrow formation (benzene) Depression of lymphocyte counts (benzene) Reproductive and developmental effects (1,3-butadiene) Irritation of eyes and mucus membranes (formaldehyde) Respiratory irritation (formaldehyde) Asthma attacks in asthmatics (formaldehyde) Asthma-like symptoms in non-asthmatics (formaldehyde) Irritation of the eyes, skin, and respiratory tract (acetaldehyde) Upper respiratory tract irritation and congestion (acrolein)
HC/Toxics Welfare	Direct toxic effects to animals Bioaccumulation in the food chain Damage to ecosystem function Odor

Notes:
[a] The public health impact of biological responses such as increased airway responsiveness to stimuli, inflammation in the lung, acute inflammation and respiratory cell damage, and increased susceptibility to respiratory infection are likely partially represented by our quantified endpoints.
[b] The public health impact of effects such as chronic respiratory damage and premature aging of the lungs may be partially represented by quantified endpoints such as hospital admissions or premature mortality, but a number of other related health impacts, such as doctor visits and decreased athletic performance, remain unquantified.
[c] 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.
[d] 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.
[e] May result in benefits or disbenefits.
[f] Many of the key hydrocarbons related to this rule are also hazardous air pollutants listed in the CAA.

While there will be impacts associated with air toxic pollutant emission changes that result from the final rule, we do not attempt to monetize those impacts. This is primarily because currently available tools and methods to assess air toxics risk from mobile sources at the national scale are not adequate for extrapolation to incidence estimations or benefits assessment. The best suite of tools and methods currently available for assessment at the national scale are those used in the National-Scale Air Toxics Assessment (NATA). The EPA Science Advisory Board specifically commented in their review of the 1996 NATA that these tools were not yet ready for use in a national-scale benefits analysis, because they did not consider the full distribution of exposure and risk, or address sub-chronic health effects.[279] 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 did not have the methods and tools available for national-scale application in time for the analysis of the final rule.[LL]

EPA is also unaware of specific information identifying any effects on listed endangered species from the small fluctuations in pollutant concentrations associated with this rule (see Section 7.2). Furthermore, our current modeling tools are not designed to trace fluctuations in ambient concentration levels to potential impacts on particular endangered species.

7.3.1.1 Human Health and Environmental Impacts

Table 7-13 and Table 7-14 present the annual $PM_{2.5}$ and ozone health impacts in the 48 contiguous U.S. states associated with the final rule for 2030. For each endpoint presented in Table 7-13 and Table 7-14, we provide both the point estimate and the 90% confidence interval.

Using EPA's preferred estimates, based on the American Cancer Society (ACS) and Six-Cities studies and no threshold assumption in the model of mortality, we estimate that the

[LL] 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, the workshop 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.

final rule will result in between 60 and 150 cases of avoided $PM_{2.5}$-related premature deaths annually in 2030. As a sensitivity analysis, when the range of expert opinion is used, we estimate between 22 and 200 fewer premature mortalities in 2030.

The range of ozone impacts is based on changes in risk estimated using several sources of ozone-related mortality effect estimates. This analysis presents six alternative estimates for the association based upon different functions reported in the scientific literature, derived from both the National Morbidity, Mortality, and Air Pollution Study (NMMAPS) (Bell et al., 2004; Huang et al., 2005; Schwartz, 2005) and from a series of recent meta-analyses (Bell et al., 2005, Ito et al., 2005, and Levy et al., 2005). This approach is not inconsistent with recommendations provided by the NRC in their recent report (NRC, 2008) on the estimation of ozone-related mortality risk reductions, "The committee recommends that the greatest emphasis be placed on estimates from new systematic multicity analyses that use national databases of air pollution and mortality, such as in the NMMAPS, without excluding consideration of meta-analyses of previously published studies." For ozone-related premature mortality in 2030, we estimate a range of between 4 to 18 additional premature mortalities related to the ethanol production volumes mandated by the recently finalized RFS2 rule[MM] (and reflected in the air quality modeling for this rule), but are not due to the final standards themselves.

Following these tables, we also provide a more comprehensive presentation of the distributions of incidence generated using the available information from empirical studies and expert elicitation. Table 7-15 presents the distributions of the reduction in $PM_{2.5}$-related premature mortality based on the C-R distributions provided by each expert, as well as that from the data-derived health impact functions, based on the statistical error associated with the ACS study (Pope et al., 2002) and the Six-Cities study (Laden et al., 2006). The 90% confidence interval for each separate estimate of PM-related mortality is also provided.

In 2030, the effect estimates of nine of the twelve experts included in the elicitation panel fall within the empirically-derived range provided by the ACS and Six-Cities studies. Only one expert falls below this range, while two of the experts are above this range. Although the overall range across experts is summarized in these tables, the full uncertainty in the estimates is reflected by the results for the full set of 12 experts. The twelve experts' judgments as to the likely mean effect estimate are not evenly distributed across the range illustrated by arraying the highest and lowest expert means.

[MM] EPA 2010, Renewable Fuel Standard Program (RFS2) Regulatory Impact Analysis. EPA-420-R-10-006. February 2010. Docket EPA-HQ-OAR-2009-0472-11332. see also 75 FR 14670, March 26, 2010.

Table 7-13 Estimated $PM_{2.5}$-Related Health Impacts[a]

Health Effect	2030 Annual Reduction in Incidence (5th% - 95th%ile)
Premature Mortality – Derived from epidemiology literature[b]	
Adult, age 30+, ACS Cohort Study (Pope et al., 2002)	60 (23 – 96)
Adult, age 25+, Six-Cities Study (Laden et al., 2006)	150 (83 – 220)
Infant, age <1 year (Woodruff et al., 1997)	0 (0-1)
Chronic bronchitis (adult, age 26 and over)	42 (8 – 77)
Non-fatal myocardial infarction (adult, age 18 and over)	100 (38 – 170)
Hospital admissions - respiratory (all ages)[c]	13 (7 – 20)
Hospital admissions - cardiovascular (adults, age >18)[d]	32 (23 – 38)
Emergency room visits for asthma (age 18 years and younger)	42 (25 – 59)
Acute bronchitis, (children, age 8-12)	95 (0 – 190)
Lower respiratory symptoms (children, age 7-14)	1,100 (540 – 1,700)
Upper respiratory symptoms (asthmatic children, age 9-18)	850 (270 – 1,400)
Asthma exacerbation (asthmatic children, age 6-18)	1,000 (120 – 2,900)
Work loss days	7,600 (6,600 – 8,500)
Minor restricted activity days (adults age 18-65)	45,000 (38,000 – 52,000)

Notes:
[a] Incidence is rounded to two significant digits. Estimates represent incidence within the 48 contiguous United States.
[b] PM-related adult mortality based upon the American Cancer Society (ACS) Cohort Study (Pope et al., 2002) and the Six-Cities Study (Laden et al., 2006). Note that these are two alternative estimates of adult mortality and should not be summed. PM-related infant mortality based upon a study by Woodruff, Grillo, and Schoendorf, (1997).[280]
[c] Respiratory hospital admissions for PM include admissions for chronic obstructive pulmonary disease (COPD), pneumonia and asthma.
[d] Cardiovascular hospital admissions for PM include total cardiovascular and subcategories for ischemic heart disease, dysrhythmias, and heart failure.

Table 7-14 Estimated Ozone-Related Health Impacts[a]

Health Effect	2030 Annual Reduction in Incidence (5th% - 95th%ile)
Premature Mortality, All ages[b]	
Multi-City Analyses	
Bell et al. (2004) – Non-accidental	-4 (-8 – 0)
Huang et al. (2005) – Cardiopulmonary	-7 (-14 – 1)
Schwartz (2005) – Non-accidental	-6 (-13 – 1)
Meta-analyses:	
Bell et al. (2005) – All cause	-13 (-24 - -2)
Ito et al. (2005) – Non-accidental	-18 (-30 - -6)
Levy et al. (2005) – All cause	-18 (-28 - -9)
Hospital admissions- respiratory causes (adult, 65 and older)c	-38 (-86 - -6)
Hospital admissions -respiratory causes (children, under 2)	-6 (-13 – 1)
Emergency room visit for asthma (all ages)	-16 (-51 – 8)
Minor restricted activity days (adults, age 18-65)	-18,000 (-40,000 – 3,700)
School absence days	-7,700 (-16,000 – 1,200)

Notes:

[a] Negatives indicate a disbenefit, or an increase in health effect incidence. Incidence is rounded to two significant digits. Estimates represent incidence within the 48 contiguous U.S.

[b] Estimates of ozone-related premature mortality are based upon incidence estimates derived from several alternative studies: Bell et al. (2004); Huang et al. (2005); Schwartz (2005) ; Bell et al. (2005); Ito et al. (2005); Levy et al. (2005). The estimates of ozone-related premature mortality should therefore not be summed.

[c] Respiratory hospital admissions for ozone include admissions for all respiratory causes and subcategories for COPD and pneumonia.

Table 7-15 Results of Application of Expert Elicitation: Annual Reductions in Premature Mortality in 2030 Associated with the Final Rule

Source of Mortality Estimate	2030 Primary Option		
	5th Percentile	Mean	95th Percentile
Pope et al. (2002)	23	60	96
Laden et al. (2006)	83	150	220
Expert A	30	160	300
Expert B	17	120	270
Expert C	22	120	270
Expert D	18	86	140
Expert E	100	200	310
Expert F	78	110	160
Expert G	0	72	130
Expert H	0	91	210
Expert I	19	120	220
Expert J	29	98	220
Expert K	0	22	100
Expert L	14	87	170

7.3.1.2 Monetized Estimates of Impacts of Changes in Non-GHG Pollutants

Table 7-16 presents the estimated monetary value of changes in the incidence of ozone and $PM_{2.5}$-related health effects. Total aggregate monetized benefits are presented in Table 7-17. All monetized estimates are presented in 2007$. Where appropriate, estimates account for growth in real gross domestic product (GDP) per capita between 2000 and 2030.[NN] The monetized value of $PM_{2.5}$-related mortality also accounts for a twenty-year segmented

[NN] Our analysis accounts for expected growth in real income over time. Economic theory argues that WTP for most goods (such as environmental protection) will increase if real incomes increase. Benefits are therefore adjusted by multiplying the unadjusted benefits by the appropriate adjustment factor to account for income growth over time. For growth between 2000 and 2030, this factor is 1.23 for long-term mortality, 1.27 for chronic health impacts, and 1.08 for minor health impacts. For a complete discussion of how these adjustment factors were derived, we refer the reader to the PM NAAQS regulatory impact analysis.[9] Note that similar adjustments do not exist for cost-of-illness-based unit values. For these, we apply the same unit value regardless of the future year of analysis.

cessation lag.[OO] To discount the value of premature mortality that occurs at different points in the future, we apply both a 3% and 7% discount rate. We also use both a 3% and 7% discount rate to value PM-related nonfatal heart attacks (myocardial infarctions).[PP] As the results indicate, total benefits are driven primarily by the reduction in $PM_{2.5}$-related premature fatalities each year.

In addition to omitted benefits categories such as air toxics and various welfare effects, not all known $PM_{2.5}$- and ozone-related health and welfare effects could be quantified or monetized. The estimate of total monetized health benefits of the final rule is thus equal to the subset of monetized $PM_{2.5}$- and ozone-related health impacts we are able to quantify plus the sum of the nonmonetized health and welfare benefits. Our estimate of total monetized benefits in 2030 for the final rule, using the ACS and Six-Cities PM mortality studies and the range of ozone mortality assumptions, is between $380 and $1,300 million, assuming a 3 percent discount rate, or between $330 and $1,200 million, assuming a 7 percent discount rate. As the results indicate, total benefits are driven primarily by the reduction in $PM_{2.5}$-related premature fatalities each year.

The next largest benefit is for reductions in chronic illness (chronic bronchitis and nonfatal heart attacks), although this value is more than an order of magnitude lower than for premature mortality. Hospital admissions for respiratory and cardiovascular causes, minor restricted activity days, and work loss days account for the majority of the remaining benefits. The remaining categories each account for a small percentage of total benefit; however, they represent a large number of avoided incidences affecting many individuals. A comparison of the incidence table to the monetary benefits table reveals that there is not always a close correspondence between the number of incidences avoided for a given endpoint and the monetary value associated with that endpoint. For example, there are over 100 times more work loss days than PM-related premature mortalities (based on the ACS study), yet work loss days account for only a very small fraction of total monetized benefits. This reflects the fact that many of the less severe health effects, while more common, are valued at a lower level than the more severe health effects. Also, some effects, such as hospital admissions, are

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[OO] Based in part on prior SAB advice, EPA has typically assumed that there is a time lag between changes in pollution exposures and the total realization of changes in health effects. Within the context of benefits analyses, this term is often referred to as "cessation lag". The existence of such a lag is important for the valuation of premature mortality incidence because economic theory suggests that benefits occurring in the future should be discounted. In this analysis, we apply a twenty-year distributed lag to PM mortality reductions. This method is consistent with the most recent recommendation by the EPA's Science Advisory Board. Refer to: EPA – Science Advisory Board, 2004. Advisory Council on Clean Air Compliance Analysis Response to Agency Request on Cessation Lag. Letter from the Health Effects Subcommittee to the U.S. Environmental Protection Agency Administrator, December.

[PP] Nonfatal myocardial infarctions (MI) are valued using age-specific cost-of-illness values that reflect lost earnings and direct medical costs over a 5-year period following a nonfatal MI.

valued using a proxy measure of willingness-to-pay (e.g., cost-of-illness). As such, the true value of these effects may be higher than that reported here.

Table 7-16 Estimated Monetary Value of Changes in Incidence of Health and Welfare Effects (in millions of 2007$) [a,b]

		2030
$PM_{2.5}$-Related Health Effect		(5th and 95th %ile)
Premature Mortality – Derived from Epidemiology Studies[c,d,]	Adult, age 30+ - ACS study (Pope et al., 2002)	
	3% discount rate	$510 ($70 - $1,300)
	7% discount rate	$460 ($63 - $1,200)
	Adult, age 25+ - Six-Cities study (Laden et al., 2006)	
	3% discount rate	$1,300 ($190 - $3,300)
	7% discount rate	$1,200 ($180 - $3,000)
	Infant Mortality, <1 year – (Woodruff et al. 1997)	$1.8 ($0 - $7.0)
Chronic bronchitis (adults, 26 and over)		$22 ($1.9 - $77)
Non-fatal acute myocardial infarctions		
3% discount rate		$14 ($3.9 - $35)
7% discount rate		$14 ($3.6 - $35)
Hospital admissions for respiratory causes		$0.20 ($0.01 - $0.29)
Hospital admissions for cardiovascular causes		$0.91 ($0.58 - $1.3)
Emergency room visits for asthma		$0.016 ($0.009 - $0.024)
Acute bronchitis (children, age 8–12)		$0.007 ($0 – $0.018)
Lower respiratory symptoms (children, 7–14)		$0.022 ($0.009 - $0.043)
Upper respiratory symptoms (asthma, 9–11)		$0.027 ($0.008 - $0.061)
Asthma exacerbations		$0.058 ($0.006 - $0.17)
Work loss days		$1.2 ($1.0 - $1.3)

Minor restricted-activity days (MRADs)		$2.9 ($1.7 - $4.2)
Ozone-related Health Effect		(5th and 95th %ile)
Premature Mortality, All ages – Derived from Multi-city analyses	Bell et al., 2004	-$38 (-$110 - $4.2)
	Huang et al., 2005	-$62 (-$180 - $4.7)
	Schwartz, 2005	-$58 (-$170 - $8.8)
Premature Mortality, All ages – Derived from Meta-analyses	Bell et al., 2005	-$120 (-$330 - -$7.9)
	Ito et al., 2005	-$170 (-$430 - -$19)
	Levy et al., 2005	-$170 (-$410 - -$21)
Hospital admissions- respiratory causes (adult, 65 and older)		-$0.92 (-$2.1 - $0.27)
Hospital admissions- respiratory causes (children, under 2)		-$.21 (-$.45 - $0.031)
Emergency room visit for asthma (all ages)		-$0.006 (-$0.018 - $0.003)
Minor restricted activity days (adults, age 18-65)		-$1.2 (-$2.7 - $0.25)
School absence days		-$0.71 (-$1.4 - $0.11)

Notes:
[a] Negatives indicate a disbenefit, or an increase in health effect incidence. Monetary benefits are rounded to two significant digits for ease of presentation and computation. PM and ozone benefits are nationwide.
[b] Monetary benefits adjusted to account for growth in real GDP per capita between 1990 and the analysis year (2030).
[c] Valuation assumes discounting over the SAB recommended 20 year segmented lag structure. Results reflect the use of 3 percent and 7 percent discount rates consistent with EPA and OMB guidelines for preparing economic analyses.

Table 7-17 Total Monetized Ozone and PM-related Benefits Associated with the Final Rule in 2030

Total Ozone and PM Benefits (billions, 2007$) – PM Mortality Derived from the ACS and Six-Cities Studies					
3% Discount Rate			**7% Discount Rate**		
Ozone Mortality Function	Reference	Mean Total Benefits	Ozone Mortality Function	Reference	Mean Total Benefits
Multi-city	Bell et al., 2004	$510 - $1,300	Multi-city	Bell et al., 2004	$460 - $1,200
	Huang et al., 2005	$490 - $1,300		Huang et al., 2005	$440 - $1,200
	Schwartz, 2005	$490 - $1,300		Schwartz, 2005	$440 - $1,200
Meta-analysis	Bell et al., 2005	$430 - $1,200	Meta-analysis	Bell et al., 2005	$380 - $1,100
	Ito et al., 2005	$380 - $1,200		Ito et al., 2005	$330 - $1,000
	Levy et al., 2005	$380 - $1,200		Levy et al., 2005	$330 - $1,000
Total Ozone and PM Benefits (billions, 2007$) – PM Mortality Derived from Expert Elicitation (Lowest and Highest Estimate)					
3% Discount Rate			**7% Discount Rate**		
Ozone Mortality Function	Reference	Mean Total Benefits	Ozone Mortality Function	Reference	Mean Total Benefits
Multi-city	Bell et al., 2004	$190 - $1,700	Multi-city	Bell et al., 2004	$170 - $1,600
	Huang et al., 2005	$160 - $1,700		Huang et al., 2005	$140 - $1,500
	Schwartz, 2005	$170 - $1,700		Schwartz, 2005	$150 - $1,500
Meta-analysis	Bell et al., 2005	$100 - $1,600	Meta-analysis	Bell et al., 2005	$86 - $1,500
	Ito et al., 2005	$56 - $1,600		Ito et al., 2005	$37 - $1,400
	Levy et al., 2005	$55 – $1,600		Levy et al., 2005	$36 - $1,400

7.3.1.3 Methodology

7.3.1.3.1 Human Health Impact Functions

Health impact functions measure the change in a health endpoint of interest, such as hospital admissions, for a given change in ambient ozone or PM concentration. Health impact functions are derived from primary epidemiology studies, meta-analyses of multiple epidemiology studies, or expert elicitations. A standard health impact function has four components: (1) an effect estimate from a particular study; (2) a baseline incidence rate for the health effect (obtained from either the epidemiology study or a source of public health statistics such as the Centers for Disease Control); (3) the size of the potentially affected population; and (4) the estimated change in the relevant ozone or PM summary measures.

A typical health impact function might look like:

$$\Delta y = y_0 \cdot \left(e^{\beta \cdot \Delta x} - 1\right),$$

where y_0 is the baseline incidence (the product of the baseline incidence rate times the potentially affected population), β is the effect estimate, and Δx is the estimated change in the summary pollutant measure. There are other functional forms, but the basic elements remain the same. The following subsections describe the sources for each of the first three elements: size of the potentially affected populations; $PM_{2.5}$ and ozone effect estimates; and baseline incidence rates. We also describe the treatment of potential thresholds in PM-related health impact functions. Section 7.2 describes the ozone and PM air quality inputs to the health impact functions.

7.3.1.3.1.1 Potentially Affected Populations

The starting point for estimating the size of potentially affected populations is the 2000 U.S. Census block level dataset.[281] Benefits Modeling and Analysis Program (BenMAP) incorporates 250 age/gender/race categories to match specific populations potentially affected by ozone and other air pollutants. The software constructs specific populations matching the populations in each epidemiological study by accessing the appropriate age-specific populations from the overall population database. BenMAP projects populations to 2030 using growth factors based on economic projections.[282]

7.3.1.3.1.2 Effect Estimate Sources

The most significant quantifiable benefits of reducing ambient concentrations of ozone and PM are attributable to reductions in human health risks. EPA's Ozone and PM Criteria Documents[283,284] and the World Health Organization's 2003 and 2004[285,286] reports outline numerous human health effects known or suspected to be linked to exposure to ambient ozone and PM. EPA recently evaluated the ozone and PM literature for use in the benefits analysis for the final 2008 Ozone NAAQS and final 2006 PM NAAQS analyses. We use the same literature in this analysis; for more information on the studies that underlie the health impacts quantified in this RIA, please refer to those documents.

It is important to note that we are unable to separately quantify all of the possible PM and ozone health effects that have been reported in the literature for three reasons: (1) the possibility of double counting (such as hospital admissions for specific respiratory diseases versus hospital admissions for all or a sub-set of respiratory diseases); (2) uncertainties in applying effect relationships that are based on clinical studies to the potentially affected population; or (3) the lack of an established concentration-response (CR) relationship. Table 7-18 lists the health endpoints included in this analysis.

Table 7-18 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)[287] – Non-accidental Huang et al (2005)[288] - Cardiopulmonary Schwartz (2005)[289] – Non-accidental Meta-analyses: Bell et al (2005)[290] – All cause Ito et al (2005)[291] – Non-accidental Levy et al (2005)[292] – All cause	All ages
Premature mortality —cohort study, all-cause	$PM_{2.5}$	Pope et al. (2002)[293] Laden et al. (2006)[294]	>29 years >25 years
Premature mortality, total exposures	$PM_{2.5}$	Expert Elicitation (IEc, 2006)[295]	>24 years
Premature mortality — all-cause	$PM_{2.5}$	Woodruff et al. (1997)[296]	Infant (<1 year)
Chronic Illness			
Chronic bronchitis	$PM_{2.5}$	Abbey et al. (1995)[297]	>26 years
Nonfatal heart attacks	$PM_{2.5}$	Peters et al. (2001)[298]	Adults (>18 years)
Hospital Admissions			
Respiratory	O_3	Pooled estimate: Schwartz (1995) - ICD 460-519 (all resp)[299] Schwartz (1994a; 1994b) - ICD 480-486 (pneumonia)[300,301] Moolgavkar et al. (1997) - ICD 480-487 (pneumonia)[302] Schwartz (1994b) - ICD 491-492, 494-496 (COPD) Moolgavkar et al. (1997) – ICD 490-496 (COPD)	>64 years
		Burnett et al. (2001)[303]	<2 years
	$PM_{2.5}$	Pooled estimate: Moolgavkar (2003)—ICD 490-496 (COPD)[304] Ito (2003)—ICD 490-496 (COPD)[305]	>64 years

	$PM_{2.5}$	Moolgavkar (2000)—ICD 490-496 (COPD)[306]	20–64 years
	$PM_{2.5}$	Ito (2003)—ICD 480-486 (pneumonia)	>64 years
	$PM_{2.5}$	Sheppard (2003)—ICD 493 (asthma)[307]	<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)[308] Peel et al (2005)[309] Wilson et al (2005)[310]	 5–34 years All ages All ages
Asthma-related ER visits (con't)	$PM_{2.5}$	Norris et al. (1999)[311]	0–18 years
Other Health Endpoints			
Acute bronchitis	$PM_{2.5}$	Dockery et al. (1996)[312]	8–12 years
Upper respiratory symptoms	$PM_{2.5}$	Pope et al. (1991)[313]	Asthmatics, 9–11 years
Lower respiratory symptoms	$PM_{2.5}$	Schwartz and Neas (2000)[314]	7–14 years
Asthma exacerbations	$PM_{2.5}$	Pooled estimate: Ostro et al. (2001)[315] (cough, wheeze and shortness of breath) Vedal et al. (1998)[316] (cough)	6–18 years[a]
Work loss days	$PM_{2.5}$	Ostro (1987)[317]	18–65 years
School absence days	O_3	Pooled estimate: Gilliland et al. (2001)[318] Chen et al. (2000)[319]	5–17 years[b]
Minor Restricted Activity Days (MRADs)	O_3	Ostro and Rothschild (1989)[320]	18–65 years
	$PM_{2.5}$	Ostro and Rothschild (1989)	18–65 years

Notes:
[a] The original study populations were 8 to 13 for the Ostro et al. (2001) study and 6 to 13 for the Vedal et al. (1998) study. Based on advice from the Science Advisory Board Health Effects Subcommittee (SAB-HES), we extended the applied population to 6 to 18, reflecting the common biological basis for the effect in children in the broader age group. See: U.S. Science Advisory Board. 2004. Advisory Plans for Health Effects Analysis in the Analytical Plan for EPA's Second Prospective Analysis –Benefits and Costs of the Clean Air Act, 1990—2020. EPA-SAB-COUNCIL-ADV-04-004. See also National Research Council (NRC). 2002. *Estimating the Public Health Benefits of Proposed Air Pollution Regulations*. Washington, DC: The National Academies Press.
[b] Gilliland et al. (2001) studied children aged 9 and 10. Chen et al. (2000) studied children 6 to 11. Based on recent advice from the National Research Council and the EPA SAB-HES, we have calculated reductions in school absences for all school-aged children based on the biological similarity between children aged 5 to 17.

In selecting epidemiological studies as sources of effect estimates, we applied several criteria to develop a set of studies that is likely to provide the best estimates of impacts in the U.S. To account for the potential impacts of different health care systems or underlying health status of populations, we give preference to U.S. studies over non-U.S. studies. In addition, due to the potential for confounding by co-pollutants, we give preference to effect estimates from models including both ozone and PM over effect estimates from single-pollutant models.[321,322]

7.3.1.3.1.3 Baseline Incidence Rates

Epidemiological studies of the association between pollution levels and adverse health effects generally provide a direct estimate of the relationship of air quality changes to the *relative risk* of a health effect, rather than estimating the absolute number of avoided cases. For example, a typical result might be that a 100 ppb decrease in daily ozone levels might, in turn, decrease hospital admissions by 3 percent. The baseline incidence of the health effect is necessary to convert this relative change into a number of cases. A baseline incidence rate is the estimate of the number of cases of the health effect per year in the assessment location, as it corresponds to baseline pollutant levels in that location. To derive the total baseline incidence per year, this rate must be multiplied by the corresponding population number. For example, if the baseline incidence rate is the number of cases per year per 100,000 people, that number must be multiplied by the number of 100,000s in the population.

Table 7-19 summarizes the sources of baseline incidence rates and provides average incidence rates for the endpoints included in the analysis. For both baseline incidence and prevalence data, we used age-specific rates where available. We applied concentration-response functions to individual age groups and then summed over the relevant age range to provide an estimate of total population benefits. In most cases, we used a single national incidence rate, due to a lack of more spatially disaggregated data. Whenever possible, the national rates used are national averages, because these data are most applicable to a national assessment of benefits. For some studies, however, the only available incidence information comes from the studies themselves; in these cases, incidence in the study population is assumed to represent typical incidence at the national level. Regional incidence rates are available for hospital admissions, and county-level data are available for premature mortality. We have projected mortality rates such that future mortality rates are consistent with our projections of population growth.[323]

Table 7-19 National Average Baseline Incidence Rates[a]

Endpoint	Source	Notes	Rate per 100 people per year[d] by Age Group						
			<18	*18-24*	*25-34*	*35-44*	*45-54*	*55-64*	*65+*
Mortality	CDC Compressed Mortality File, accessed through CDC Wonder (1996-1998)	non-accidental	0.025	0.022	0.057	0.150	0.383	1.006	4.937
Respiratory Hospital Admissions.	1999 NHDS public use data files[b]	incidence	0.043	0.084	0.206	0.678	1.926	4.389	11.62
Asthma ER visits	2000 NHAMCS public use data files[c]; 1999 NHDS public use data files[b]	incidence	1.011	1.087	0.751	0.438	0.352	0.425	0.232
Minor Restricted Activity Days (MRADs)	Ostro and Rothschild (1989, p. 243)	incidence	–	780	780	780	780	780	–
School Loss Days	National Center for Education Statistics (1996) and 1996 HIS (Adams et al., 1999, Table 47); estimate of 180 school days per year	all-cause	990.0	–	–	–	–	–	–

Notes:

[a] The following abbreviations are used to describe the national surveys conducted by the National Center for Health Statistics: HIS refers to the National Health Interview Survey; NHDS - National Hospital Discharge Survey; NHAMCS - National Hospital Ambulatory Medical Care Survey.

[b] See ftp://ftp.cdc.gov/pub/Health_Statistics/NCHS/Datasets/NHDS/

[c] See ftp://ftp.cdc.gov/pub/Health_Statistics/NCHS/Datasets/NHAMCS/

[d] All of the rates reported here are population-weighted incidence rates per 100 people per year. Additional details on the incidence and prevalence rates, as well as the sources for these rates are available upon request.

Table 7-19 National Average Baseline Incidence Rates (continued)

Endpoint	Source	Notes		Rate per 100 people per year
Asthma Exacerbations	Ostro et al. (2001)	Incidence (and prevalence) among asthmatic African-American children	Daily wheeze Daily cough Daily dyspnea	0.076 (0.173) 0.067 (0.145) 0.037 (0.074)
	Vedal et al. (1998)	Incidence (and prevalence) among asthmatic children	Daily wheeze Daily cough Daily dyspnea	0.038 0.086 0.045

7.3.1.3.1.4 Treatment of Potential Thresholds in $PM_{2.5}$-Related Health Impact Functions

In past analyses, OTAQ has estimated $PM_{2.5}$-related benefits assuming that a threshold exists in the PM-related concentration-response functions (at 10 $\mu g/m^3$) below which there are no associations between exposure to $PM_{2.5}$ and health impacts. Based on our review of the body of scientific literature, however, EPA's preferred benefits estimation approach assumes a no-threshold model that calculates incremental benefits down to the lowest modeled $PM_{2.5}$ air quality levels.

EPA strives to use the best available science to support our benefits analyses, and we recognize that interpretation of the science regarding air pollution and health is dynamic and evolving. EPA's Integrated Science Assessment,[QQ] which was recently reviewed by EPA's Clean Air Scientific Advisory Committee,[RR,SS] concluded that the scientific literature consistently finds that a no-threshold log-linear model most adequately portrays the PM-mortality concentration-response relationship while recognizing potential uncertainty about the

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[QQ] U.S. Environmental Protection Agency (U.S. EPA). 2009. Integrated Science Assessment for Particulate Matter . National Center for Environmental Assessment, Research Triangle Park, NC. EPA/600/R-08/139F. December. Available on the Internet at <http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=216546>. Accessed March 15, 2010.

[RR] U.S. Environmental Protection Agency - Science Advisory Board (U.S. EPA-SAB). Review of EPA's Integrated Science Assessment for Particulate Matter (First External Review Draft, December 2008). EPA-COUNCIL-09-008. May. Available on the Internet at <http://yosemite.epa.gov/sab/SABPRODUCT.NSF/81e39f4c09954fcb85256ead006be86e/73ACCA834AB44A10852575BD0064346B/$File/EPA-CASAC-09-008-unsigned.pdf>.

[SS] U.S. Environmental Protection Agency - Science Advisory Board (U.S. EPA-SAB). Consultation on EPA's Particulate Matter National Ambient Air Quality Standards: Scope and Methods Plan for Health Risk and Exposure Assessment. EPA-COUNCIL-09-009. May. Available on the Internet at <http://yosemite.epa.gov/sab/SABPRODUCT.NSF/81e39f4c09954fcb85256ead006be86e/723FE644C5D758DF852575BD00763A32/$File/EPA-CASAC-09-009-unsigned.pdf>.

exact shape of the concentration-response function.[TT] Although this document does not necessarily represent final agency policy, it provides a basis for reconsidering the application of thresholds in $PM_{2.5}$ concentration-response functions used in EPA's RIAs. It is important to note that while CASAC provides advice regarding the science associated with setting the National Ambient Air Quality Standards, typically other scientific advisory bodies provide specific advice regarding benefits analysis.[UU] This approach reflects EPA's most current interpretation of the scientific literature on $PM_{2.5}$ and mortality. Please refer to the documentation associated with the proposed Portland Cement MACT RIA for a description of the history of the treatment of thresholds in our analyses.[324]

As can be seen in Table 7-7-20, we conducted a sensitivity analysis for premature mortality, with alternative thresholds at 3 $\mu g/m^3$ (the "background," or no-threshold, assumption), 7.5 $\mu g/m^3$, 10 $\mu g/m^3$, 12 $\mu g/m^3$, and 14 $\mu g/m^3$**.** By replacing the no-threshold assumption in the ACS premature mortality function with a 10 $\mu g/m^3$ threshold model, the number of avoided incidences of premature mortality would decrease by approximately 22 percent.

[TT] It is important to note that uncertainty regarding the shape of the concentration-response function is conceptually distinct from an assumed threshold. An assumed threshold (below which there are no health effects) is a discontinuity, which is a specific example of non-linearity.

[UU] In the proposed Portland Cement RIA, EPA solicited comment on the use of the no-threshold model for benefits analysis within the preamble of that proposed rule. The comment period for the Portland Cement proposed NESHAP closed on September 4, 2009 (Docket ID No. EPA–HQ–OAR–2002–0051 available at http://www.regulations.gov). EPA is currently reviewing those comments. U.S. Environmental Protection Agency. (2009). Regulatory Impact Analysis: National Emission Standards for Hazardous Air Pollutants from the Portland Cement Manufacturing Industry. Office of Air and Radiation. Retrieved on May 4, 2009, from http://www.epa.gov/ttn/ecas/regdata/RIAs/portlandcementria_4-20-09.pdf

Table 7-7-20 PM-Related Mortality Benefits Associated with the Final Rule: Threshold Sensitivity Analysis Using the ACS Study (Pope et al., 2002)[a]

Level of Assumed Threshold	PM Mortality Incidence
	2030
14 µg/m3 [b]	30
12 µg/m3	35
10 µg/m3 [c]	47
7.5 µg/m3 [d]	56
3 µg/m3 [e]	60

Notes:

[a] Note that this table only presents the effects of a threshold on PM-related mortality incidence based on the ACS study.
[b] Alternative annual PM NAAQS.
[c] Previous threshold assumption
[d] SAB-HES (2004)[86]
[e] NAS (2002)[87]

7.3.1.3.2 Economic Values for Health Outcomes

Reductions in ambient concentrations of air pollution generally lower the risk of future adverse health effects for a large population. Therefore, the appropriate economic measure is willingness-to-pay (WTP) for changes in risk of a health effect rather than WTP for a health effect that would occur with certainty (Freeman, 1993). Epidemiological studies generally provide estimates of the relative risks of a particular health effect that is avoided because of a reduction in air pollution. We converted those to units of avoided statistical incidence for ease of presentation. We calculated the value of avoided statistical incidences by dividing individual WTP for a risk reduction by the related observed change in risk. For example, suppose a pollution-reduction regulation is able to reduce the risk of premature mortality from 2 in 10,000 to 1 in 10,000 (a reduction of 1 in 10,000). If individual WTP for this risk reduction is $100, then the WTP for an avoided statistical premature death is $1 million ($100/0.0001 change in risk).

WTP estimates generally are not available for some health effects, such as hospital admissions. In these cases, we used the cost of treating or mitigating the effect as a primary estimate. These cost-of-illness (COI) estimates generally understate the true value of reducing the risk of a health effect, because they reflect the direct expenditures related to treatment, but not the value of avoided pain and suffering (Harrington and Portney, 1987; Berger, 1987). We provide unit values for health endpoints (along with information on the distribution of the unit value) in Table 7-7-21. All values are in constant year 2000 dollars, adjusted for growth in real income out to 2020 and 2030 using projections provided by Standard and Poor's. Economic theory argues that WTP for most goods (such as environmental protection) will increase if real income increases. Many of the valuation studies used in this analysis were conducted in the late 1980s and early 1990s. Because real income has grown since the studies were conducted, people's willingness to pay for reductions in the risk of premature death and disease likely has grown as well. We did not adjust cost of illness-based values because they are based on current costs. Similarly, we did not adjust the value of school absences, because that value is based on current wage rates. For details on valuation estimates for PM-related endpoints, see the 2006 PM NAAQS RIA. For details on valuation estimates for ozone-related endpoints, see the 2008 Ozone NAAQS RIA.

Table 7-7-21 Unit Values Used for Economic Valuation of Health Endpoints (2000$)[a]

Health Endpoint	Central Estimate of Value Per Statistical Incidence			Derivation of Estimates
	1990 Income Level	2020 Income Level[b]	2030 Income Level[b]	
Premature Mortality (Value of a Statistical Life): $PM_{2.5}$- and Ozone-related	$6,320,000	$7,590,000	$7,800,000	EPA currently recommends a default central VSL of $6.3 million based on a Weibull distribution fitted to twenty-six published VSL estimates (5 contingent valuation and 21 labor market studies). The underlying studies, the distribution parameters, and other useful information are available in Appendix B of EPA's current Guidelines for Preparing Economic Analyses. The guidelines can be accessed at: http://yosemite.epa.gov/ee/epa/eermfile.nsf/vwAN/EE-0516-01.pdf/$File/EE-0516-01.pdf
Chronic Bronchitis (CB)	$340,000	$420,000	$430,000	Point estimate is the mean of a generated distribution of WTP to avoid a case of pollution-related CB. WTP to avoid a case of pollution-related CB is derived by adjusting WTP (as described in Viscusi et al., 1991[325]) to avoid a severe case of CB for the difference in severity and taking into account the elasticity of WTP with respect to severity of CB.
Nonfatal Myocardial Infarction (heart attack) 3% discount rate Age 0–24 Age 25–44 Age 45–54 Age 55–65 Age 66 and over 7% discount rate Age 0–24 Age 25–44 Age 45–54 Age 55–65 Age 66 and over	 $66,902 $74,676 $78,834 $140,649 $66,902 $65,293 $73,149 $76,871 $132,214 $65,293	 $66,902 $74,676 $78,834 $140,649 $66,902 $65,293 $73,149 $76,871 $132,214 $65,293	 $66,902 $74,676 $78,834 $140,649 $66,902 $65,293 $73,149 $76,871 $132,214 $65,293	Age-specific cost-of-illness values reflect lost earnings and direct medical costs over a 5-year period following a nonfatal MI. Lost earnings estimates are based on Cropper and Krupnick (1990).[326] Direct medical costs are based on simple average of estimates from Russell et al. (1998)[327] and Wittels et al. (1990).[328] Lost earnings: Cropper and Krupnick (1990). Present discounted value of 5 years of lost earnings: age of onset: at 3% at 7% 25-44 $8,774 $7,855 45-54 $12,932 $11,578 55-65 $74,746 $66,920 Direct medical expenses: An average of: 1. Wittels et al. (1990) ($102,658—no discounting) 2. Russell et al. (1998), 5-year period ($22,331 at 3% discount rate; $21,113 at 7% discount rate)

Table 7-7-21 Unit Values Used for Economic Valuation of Health Endpoints (2000$)[a] (continued)

Health Endpoint	Central Estimate of Value Per Statistical Incidence			Derivation of Estimates
	1990 Income Level	2020 Income Level[b]	2030 Income Level[b]	
Hospital Admissions				
Chronic Obstructive Pulmonary Disease (COPD) (ICD codes 490-492, 494-496)	$12,378	$12,378	$12,378	The COI estimates (lost earnings plus direct medical costs) are based on ICD-9 code-level information (e.g., average hospital care costs, average length of hospital stay, and weighted share of total COPD category illnesses) reported in Agency for Healthcare Research and Quality (2000)[329] (www.ahrq.gov).
Pneumonia (ICD codes 480-487)	$14,693	$14,693	$14,693	The COI estimates (lost earnings plus direct medical costs) are based on ICD-9 code-level information (e.g., average hospital care costs, average length of hospital stay, and weighted share of total pneumonia category illnesses) reported in Agency for Healthcare Research and Quality (2000) (www.ahrq.gov).
Asthma Admissions	$6,634	$6,634	$6,634	The COI estimates (lost earnings plus direct medical costs) are based on ICD-9 code-level information (e.g., average hospital care costs, average length of hospital stay, and weighted share of total asthma category illnesses) reported in Agency for Healthcare Research and Quality (2000) (www.ahrq.gov).
All Cardiovascular (ICD codes 390-429)	$18,387	$18,387	$18,387	The COI estimates (lost earnings plus direct medical costs) are based on ICD-9 code-level information (e.g., average hospital care costs, average length of hospital stay, and weighted share of total cardiovascular category illnesses) reported in Agency for Healthcare Research and Quality (2000) (www.ahrq.gov).
Emergency Room Visits for Asthma	$286	$286	$286	Simple average of two unit COI values: (1) $311.55, from Smith et al. (1997)[330] and (2) $260.67, from Stanford et al. (1999).[331]

Table 7-7-21 Unit Values Used for Economic Valuation of Health Endpoints (2000$)[a] (continued)

Health Endpoint	Central Estimate of Value Per Statistical Incidence			Derivation of Estimates
	1990 Income Level	2020 Income Level[b]	2030 Income Level[b]	
Respiratory Ailments Not Requiring Hospitalization				
Upper Respiratory Symptoms (URS)	$25	$27	$27	Combinations of the three symptoms for which WTP estimates are available that closely match those listed by Pope et al. result in seven different "symptom clusters," each describing a "type" of URS. A dollar value was derived for each type of URS, using mid-range estimates of WTP (IEc, 1994)[332] to avoid each symptom in the cluster and assuming additivity of WTPs. The dollar value for URS is the average of the dollar values for the seven different types of URS.
Lower Respiratory Symptoms (LRS)	$16	$17	$17	Combinations of the four symptoms for which WTP estimates are available that closely match those listed by Schwartz et al. result in 11 different "symptom clusters," each describing a "type" of LRS. A dollar value was derived for each type of LRS, using mid-range estimates of WTP IEc, 1994) to avoid each symptom in the cluster and assuming additivity of WTPs. The dollar value for LRS is the average of the dollar values for the 11 different types of LRS.
Asthma Exacerbations	$42	$45	$45	Asthma exacerbations are valued at $42 per incidence, based on the mean of average WTP estimates for the four severity definitions of a "bad asthma day," described in Rowe and Chestnut (1986).[333] This study surveyed asthmatics to estimate WTP for avoidance of a "bad asthma day," as defined by the subjects. For purposes of valuation, an asthma attack is assumed to be equivalent to a day in which asthma is moderate or worse as reported in the Rowe and Chestnut (1986) study.
Acute Bronchitis	$360	$380	$390	Assumes a 6-day episode, with daily value equal to the average of low and high values for related respiratory symptoms recommended in Neumann et al. (1994).[334]

Table 7-7-21 Unit Values Used for Economic Valuation of Health Endpoints (2000$)[a] (continued)

Health Endpoint	Central Estimate of Value Per Statistical Incidence			Derivation of Estimates
	1990 Income Level	2020 Income Level[b]	2030 Income Level[b]	
Restricted Activity and Work/School Loss Days				
Work Loss Days (WLDs)	Variable (national median =)			County-specific median annual wages divided by 50 (assuming 2 weeks of vacation) and then by 5—to get median daily wage. U.S. Year 2000 Census, compiled by Geolytics, Inc.
School Absence Days	$75	$75	$75	Based on expected lost wages from parent staying home with child. Estimated daily lost wage (if a mother must stay at home with a sick child) is based on the median weekly wage among women age 25 and older in 2000 (U.S. Census Bureau, Statistical Abstract of the United States: 2001, Section 12: Labor Force, Employment, and Earnings, Table No. 621). This median wage is $551. Dividing by 5 gives an estimated median daily wage of $103. The expected loss in wages due to a day of school absence in which the mother would have to stay home with her child is estimated as the probability that the mother is in the workforce times the daily wage she would lose if she missed a day = 72.85% of $103, or $75.
Worker Productivity	$0.95 per worker per 10% change in ozone per day	$0.95 per worker per 10% change in ozone per day	$0.95 per worker per 10% change in ozone per day	Based on $68 – median daily earnings of workers in farming, forestry and fishing – from Table 621, Statistical Abstract of the United States ("Full-Time Wage and Salary Workers – Number and Earnings: 1985 to 2000") (Source of data in table: U.S. Bureau of Labor Statistics, Bulletin 2307 and Employment and Earnings, monthly).
Minor Restricted Activity Days (MRADs)	$51	$54	$55	Median WTP estimate to avoid one MRAD from Tolley et al. (1986).[335]

[a] All monetized annual benefit estimates are presented in year 2000 dollars. We use the Consumer Price Indexes to adjust both WTP- and COI-based benefits estimates to 2007 dollars from 2000 dollars.[336] For WTP-based estimates, we use an inflation factor of 1.20 based on the CPI-U for "all items." For COI-based estimates, we use an inflation factor of 1.35 based on the CPI-U for medical care.

[b] Our analysis accounts for expected growth in real income over time. Economic theory argues that WTP for most goods (such as environmental protection) will increase if real incomes increase. Benefits are therefore adjusted by multiplying the unadjusted benefits by the appropriate adjustment factor to account for income growth over time. For a complete discussion of how these adjustment factors were derived, we refer the reader to the PM NAAQS regulatory impact analysis. Note that similar adjustments do not exist for cost-of-illness-based unit values. For these, we apply the same unit value regardless of the future year of analysis.

7.3.1.3.3 Manipulating Air Quality Modeling Data for Health Impacts Analysis

In Section 7.2, we summarized the methods for and results of estimating air quality for the final rule. These air quality results are in turn associated with human populations to estimate changes in health effects. For the purposes of this analysis, we focus on the health effects that have been linked to ambient changes in ozone and $PM_{2.5}$ related to emission reductions estimated to occur due to the implementation of the final rule. We estimate ambient $PM_{2.5}$ and ozone concentrations using the Community Multiscale Air Quality model (CMAQ). This section describes how we converted the CMAQ modeling output into full-season profiles suitable for the health impacts analysis.

7.3.1.3.3.1 General Methodology

First, we extracted hourly, surface-layer PM and ozone concentrations for each grid cell from the standard CMAQ output files. For ozone, these model predictions are used in conjunction with the observed concentrations obtained from the Aerometric Information Retrieval System (AIRS) to generate ozone concentrations for the entire ozone season.[VV,WW] The predicted changes in ozone concentrations from the future-year base case to future-year control scenario serve as inputs to the health and welfare impact functions of the benefits analysis (i.e., BenMAP).

To estimate ozone-related health effects for the contiguous United States, full-season ozone data are required for every BenMAP grid-cell. Given available ozone monitoring data, we generated full-season ozone profiles for each location in two steps: (1) we combined monitored observations and modeled ozone predictions to interpolate hourly ozone concentrations to a grid of 12-km by 12-km population grid cells for the contiguous 48 states, and (2) we converted these full-season hourly ozone profiles to an ozone measure of interest, such as the daily 8-hour maximum.[XX,YY]

For $PM_{2.5}$, we also use the model predictions in conjunction with observed monitor data. CMAQ generates predictions of hourly PM species concentrations for every grid. The species include a primary coarse fraction (corresponding to PM in the 2.5 to 10 micron size range), a primary fine fraction (corresponding to PM less than 2.5 microns in diameter), and several secondary particles (e.g., sulfates, nitrates, and organics). $PM_{2.5}$ is calculated as the sum of the primary fine fraction and all of the secondarily formed particles. Future-year estimates of $PM_{2.5}$ were calculated using relative reduction factors (RRFs) applied to 2002 ambient $PM_{2.5}$ and $PM_{2.5}$ species concentrations. A gridded field of $PM_{2.5}$ concentrations was created by interpolating Federal Reference Monitor ambient data and IMPROVE ambient

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[VV] The ozone season for this analysis is defined as the 5-month period from May to September.
[WW] Based on AIRS, there were 961 ozone monitors with sufficient data (i.e., 50 percent or more days reporting at least nine hourly observations per day [8 am to 8 pm] during the ozone season).
[XX] The 12-km grid squares contain the population data used in the health benefits analysis model, BenMAP.
[YY] This approach is a generalization of planar interpolation that is technically referred to as enhanced Voronoi Neighbor Averaging (EVNA) spatial interpolation. See the BenMAP manual for technical details, available for download at http://www.epa.gov/air/benmap.

data. Gridded fields of $PM_{2.5}$ species concentrations were created by interpolating EPA speciation network (ESPN) ambient data and IMPROVE data. The ambient data were interpolated to the CMAQ 12 km grid.

The procedures for determining the RRFs are similar to those in EPA's draft guidance for modeling the $PM_{2.5}$ standard (EPA, 1999). The guidance recommends that model predictions be used in a relative sense to estimate changes expected to occur in each major $PM_{2.5}$ species. The procedure for calculating future-year $PM_{2.5}$ design values is called the "Speciated Modeled Attainment Test (SMAT)." EPA used this procedure to estimate the ambient impacts of the final rule.

Table 7-7-22 provides those ozone and $PM_{2.5}$ metrics for grid cells in the modeled domain that enter the health impact functions for health benefits endpoints. The population-weighted average reflects the baseline levels and predicted changes for more populated areas of the nation. This measure better reflects the potential benefits through exposure changes to these populations.

Table 7-7-22 Summary of CMAQ-Derived Population-Weighted Ozone and $PM_{2.5}$ Air Quality Metrics for Health Benefits Endpoints Associated with the Final Rule

	2030	
Statistic[a]	Baseline	Change[b]
Ozone Metric: National Population-Weighted Average (ppb)[c]		
Daily Maximum 8-Hour Average Concentration	43.5620	-0.0104
$PM_{2.5}$ Metric: National Population-Weighted Average (ug/m^3)		
Average Concentration	9.7548	0.0036

Notes:

[a] Ozone and $PM_{2.5}$ metrics are calculated at the CMAQ grid-cell level for use in health effects estimates. Ozone metrics are calculated over relevant time periods during the daylight hours of the "ozone season" (i.e., May through September).

[b] The change is defined as the base-case value minus the control-case value. A negative value indicates an increase in population-weighted average air quality from the baseline to the control scenario.

[c] Calculated by summing the product of the projected CMAQ grid-cell population and the estimated CMAQ grid cell seasonal ozone concentration and then dividing by the total population.

Emissions and air quality modeling decisions are made early in the analytical process. For this reason, the emission control scenarios used in the air quality and benefits modeling are slightly different than the final emission inventories estimated for the final rule. Please refer to Chapter 5.5 for more information about the inventories used in the air quality modeling that supports the health impacts analysis.

7.3.1.4 Methods for Describing Uncertainty

The National Research Council (NRC)[337] highlighted the need for EPA to conduct rigorous quantitative analysis of uncertainty in its benefits estimates and to present these estimates to decision makers in ways that foster an appropriate appreciation of their inherent uncertainty. In response to these comments, EPA's Office of Air and Radiation (OAR) is developing a comprehensive strategy for characterizing the aggregate impact of uncertainty in key modeling elements on both health incidence and benefits estimates. Components of that process include emissions modeling, air quality modeling, health effects incidence estimation, and valuation.

In benefit analyses of air pollution regulations conducted to date, the estimated impact of reductions in premature mortality has accounted for 85% to 95% of total benefits. Therefore, it is particularly important to characterize the uncertainties associated with reductions in premature mortality. The health impact functions used to estimate avoided premature deaths associated with reductions in ozone have associated standard errors that represent the statistical errors around the effect estimates in the underlying epidemiological studies.[ZZ] In our results, we report credible intervals based on these standard errors, reflecting the uncertainty in the estimated change in incidence of avoided premature deaths. We also provide multiple estimates, to reflect model uncertainty between alternative study designs.

For premature mortality associated with exposure to PM, we follow the same approach that has been used in several recent RIAs.[338,339,340] First, we use Monte Carlo methods for estimating random sampling error associated with the concentration response functions from epidemiological studies and economic valuation functions. Monte Carlo simulation uses random sampling from distributions of parameters to characterize the effects of uncertainty on output variables, such as incidence of premature mortality. Specifically, we used Monte Carlo methods to generate confidence intervals around the estimated health impact and dollar benefits. Distributions for individual effect estimates are based on the reported standard errors in the epidemiological studies. Distributions for unit values are described in Table 7-7-21.

Second, as a sensitivity analysis, we use the results of our expert elicitation of the concentration response function describing the relationship between premature mortality and ambient $PM_{2.5}$ concentration.[AAA, 341] Incorporating only the uncertainty from random sampling error omits important sources of uncertainty (e.g., in the functional form of the model; whether or not a threshold may exist). This second approach attempts to incorporate these other sources of uncertainty.

Use of the expert elicitation and incorporation of the standard errors approaches provide insights into the likelihood of different outcomes and about the state of knowledge regarding the benefits estimates. Both approaches have different strengths and weaknesses, which are fully described in Chapter 5 of the PM NAAQS RIA.

These multiple characterizations, including confidence intervals, omit the contribution

[ZZ] Health impact functions measure the change in a health endpoint of interest, such as hospital admissions, for a given change in ambient ozone or PM concentration.

[AAA] Expert elicitation is a formal, highly structured and well documented process whereby expert judgments, usually of multiple experts, are obtained (Ayyb, 2002).

to overall uncertainty of uncertainty in air quality changes, baseline incidence rates, populations exposed and transferability of the effect estimate to diverse locations. Furthermore, the approach presented here does not yet include methods for addressing correlation between input parameters and the identification of reasonable upper and lower bounds for input distributions characterizing uncertainty in additional model elements. As a result, the reported confidence intervals and range of estimates give an incomplete picture about the overall uncertainty in the estimates. This information should be interpreted within the context of the larger uncertainty surrounding the entire analysis.

As mentioned above, total benefits are driven primarily by the reduction in $PM_{2.5}$-related premature mortalities each year. Some key assumptions underlying the premature mortality estimates include the following, which may also contribute to uncertainty:

- Inhalation of fine particles is causally associated with premature death at concentrations near those experienced by most Americans on a daily basis. Although biological mechanisms for this effect have not yet been completely established, the weight of the available epidemiological, toxicological, and experimental evidence supports an assumption of causality. The impacts of including a probabilistic representation of causality were explored in the expert elicitation-based results of the PM NAAQS RIA.

- All fine particles, regardless of their chemical composition, are equally potent in causing premature mortality. This is an important assumption, because PM produced via transported precursors emitted from engines may differ significantly from PM precursors released from electric generating units and other industrial sources. However, no clear scientific grounds exist for supporting differential effects estimates by particle type.

- The C-R function for fine particles is approximately 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, including both regions that may be in attainment with $PM_{2.5}$ standards and those that are at risk of not meeting the standards.

- There is uncertainty in the magnitude of the association between ozone and premature mortality. The range of ozone impacts associated with the final rule is estimated based on the risk of several sources of ozone-related mortality effect estimates. In a recent report on the estimation of ozone-related premature mortality published by the National Research Council, 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.[342] EPA has requested advice from the National Academy of Sciences on how best to quantify uncertainty in the relationship between ozone exposure and premature mortality in the context of quantifying benefits.

Acknowledging omissions and uncertainties, we present a best estimate of the total benefits based on our interpretation of the best available scientific literature and methods supported by EPA's technical peer review panel, the Science Advisory Board's Health Effects Subcommittee (SAB-HES). The National Academies of Science (NRC, 2002) has also reviewed EPA's methodology for analyzing the health benefits of measures taken to reduce air pollution. EPA addressed many of these comments in the analysis of the final PM NAAQS.[343,344] This analysis incorporates this most recent work to the extent possible.

7.3.2 PM-related Monetized Benefits of the Model Year (MY) Analysis

As described in Chapter 5.5, the final standards will reduce emissions of several criteria and toxic pollutants and precursors. In the MY analysis, EPA estimates the economic value of the human health benefits associated with reducing $PM_{2.5}$ exposure. Due to analytical limitations, this analysis does not estimate benefits related to other criteria pollutants (such as ozone, NO_2 or SO_2) or toxics pollutants, nor does it monetize all of the potential health and welfare effects associated with $PM_{2.5}$.

The MY analysis uses a "benefit-per-ton" method to estimate a selected suite of $PM_{2.5}$-related health benefits described below. These $PM_{2.5}$ 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 NO_X, SO_X, and VOCs), from a specified source. Ideally, the human health benefits associated with the MY analysis 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 the final rule due to the time and resource constraints associated with running full-scale photochemical air quality modeling.

The dollar-per-ton estimates used in this analysis are provided in Table 7-23. In the summary of costs and benefits, Chapter 8.4 of this RIA, EPA presents the monetized value of PM-related improvements associated with the final rule.

Table 7-23 Benefits-per-ton Values (2007$) Derived Using the ACS Cohort Study for PM-related Premature Mortality (Pope et al., 2002)[a]

Year[c]	All Sources[d]		Stationary (Non-EGU) Sources		Mobile Sources	
	SO_X	VOC	NO_X	Direct $PM_{2.5}$	NO_X	Direct $PM_{2.5}$
Estimated Using a 3 Percent Discount Rate[b]						
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
Estimated Using a 7 Percent Discount Rate[b]						
2015	$26,000	$1,100	$4,200	$200,000	$4,400	$240,000
2020	$28,000	$1,200	$4,600	$220,000	$4,800	$270,000
2030	$33,000	$1,400	$5,500	$250,000	$5,800	$320,000
2040	$39,000	$1,600	$6,600	$300,000	$6,900	$380,000

[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 either a 3 percent or 7 percent discount rate in the valuation of premature mortality to account for a twenty-year segmented cessation lag.
[c] Benefit-per-ton values were estimated for the years 2015, 2020, and 2030. For 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,[345] the proposed Portland Cement National Emissions Standards for Hazardous Air Pollutants (NESHAP) RIA (U.S. EPA, 2009a),[346] and the final NO_2 NAAQS (U.S. EPA, 2009b).[347] Table 7-24 shows the quantified and unquantified $PM_{2.5}$-related co-benefits captured in those benefit-per-ton estimates.

Table 7-24 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 final NO_2 NAAQS,[BBB] 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)[348] accompanying the recent final ozone NAAQS RIA. Readers can also refer to Fann et al. (2009)[349] for a detailed description of the benefit-per-ton methodology.[CCC] 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 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

[BBB] Although we summarize the main issues in this chapter, we encourage interested readers to see the benefits chapter of the final primary NO2 NAAQS RIA for a more detailed description of recent changes to the PM benefits presentation and preference for the no-threshold model.

[CCC] 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 mortality that EPA usually conducts in association with its benefits analysis was not conducted for this analysis.

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)[350] and the Harvard Six-Cities cohort (Laden et al., 2006).[351] 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).[352,353] 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)[354] meta-analysis of 33 studies. The $10 million value represented the upper end of the interquartile range from the Viscusi and Aldy (2003)[355] 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)[356] 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)[357] while they continue efforts to update their guidance on this issue.[DDD] 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.

- Dollar-per-ton estimates do not reflect local variability in population density, meteorology, exposure, baseline health incidence rates, or other local factors that might lead to an overestimate or underestimate of the actual benefits of controlling fine particulates. In Chapter 7.2, we describe the full-scale air quality modeling conducted for the 2030 calendar year analysis in an effort to capture this variability.
- There are several health benefits categories that EPA was unable to quantify in the MY analysis due to limitations associated with using benefits-per-ton estimates, several of which could be substantial. Because NO_X and VOC emissions are also precursors to ozone, changes in NO_X and VOC would also impact ozone formation and the health effects associated with ozone exposure. Benefits-per-ton estimates for ozone, however, 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 the previous section of this RIA (Chapter 7.3.1)for a description of the quantification and monetization of health impacts for the CY analysis and a description of the unquantified co-pollutant benefits associated with this rulemaking.
- 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.

[DDD] 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>.

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 this 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. Timing and resource constraints precluded EPA from conducting full-scale photochemical air quality modeling for the MY analysis. We have, however, conducted national-scale air quality modeling for the CY analysis to analyze the impacts of the standards on $PM_{2.5}$, ozone, and selected air toxics.

7.4 Changes in Global Mean Temperature and Sea Level Rise Associated with the Rule's GHG Emissions Reductions

7.4.1 Introduction

Based on modeling analysis performed by the EPA, reductions in CO_2 and other GHGs associated with the rule will affect climate change projections. Since GHGs are well-mixed in the atmosphere and have long atmospheric lifetimes, changes in GHG emissions will affect atmospheric concentrations of greenhouse gases and future climate for decades to centuries. Two common indicators of climate change are global mean surface temperature and sea level rise. This section provides estimates for the response in global mean surface temperature and sea level rise projections to the estimated net global GHG emissions reductions associated with the this rule (see Chapter 5 for the estimated net reductions in global emissions over time by GHG).

7.4.2 Estimated Projected Reductions in Atmospheric CO_2 Concentrations, Global Mean Surface Temperatures and Sea Level Rise

To assess the impact of the emissions reductions from the rule, EPA estimated changes in projected atmospheric CO_2 concentrations, global mean surface temperature and sea-level rise to 2100 using the GCAM (Global Change Assessment Model, formerly MiniCAM), integrated assessment model[EEE] coupled with the MAGICC (Model for the

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[EEE] 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.

Assessment of Greenhouse-gas Induced Climate Change) simple climate model.[FFF] GCAM 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 rule was developed by applying the rule's estimated emissions reductions to the GCAM reference (no climate policy or baseline) scenario (used as the basis for the Representative Concentration Pathway RCP4.5[GGG]). Specifically, the CO_2, N_2O, CH_4, and HFC-134a emissions reductions from Chapter 5 were applied as net reductions to the GCAM 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

[FFF] 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.

[GGG]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).

scaled with total U.S. road transportation fuel consumption from the GCAM reference scenario. Using MAGICC, the change in atmospheric CO_2 concentrations, global mean temperature, and sea level were projected at five-year time steps to 2100 for both the reference (no climate policy) scenario and the emissions reduction scenario specific to this action. To capture some of the uncertainty in the climate system, the changes in projected atmospheric CO_2 concentrations, global mean temperature and sea level were estimated across the most current Intergovernmental Panel on Climate Change (IPCC) range of climate sensitivities, 1.5°C to 6.0°C.[HHH]

To compute the reductions in atmospheric CO_2 concentration, temperature, and sea level rise specifically attributable to the rule, the output from the rule's emissions scenario was subtracted from the reference (no policy or baseline) emissions case scenario. As a result of the rule's specified emissions reductions, the atmospheric CO_2 concentration is projected to be reduced by approximately 2.7 to 3.1 parts per million (ppm), the global mean temperature is projected to be reduced by approximately 0.006-0.015°C by 2100 and global mean sea level rise is projected to be reduced by approximately 0.06-0.14 cm by 2100.

Figure 7-25 provides the results for the estimated reductions in atmospheric CO_2 concentration associated with the rule. Figure 7-26 provides the estimated reductions in projected global mean temperatures associated with the rule. Figure 7-27 provides the estimated reductions in global mean sea level rise associated with the rule.

[HHH] 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/.

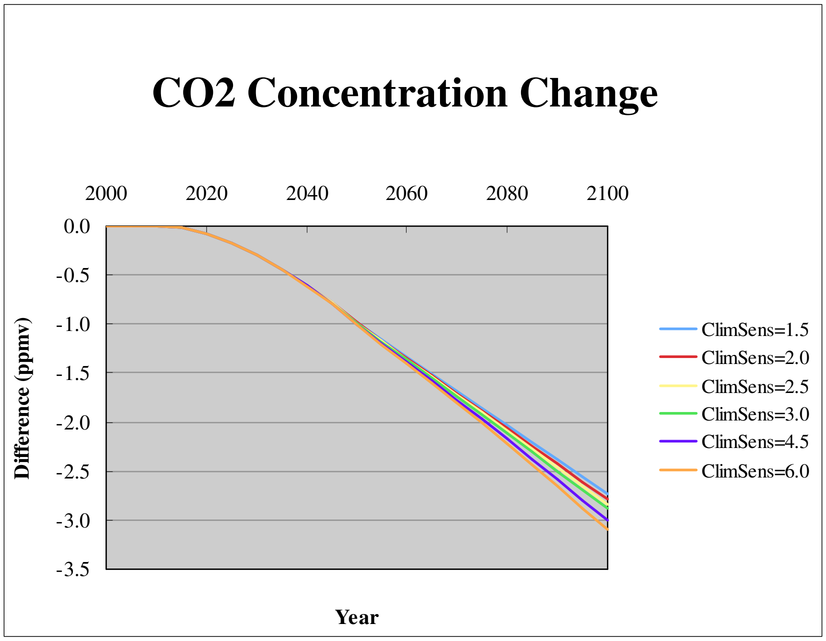

Figure 7-25 Estimated Projected Reductions in Atmospheric CO2 Concentrations (parts per million by volume) from Baseline for the Final Vehicles Rulemaking (for climate sensitivities ranging from 1.5-6°C)

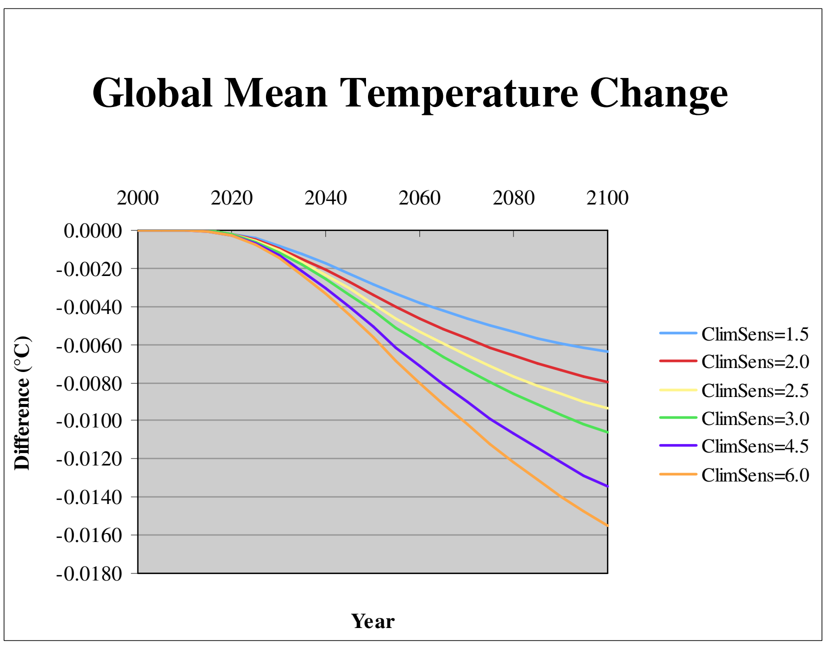

Figure 7-26 Estimated Projected Reductions in Global Mean Surface Temperatures from Baseline for the Final Vehicles Rulemaking (for climate sensitivities ranging from 1.5-6°C)

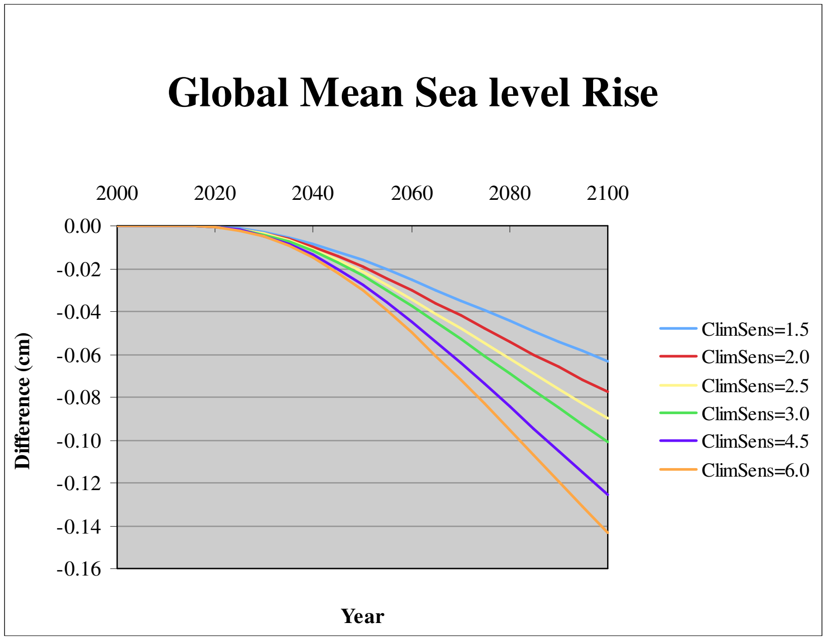

Figure 7-27 Estimated Projected Reductions in Global Mean Sea Level Rise from Baseline for the Final Vehicles Rulemaking (for climate sensitivities ranging from 1.5-6°C)

The results in both Figure 7-26 and Figure 7-27 show a relatively small reduction in the projected global mean 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.[358]

In today's rule, EPA analyzes another climate-related variable and calculates the projected changes in tropical ocean pH. EPA estimated the change in ocean pH using the Program CO2SYS,[III] version 1.05, a program which performs calculations relating parameters of the carbon dioxide (CO_2) system in seawater. EPA used the program to calculate ocean pH as a function of atmospheric CO_2, among other specified input conditions. Based on the projected atmospheric CO_2 concentration reductions (average of 2.9 ppm by 2100) that would result from this rule, the program calculates an increase in ocean pH of approximately 0.0014 pH units in 2100. Thus, this analysis indicates the projected decrease in atmospheric CO_2 concentrations from today's rule would result in an increase in ocean pH.

7.4.3 Summary

EPA's analysis of the rule's effect on global climate conditions is intended to quantify these potential reductions using the best available science. While EPA's modeling results of

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[III] Lewis, E., and D. W. R. Wallace. 1998. Program Developed for CO_2 System Calculations. ORNL/CDIAC-105. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tennessee.

the effect of this rule alone show small differences in climate effects (CO_2 concentration, temperature, sea-level rise, ocean pH), when expressed in terms of global climate endpoints and global GHG emissions, they yield results that are repeatable and consistent within the modeling frameworks used.

These projected reductions are proportionally representative of changes to U.S. GHG emissions in the transportation sector. While not formally estimated for this rulemaking, a reduction in projected global mean temperature and sea level rise implies a reduction in the risks associated with 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 (see Chapter 7.5). There are substantial uncertainties in modeling the global risks of climate change, which complicates quantification and cost-benefits assessments. Changes in climate variables are a meaningful proxy for changes in the risk of 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., 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 CO_2 emissions, 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 CO_2 emissions, procedures used to model the economic impacts of climate change, and the choice of discount rates. Furthermore, 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."[359]

In today’s final rule, EPA assigned a dollar value to reductions in CO_2 emissions using SCC estimates that were recently developed by an interagency process. The general approach to estimating SCC values was to run three integrated assessment models (FUND, DICE, and PAGE) using inputs agreed upon by the interagency group. The technical support document, *Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866*, (i.e., SCC TSD) presents a more detailed description of the methodology used to generate the new estimates, the underlying assumptions, and the limitations of the new SCC estimates.[360]

For 2010, these estimates are \$5, \$21, \$35, and \$65 (in 2007 dollars), and are based on a CO_2 emissions change of 1 metric ton in 2010. The first three estimates are based on the average SCC across models and socio-economic and emissions scenarios at the 5, 3, and 2.5 percent discount rates, respectively. The fourth value is included to represent the higher-than-expected impacts from temperature change further out in the tails of the SCC distribution. For this purpose, EPA has used the SCC value for the 95th percentile at a 3 percent discount rate. The central value is the average SCC across models at the 3 percent discount rate.

For purposes of capturing the uncertainties involved in regulatory impact analysis, we emphasize the importance and value of considering the full range. These SCC estimates also grow over time. For instance, the central value increases to $24 per ton of CO_2 in 2015 and $26 per ton of CO_2 in 2020. The table below shows how the SCC estimates change between 2010 and 2050. The complete model results are available in the docket for this final rule [EPA-HQ-OAR-2009-0472].

Table 7-25 Social Cost of CO2, 2010 – 2050 (in 2007 dollars)

Discount Rate	**5%**	**3%**	**2.5%**	**3%**
Year	Avg	Avg	Avg	95th
2010	5	21	35	65
2020	7	26	42	81
2030	10	33	50	100
2040	13	39	58	119
2050	16	45	65	136

The tables below summarize the total GHG benefits for the lifetime of the rule, which are calculated by using the four new 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. However, these monetized GHG benefits exclude the value of reductions in non-CO_2 GHG emissions (HFC, CH_4, N_2O) expected under this final rule. Although EPA has not monetized the benefits of reductions in non-CO_2 GHGs, the value of these reductions should not be interpreted as zero. Rather, the reductions in non-CO_2 GHGs will contribute to this rule's climate benefits, as explained in Section III.F. The SCC TSD notes the difference between the social cost of non-CO_2 emissions and SCC and specifies a goal to develop methods to value non-CO_2 emissions in future analyses.

Table 7-26 Upstream and Downstream CO_2 Benefits for the Given SCC Value, Calendar Year Analysis[a] (Millions of 2007 dollars)

YEAR	5% (AVERAGE SCC) $5 IN 2010	3% (AVERAGE SCC) $21 IN 2010	2.5% (AVERAGE SCC) $35 IN 2010	3% (95^{TH} PERCENTILE) $65 IN 2010
2012	$31	$135	$220	$412
2013	$78	$334	$541	$1,016
2014	$143	$602	$972	$1,834
2015	$239	$989	$1,593	$3,020
2016	$373	$1,525	$2,447	$4,660
2017	$512	$2,060	$3,295	$6,301
2018	$651	$2,586	$4,123	$7,918
2019	$797	$3,120	$4,960	$9,563
2020	$946	$3,657	$5,799	$11,223
2021	$1,111	$4,221	$6,663	$12,944
2022	$1,277	$4,768	$7,496	$14,615
2023	$1,449	$5,322	$8,333	$16,303
2024	$1,621	$5,868	$9,151	$17,966
2025	$1,799	$6,418	$9,972	$19,639
2026	$1,973	$6,947	$10,756	$21,250
2027	$2,151	$7,475	$11,534	$22,855
2028	$2,321	$7,973	$12,261	$24,365
2029	$2,494	$8,468	$12,981	$25,867
2030	$2,664	$8,949	$13,677	$27,326
2031	$2,839	$9,438	$14,381	$28,807
2032	$3,012	$9,915	$15,065	$30,252
2033	$3,191	$10,408	$15,770	$31,744
2034	$3,372	$10,900	$16,472	$33,234
2035	$3,561	$11,412	$17,202	$34,785
2036	$3,752	$11,926	$17,932	$36,339
2037	$3,951	$12,460	$18,689	$37,954
2038	$4,152	$12,998	$19,451	$39,582
2039	$4,362	$13,558	$20,243	$41,274
2040	$4,577	$14,127	$21,046	$42,992
2041	$4,802	$14,690	$21,815	$44,691
2042	$5,033	$15,267	$22,601	$46,428
2043	$5,274	$15,866	$23,417	$48,234
2044	$5,523	$16,481	$24,253	$50,087
2045	$5,781	$17,118	$25,117	$52,005
2046	$6,046	$17,773	$26,004	$53,976
2047	$6,322	$18,449	$26,919	$56,013
2048	$6,606	$19,143	$27,857	$58,103
2049	$6,899	$19,859	$28,823	$60,258
2050	$7,202	$20,596	$29,816	$62,476
NPV[b]	$34,500	$176,700	$299,600	$538,500

[a] Monetized GHG benefits exclude the value of reductions in non-CO_2 GHG emissions (HFC, CH_4 and N_2O) expected under this final rule. Although EPA has not monetized the benefits of reductions in these non-CO_2 emissions, the value of these reductions should not be interpreted as zero. Rather, the reductions in non-CO_2 GHGs will contribute to this rule's climate benefits, as explained in Section III.F.2. The SCC TSD notes the difference between the social cost of non-CO_2 emissions and CO_2 emissions, and specifies a goal to develop methods to value non-CO_2 emissions in future analyses.

[b] Note that net present value of reduced GHG emissions is calculated differently than other benefits. The same discount rate used to discount the value of damages from future emissions (SCC at 5, 3, 2.5 percent) is used to calculate net present value of SCC for internal consistency. Refer to SCC TSD for more detail.

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 RIA chapter 5. The GHG benefits of the full life of each of the five model years from 2012 through 2016 are shown in Table 7-27 through Table 7-30 for each of the four different social cost of carbon values. The GHG benefits are shown for each year in the model year life and in net present value. The same discount rate used to discount the value of damages from future emissions (SCC at 5, 3, 2.5 percent) is used to calculate net present value of SCC for internal consistency.

Table 7-27 Upstream and Downstream CO_2 Benefits for the 5% (Average SCC) Value, Model Year Analysis[a] (Millions of 2007 dollars)

YEAR	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016	SUM
2012	$36	$0	$0	$0	$0	$36
2013	$36	$53	$0	$0	$0	$89
2014	$36	$54	$73	$0	$0	$163
2015	$36	$54	$74	$107	$0	$271
2016	$36	$54	$74	$108	$151	$422
2017	$35	$53	$74	$108	$151	$421
2018	$34	$52	$73	$107	$152	$418
2019	$33	$51	$71	$106	$150	$411
2020	$31	$49	$69	$104	$148	$402
2021	$30	$47	$67	$102	$147	$393
2022	$29	$45	$65	$99	$144	$382
2023	$26	$43	$62	$95	$140	$366
2024	$23	$39	$59	$91	$134	$346
2025	$20	$35	$54	$86	$128	$322
2026	$17	$30	$47	$79	$120	$293
2027	$14	$25	$41	$69	$111	$259
2028	$12	$21	$34	$59	$97	$223
2029	$10	$18	$29	$50	$83	$189
2030	$8	$15	$24	$42	$70	$158
2031	$7	$12	$20	$35	$58	$132
2032	$6	$10	$17	$29	$49	$110
2033	$5	$8	$14	$24	$40	$91
2034	$4	$7	$11	$20	$33	$76
2035	$3	$6	$10	$16	$27	$63
2036	$3	$5	$8	$14	$23	$53
2037	$3	$4	$7	$12	$19	$45
2038	$2	$4	$6	$10	$16	$38
2039	$2	$3	$5	$9	$14	$32
2040	$1	$3	$4	$7	$12	$27
2041	$1	$2	$4	$5	$10	$23
2042	$1	$2	$3	$5	$8	$19
2043	$1	$2	$3	$4	$7	$17
2044	$1	$2	$2	$4	$6	$15
2045	$1	$1	$2	$3	$5	$13
2046	$1	$1	$2	$3	$5	$12
2047	$1	$1	$2	$3	$4	$10
2048	$0	$1	$2	$2	$4	$9
2049	$0	$0	$1	$2	$3	$7
2050	$0	$0	$0	$2	$3	$5
NPV, 5%	$400	$500	$700	$1,000	$1,300	$3,800

[a] As noted above, these monetized GHG benefits exclude the value of reductions in non-CO_2 GHG emissions expected under this final rule. Although EPA has not monetized the benefits of reductions in non-CO_2 GHGs, the value of these reductions should not be interpreted as zero.

Table 7-28 Upstream and Downstream CO_2 Benefits for the 3% (Average SCC) SCC Value, Model Year Analysis[a] (Millions of 2007 dollars)

YEAR	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016	SUM
2012	$155	$0	$0	$0	$0	$155
2013	$154	$230	$0	$0	$0	$383
2014	$152	$227	$310	$0	$0	$689
2015	$149	$225	$306	$445	$0	$1,124
2016	$146	$220	$303	$439	$616	$1,723
2017	$141	$215	$296	$435	$608	$1,695
2018	$136	$208	$289	$425	$601	$1,659
2019	$129	$199	$279	$415	$589	$1,611
2020	$122	$189	$268	$401	$574	$1,554
2021	$115	$179	$256	$387	$557	$1,494
2022	$107	$169	$242	$369	$537	$1,425
2023	$97	$157	$228	$350	$513	$1,345
2024	$84	$142	$212	$329	$485	$1,253
2025	$71	$124	$192	$306	$457	$1,149
2026	$59	$105	$167	$277	$424	$1,032
2027	$49	$88	$141	$240	$384	$902
2028	$40	$73	$118	$203	$332	$766
2029	$33	$60	$98	$169	$281	$641
2030	$27	$50	$81	$140	$234	$532
2031	$22	$41	$67	$116	$194	$439
2032	$18	$34	$55	$95	$160	$362
2033	$15	$28	$45	$78	$131	$297
2034	$13	$23	$37	$64	$107	$244
2035	$11	$19	$31	$52	$88	$202
2036	$9	$17	$26	$44	$73	$168
2037	$8	$14	$22	$37	$61	$142
2038	$6	$12	$19	$31	$51	$119
2039	$5	$9	$16	$26	$43	$100
2040	$5	$8	$12	$23	$37	$84
2041	$4	$7	$11	$17	$31	$70
2042	$4	$6	$9	$15	$23	$57
2043	$3	$6	$8	$13	$20	$51
2044	$3	$5	$7	$12	$18	$45
2045	$2	$4	$7	$10	$16	$39
2046	$2	$4	$6	$9	$14	$35
2047	$2	$3	$5	$8	$12	$31
2048	$0	$3	$4	$7	$11	$25
2049	$0	$0	$4	$6	$10	$20
2050	$0	$0	$0	$5	$8	$14
NPV, 3%	$1,700	$2,400	$3,100	$4,400	$5,900	$17,000

[a] As noted above, these monetized GHG benefits exclude the value of reductions in non-CO_2 GHG emissions expected under this final rule. Although EPA has not monetized the benefits of reductions in non-CO_2 GHGs, the value of these reductions should not be interpreted as zero.

Table 7-29 Upstream and Downstream CO_2 Benefits for the from 2.5% (Average SCC) SCC Value, Model Year Analysis[a] (Millions of 2007 dollars)

YEAR	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016	SUM
2012	$253	$0	$0	$0	$0	$253
2013	$249	$372	$0	$0	$0	$621
2014	$246	$366	$500	$0	$0	$1,113
2015	$241	$362	$492	$716	$0	$1,810
2016	$234	$353	$486	$705	$988	$2,766
2017	$226	$344	$474	$695	$972	$2,711
2018	$216	$331	$461	$679	$959	$2,646
2019	$205	$317	$444	$660	$936	$2,562
2020	$193	$300	$425	$636	$910	$2,463
2021	$181	$283	$404	$611	$880	$2,359
2022	$168	$266	$381	$581	$845	$2,240
2023	$152	$246	$357	$547	$803	$2,106
2024	$131	$222	$331	$514	$757	$1,954
2025	$110	$192	$299	$475	$710	$1,786
2026	$92	$162	$258	$429	$656	$1,597
2027	$76	$135	$218	$370	$593	$1,392
2028	$62	$112	$182	$312	$511	$1,178
2029	$51	$93	$150	$259	$430	$983
2030	$41	$76	$124	$214	$358	$813
2031	$34	$62	$102	$176	$295	$670
2032	$28	$51	$83	$144	$243	$550
2033	$23	$42	$68	$118	$199	$450
2034	$19	$35	$56	$96	$162	$369
2035	$16	$29	$47	$79	$133	$304
2036	$14	$25	$39	$66	$109	$253
2037	$12	$21	$34	$55	$91	$213
2038	$9	$18	$28	$47	$76	$178
2039	$8	$14	$24	$39	$65	$150
2040	$7	$12	$18	$34	$54	$125
2041	$6	$11	$16	$25	$47	$104
2042	$5	$9	$14	$22	$34	$85
2043	$5	$8	$12	$19	$30	$75
2044	$4	$7	$11	$17	$27	$66
2045	$4	$6	$10	$15	$23	$58
2046	$3	$6	$8	$13	$21	$51
2047	$3	$5	$7	$12	$18	$45
2048	$0	$4	$6	$10	$16	$37
2049	$0	$0	$6	$9	$14	$29
2050	$0	$0	$0	$8	$12	$20
NPV, 2.5%	$2,700	$3,900	$5,200	$7,200	$9,700	$29,000

[a] As noted above, these monetized GHG benefits exclude the value of reductions in non-CO_2 GHG emissions expected under this final rule. Although EPA has not monetized the benefits of reductions in non-CO_2 GHGs, the value of these reductions should not be interpreted as zero.

Table 7-30 Upstream and Downstream CO_2 Benefits for the 3% (95th Percentile) SCC Value, Model Year Analysis[a] (Millions of 2007 dollars)

YEAR	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016	SUM
2012	$473	$0	$0	$0	$0	$473
2013	$468	$699	$0	$0	$0	$1,167
2014	$465	$691	$944	$0	$0	$2,100
2015	$456	$685	$933	$1,357	$0	$3,432
2016	$446	$672	$925	$1,342	$1,882	$5,267
2017	$432	$657	$907	$1,329	$1,859	$5,184
2018	$415	$636	$886	$1,303	$1,841	$5,081
2019	$395	$611	$856	$1,272	$1,804	$4,939
2020	$373	$581	$822	$1,230	$1,761	$4,767
2021	$352	$550	$785	$1,186	$1,709	$4,582
2022	$327	$518	$743	$1,132	$1,647	$4,367
2023	$297	$481	$699	$1,071	$1,572	$4,120
2024	$257	$436	$649	$1,008	$1,486	$3,836
2025	$217	$378	$589	$936	$1,398	$3,517
2026	$181	$320	$510	$848	$1,297	$3,156
2027	$150	$268	$432	$733	$1,175	$2,757
2028	$124	$222	$361	$619	$1,016	$2,342
2029	$101	$184	$299	$517	$858	$1,959
2030	$83	$152	$248	$428	$715	$1,625
2031	$68	$124	$204	$353	$592	$1,341
2032	$56	$102	$167	$290	$489	$1,104
2033	$47	$85	$137	$237	$401	$906
2034	$39	$71	$113	$194	$328	$745
2035	$33	$59	$95	$160	$268	$616
2036	$28	$51	$79	$134	$221	$513
2037	$24	$43	$68	$112	$185	$432
2038	$18	$37	$58	$96	$154	$362
2039	$16	$28	$50	$81	$132	$305
2040	$14	$25	$37	$69	$111	$256
2041	$12	$22	$33	$51	$95	$213
2042	$11	$19	$29	$45	$70	$174
2043	$10	$17	$25	$40	$62	$154
2044	$8	$15	$22	$35	$55	$136
2045	$7	$13	$20	$31	$48	$120
2046	$6	$12	$17	$27	$43	$106
2047	$6	$10	$15	$24	$38	$93
2048	$0	$9	$14	$21	$33	$77
2049	$0	$0	$12	$19	$29	$60
2050	$0	$0	$0	$16	$26	$42
NPV, 3%	$5,100	$7,300	$9,600	$13,000	$18,000	$53,000

[a] As noted above, these monetized GHG benefits exclude the value of reductions in non-CO_2 GHG emissions expected under this final rule. Although EPA has not monetized the benefits of reductions in non-CO_2 GHGs, the value of these reductions should not be interpreted as zero.

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 7-28 below from EPA's Fuel Economy Trends Report).[361] 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. As the figure also shows, little of this efficiency improvement has been realized in fuel economy gains or GHG emissions reductions.

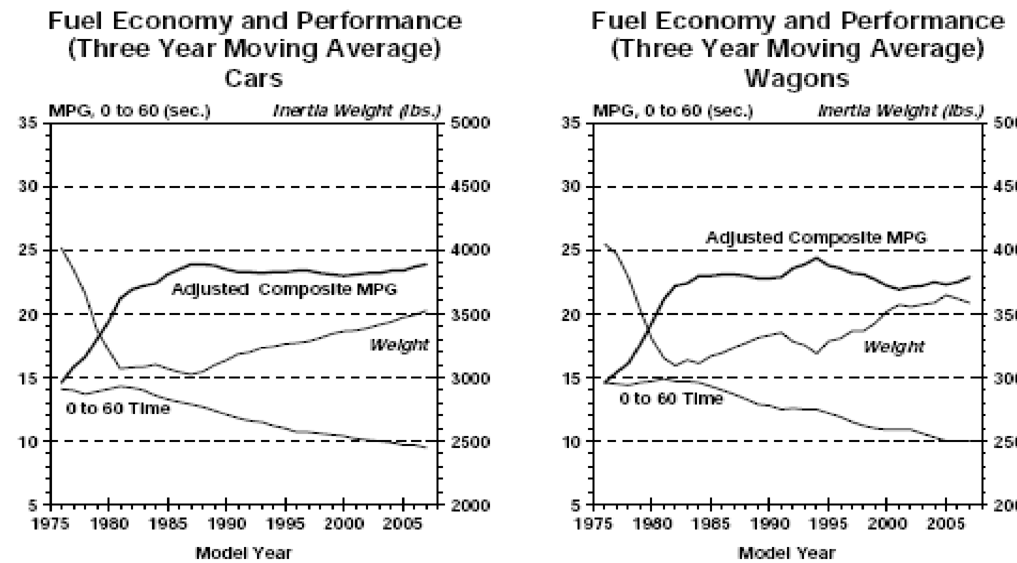

Figure 7-28 Weight, 0-to-60 MPH acceleration time and adjusted fuel economy for light-duty vehicles

During this same period, due in part to increasing numbers of Federal Motor Vehicle Safety Standards and increasingly stringent NCAP standards from NHTSA, 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 anti-lock brakes (ABS), electronic stability control (ESC), and improved tires and suspensions help drivers avoid accidents. NHTSA stated in its NPRM that it anticipated a 12.6 percent reduction in fatality levels between 2007 and 2020 with safety improvements due to pending NHTSA FMVSS and other factors, such as behavioral improvements (less drunk driving and increased seat belt usage, for example).[JJJ,KKK]

[JJJ] NHTSA stated in section IX of their PRIA for this rule: "The agency examined the impacts of identifiable safety trends over the lifetime of the vehicles produced in each model year. An estimate of these impacts was

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. The EPA believes that though much work has been done to advance the understanding of the effects of vehicle weight on safety, there is much yet to do. EPA also acknowledges that for the analysis of various topics contained in this RIA and in the preamble, there are a number of uncertainties which exist with these analysis and any results must be viewed in light of those uncertainties. In the context of safety, for example, due to limitations in modeling consumer and producer behavioral responses to the new standards, this analysis does not explore the net fleetwide safety implications of potential changes in the distribution of vehicles in the on road fleet (e.g., changes in the variance of size, weight, vehicle types on the road) if consumers respond to the rulemaking by purchasing a distribution of vehicles which are significantly different than what EPA has forecast.

This section of the RIA describes and compares some of the key studies that have been conducted in the recent past – including NHTSA's recent 2010 analysis, and presents some potential research options going forward.

7.6.1 What did EPA say in the NPRM and in the Draft RIA with regard to Potential Safety Effects?

In the NPRM, EPA discussed potential safety effects of the proposed standards. In the joint technology analysis, EPA and NHTSA predicted that automakers could reduce vehicle weight as one part of the industry's strategy for meeting the proposed standards. EPA's modeling projected (and still projects) that vehicle manufacturers will reduce the weight of their vehicles by 4% on average between 2011 and 2016, with the average per-vehicle mass reduction in absolute terms being greater for light-trucks than for passenger cars. For the NPRM, this mass reduction estimate was generally smaller on both an absolute and a percentage basis for smaller car than for larger vehicles. Specifically, we estimated an average reduction of 2.3% (62 lbs) for cars with a curb weight below 2,950 lbs, 4.4% (154 lbs) for cars with a curb weight above 2,950, 3.5% (119 lbs) for trucks with a curb weight below 3,850 lbs, and 4.5% for trucks with a curb weight above 3,850 lbs (215 lbs). The

contained in a previous agency report. (The next citation in this document, Blincoe, L. and Shankar, U, January 2007.) The impacts were estimated on a year-by-year basis, but could be examined in a combined fashion. The agency assumed that the safety trends will result in a reduction in the target population of fatalities from which the weight impacts are derived. Using this method, we found a 12.6 percent reduction in fatality levels between 2007 and 2020. The estimates derived from applying Kahane's percentages to a baseline of 2007 fatalities were thus multiplied by 0.874 to account for changes that the agency believes will take place in passenger car and light truck safety between the 2007 baseline on-road fleet used for this particular analysis and year 2020.

[KKK] Blincoe, L. and Shankar, U, "The Impact of Safety Standards and Behavioral Trends on Motor Vehicle Fatality Rates," DOT HS 810 777, January 2007. See Table 4 comparing 2020 to 2007 (37,906/43,363 = 12.6% reduction.

penetration and magnitude of these modeled changes are consistent with the public announcements made by many manufacturers since early 2008 and are consistent with 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 March 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 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[362]
- Toyota: 30% weight reduction on 2015 Corolla and a 10% weight reduction on mid-size vehicles by 2015[363]
- Nissan: 15% average weight reduction by 2015[363]
- Mazda: 100 kg (220 pound) weight reduction by 2011 and an additional 100 kg weight reduction by 2016[363, 364]
- Mercedes: 2-3 % weight reduction on recently introduced 2009 "BlueEFFICIENCY" models[365]

The EPA believes that reducing vehicle mass of the magnitude we estimated for the proposal and the final rule (up to 10% for certain vehicles by model year 2016)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 RIA. In the NPRM, EPA described how 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. In their comments to the proposed rule, the American Iron and Steel Institute (AISI) noted: "AISI has shown in its research with the Auto/Steel Partnership and in programs supported by the U.S. Department of Energy, the use of new Advanced High Strength Steel (AHSS) steel grades can enable the mass of critical crash structures, such as front rails and bumper systems, to be reduced by 25%."

- 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 mass reduction that can be realized in the powertrain is due to reduced powertrain output requirements. 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, mass reduction 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.[366]

The EPA stated in the NPRM that it believes that 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 mentioned that 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 goals. We requested 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 projected that automakers will not reduce vehicle footprint in response to the proposed CO2 standards in our modeling analysis. NHTSA and EPA have taken two measures to help ensure that this final rule does not provide an 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 rule is that the CO_2 or fuel economy targets are based on the attribute of footprint (which is a surrogate for vehicle size).[LLL] The second design feature is that the shape of the footprint curve (or function) has been carefully designed with the intention that it neither encourages manufacturers to increase, nor decrease the footprint of their fleet. Changes in relative safety are related to shifts in the distribution of vehicles on the road. A policy that induces a widening in the size distribution of vehicles on the road, could result in negative impacts on safety. The primary mechanism in this rulemaking for mitigating the potential negative effects on safety is the application of footprint-based standards, which create a disincentive for manufacturers to produce smaller-footprint vehicles. This is because as footprint decreases, the corresponding fuel economy/GHG emission target becomes more stringent.[MMM] The shape of the footprint curves themselves have also been designed to be approximately "footprint neutral" within the sloped portion of the functions – that is, to neither encourage manufacturers to increase the footprint of their fleets, nor to decrease it. Upsizing also is discouraged through a "cut-off" at larger footprints. For both cars and light trucks there is a "cut-off" that affects vehicles smaller than 41 square feet. The agencies recognize that for manufacturers who make small vehicles in this size range, this cut off creates some incentive to downsize (i.e. further reduce the size and/or increase the production of models currently smaller than 41 square feet) to make it easier to meet the target. The cut off may also create some incentive for manufacturers who do not currently offer such models to do so in the future. However, at the same time, the agencies believe that there is a limit to the market for cars smaller than 41 square feet - most consumers likely have some minimum expectation about interior volume, among other things. In addition, vehicles in this market segment are the lowest price point for the light-duty automotive market, with a number of models in the $10,000 to $15,000 range. In order to justify selling more vehicles in this market in order to generate fuel economy or CO_2 credits (that is, for this final rule to be the incentive for selling more vehicles in this small car segment), a manufacturer would need to add additional technology to the lowest price segment vehicles, which could be challenging. Therefore, due to these two reasons (a likely limit in the market place for the smallest sized cars and the potential consumer acceptance difficulty in adding the necessary technologies in order to generate fuel economy and CO2 credits), the agencies believe that the incentive for manufacturers to increase the sale of vehicles smaller than 41 square feet due to this rulemaking, if present, is small. For further discussion on these aspects of the standards, please see Section II.C above and Chapter 2 of the Joint TSD. However, EPA acknowledges

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[LLL] 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. However, EPA does acknowledge that front and rear and side overhang are not included in footprint and that there may be changes in this part of the vehicle in the future.

[MMM] We note, however, that vehicle footprint is not synonymous with vehicle size. Since the footprint is only that portion of the vehicle between the front and rear axles, footprint-based standards do not discourage downsizing the portions of a vehicle in front of the front axle and to the rear of the rear axle, or to other portions of the vehicle outside the wheels. The crush space provided by those portions of a vehicle can make important contributions to managing crash energy. At least one manufacturer has confidentially indicated plans to reduce overhang as a way of reducing mass on some vehicles during the rulemaking time frame. Additionally, simply because footprint-based standards create no incentive to downsize vehicles, does not mean that manufacturers may not choose to do so if doing so makes it easier to meet the overall standard (as, for example, if the smaller vehicles are so much lighter that they exceed their targets by much greater amounts).

some uncertainty regarding how consumer purchases will change in response to the vehicles designed to meet the model years 2012-2016 standards. This could potentially affect the mix of vehicles sole in the future, including the mass and footprint distribution, and thus result in a different impact on safety than is discussed and presented in this final rule.

EPA also discussed safety in the context of NHTSA's analysis presented in Section IV of the NPRM preamble, in which NHTSA presented an analysis of the proposed CAFE standards based on the 2003 Kahane safety 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.[367,368] 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. Based on this, NHTSA developed and presented a worst case estimate of the effect of weight reductions on fatalities. The underlying data used for that analysis did not allow NHTSA to analyze the specific effect 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 included vehicles that were either smaller and lighter or larger and heavier. The numbers in the NHTSA analysis predicted 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 (as well as structural integrity). EPA acknowledged that the safety analysis conducted by NHTSA and presented in Section IV of the NPRM Preamble could be a worst case analysis for fatalities, but that the actual effects on vehicle safety could (and would likely) be much less. However, EPA and NHTSA were not able to quantify the lower-bound potential effects at that time.

Thus, the 2003 and earlier Kahane studies (as summarized in the NPRM) concerning weight reductions and safety indicate that there is not a clear cut answer to the issue before the agencies of potential safety impacts of the rule due to mass reduction which may occur in the fleet absent size reductions. These studies draw upon historical vehicle data where mass reduction were (for the most part) linked with size reductions, thus they occurred in ways different from the way the agencies project weight reduction will occur for MY 2012-2016 vehicles. As such the pre-2010 Kahane studies may not be directly relevant to predicting or quantifying the safety impact of the projected use of weight reduction technologies in this rule. Several commenters to the proposed rule support this conclusion, including the International Council on Clean Transportation (ICCT): "The results of the Kahane study would be great for analyzing the safety impacts of a weight-based attribute system…. Kahane's methodology was simply not designed to assess the safety impacts of lightweight materials.", and the National Association of Clean Air Agencies (NACAA): "significant portions of NHTSA's safety analysis are based on out-of-date data".

In contrast to the pre-2010 Kahane studies, Dynamic Research Incorporated (DRI) has 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,[369,370,NNN] DRI presented results that indicated that vehicle weight reduction tended to decrease fatalities, but vehicle wheelbase and track reduction tended to increase fatalities.

In the RIA for the proposed rule, EPA attempted to summarize DRI's results in four major points. These points are re-summarized below to reflect comments from DRI as to present this information more accurately:[OOO]

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 and/or increases in wheel base and track.
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 a potentially lower center of gravity and lower loads on the roof structures.

The data used for the DRI analysis was similar to that used in 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 1998 vehicles. DRI also used a logistic 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. NHTSA stated that 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.[PPP] 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. 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.

[NNN] One of these studies was published as a Society of Automotive Engineers Technical Paper and received peer review through that body

[OOO] DRI stated: "The DRI work focused on the effects of vehicle size and weight (i.e. curb weight, wheelbase, and track) on vehicle crash avoidance, crashworthiness, and compatibility, based on accident and fatality data. There were numerous conclusions in addition to those listed, including the benefits of both increased size and weight."

[PPP] 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 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 (along with many commenters) recognized 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 in the 2003 Kahane study above.

The DRI and Kahane studies also differed 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 indicated 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 offered 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.

In the NPRM, NHTSA rejected many elements of the DRI analysis, and did not rely on it for its evaluation of safety impact changes from the proposed CAFE standards. See Section IV.G.6 of the Notice of Proposed Rulemaking, as well as NHTSA March 2009 Final Rulemaking for MY2011 CAFE standards (74 FR at 14402-05).

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 noted 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. There were many commenters who supported this notion. Further discussion of these comments is included below.

7.6.2 What Public Comments did EPA Receive in Regard to its Safety Discussion and what is EPA's Response?

EPA requested and received public comments from several sources regarding the NPRM Preamble positions noted above. Many of the comments received were in support of EPA's safety assessment, such as those from Dynamics Research Institute (DRI), International Council on Clean Transportation (ICCT), Public Citizen, Union of Concerned Scientists, California Air Resources Board (CA-ARB) and the National Association of Clean Air Agencies (NACAA).

In a technical comment, DRI's agreed with EPA that directional control and therefore crash avoidance improves with a reduction in curb weight. DRI went further and commented that control also improved with an increase in wheel base and track width., The latter point acknowledges that a corresponding potential decrease in wheel base or track width could result in an increase in fatalities. DRI offered results from the application of the "quasi-steady vehicle directional equations of motion". These results show "that passenger cars with shorter wheelbases tend to have smaller characteristic speeds, resulting in higher [yaw rate] natural frequency and less damping, based on analysis of quasi-steady vehicle equations of motion".

EPA concurs with DRI's comments regarding their analysis. This supports the argument made by EPA in the NPRM that, vehicles with reduced mass are better able to avoid accidents that cause fatalities due to increased vehicle maneuverability that better matches a driver's intended steering inputs.[QQQ] EPA analyzed Consumer Reports Double Lane Change Data[RRR] to determine how curb weight affects emergency handling. Consumer Reports provided EPA with a summary of their double lane change tests for vehicles from MY 2003 through MY 2010 along with the vehicles' curb weight.[SSS] By plotting the vehicle double lane change speed with respect to curb weight, EPA is able to show how the speed at which a double lane change can be safely executed goes up as curb weight decreases, as shown in Figure 7-29 below. As the weight of all vehicles is decreased, their maneuverability and handling will increase, thus giving the driver greater control and increased capability to avoid accidents. This relationship held true for both vehicles equipped with and without Electronic Stability Control (ESC), although the same data show that capability is further enhanced with the addition of ESC. At any given curb weight, the addition of ESC resulted in a higher average double lane change speed than those vehicles without stability control. Under all stability control events, the ESC system will be working against the momentum of the vehicle. Reductions in mass will generally increase ESC effectiveness in terms of the ability of a vehicle to enter a double lane change maneuver at a higher speed. However, NHTSA's review of historical FARS data for MY 1991-1999 cars has found that smaller cars are responsible for a higher number of crashes than other vehicle types.

[QQQ] FMVSS126 - "Oversteering and understeering are typically cases of loss-of-control where vehicles move in a direction different from the driver's intended direction".

[RRR] The Consumer Reports double lane change maneuver is referred to as "Emergency Handling" within Consumer Reports vehicle assessments. The maneuver consists of a set of traffic cones arranged in such a pattern as to force the vehicle into a left lane, and then a return to the right lane over a controlled distance. The double lane change speed is based on the driver's entrance speed at the beginning of the course. The highest entrance speed with which the driver is able to negotiate the course without disturbing the cones is deemed the "Emergency Handling" metric.

[SSS] The data used for Figure 7.6.2 is available in the memorandum "Vehicle Double Lane Change Data Provided by Consumer Reports", which has been placed in the EPA docket for this final rule.

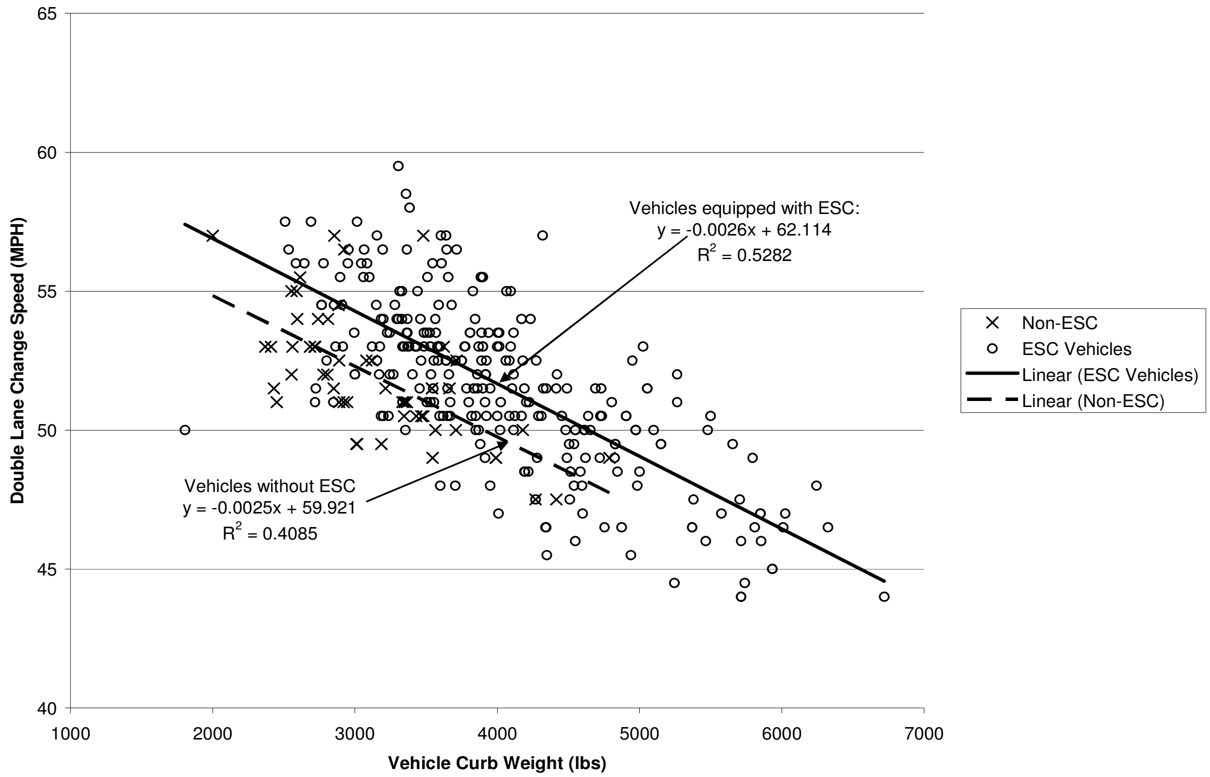

Figure 7-29 Double Lane Change Speed vs. Vehicle Curb Weight

The International Council on Clean Transportation (ICCT) endorsed the DRI comments (described in the previous section) in their comments to the proposal. ICCT went a step further and applied the DRI results to calculate a potential benefit from reducing curb weight while maintaining footprint. Accounting for the downward trend in annual vehicle fatalities, and the actual weight reduction anticipated by agencies' modeling results, ICCT determined that there would be a reduction of 599 fatalities and 354 fatalities for a 100 lb weight reduction in cars and trucks respectively.

In contrast, there were comments received from the American Iron and Steel Institute (AISI) and the Competitive Enterprise Institute (CEI) that contended EPA's conclusions. Both AISI and CEI noted in their comments that historically heavier vehicles have demonstrated a safety advantage over lighter vehicles. AISI presented the results from Desapriya that "*sedans are two times more likely to be injured than drivers or passengers in larger pickup trucks and SUV's*", and CEI endorsed the results from the 2003 Kahane study in support of their position.

AISI also noted that: "*AISI has shown in its research with the Auto/Steel Partnership and in programs supported by the U.S. Department of Energy, the use of new (Advanced High Stength Steel) AHSS steel grades can enable mass of critical crash structures, such as front rails and bumper systems, to be reduced by 25 percent. Such vehicle structures with reduced mass can perform as well as their heavier counterparts in standard NHTSA frontal or IIHS offset instrumented crash tests*." This is exactly the type of material substitution that EPA noted in the NPRM. In this case a vehicle can be made lighter without a concomitant decrease in crush and crumple zones.

CEI noted the historical studies that analyzed the relationships between CAFE standards and vehicle fatalities, specifically, R.W. Crandall and J.D. Graham, authors of "The Effect of Fuel Economy Standards on Automobile Safety" and the 2003 Kahane report. According to CEI, the Crandall and Graham analysis reported that CAFE regulations had a downsizing effect of 500 pounds per car in 1989. The applicability of the 1989 analyses is questionable in the context of this rule and its associated effectiveness from MY 2012 through 2016. Vehicle design capability, including computer aided engineering (CAE) has changed substantially in the 20 years since this report was completed. Increased stringency of FMVSS standards combined with the improved strength of materials available and used in automobile manufacturing has allowed auto manufacturers to improve impact performance without a commensurate increase in vehicle weight. In addition, the 500 pound reduction analyzed by Crandall and Graham is substantially greater than the estimated weight reduction associated with this final rule. Regarding the 2003 Kahane report, NHTSA has recognized some of the limitations of the 2003 analysis in the context of this rulemaking and presents a summary and review of the 2010 Kahane report in the preamble and within NHTSA's FRIA.

CEI further comments that "new technologies and attribute-based regulation will not eliminate the safety tradeoff". CEI states that "*some proponents of higher CAFE standards, and of CO2 emission limits, claim that new technologies can eliminate these lethal effects. This claim is simply false, even if such technologies do not themselves involve downsizing. Consider a hi-tech prototype car capable of meeting either a higher CAFE standard, or a stringent CO2 emissions standard. Imagine that you then increase this car's size and weight by adding several cubic feet of trunk space and occupant space. The result would be an even safer car.*" EPA recognizes that more recent vehicles have more safety features than 1990s vehicles, which are likely to make them safer overall. To account for this, NHTSA did adjust the results of both its NPRM and final rule analysis to include known safety improvements, like ESC and increases in seat belt use, that have occurred since MYs 1991-1999.[TTT] However, simply because newer vehicles have more safety countermeasures, does not mean that the weight/safety relationship necessarily changes. More likely, it would change the target population (the number of fatalities) to which one would apply the weight/safety relationship. Thus, EPA acknowledges that while mass reduction can be done in a safety neutral manner, some mass reduction techniques for both passenger cars and light trucks can make them less safe in certain crashes as discussed in NHTSA's FRIA.[UUU]

[TTT] See Chapter IX of the NHTSA FRIA for details on this adjustment.

[UUU] If one has a vehicle (vehicle A), and both reduces the vehicle's mass and adds new safety equipment to it, thus creating a variant (vehicle A_1), the variant might conceivably have a level of overall safety for its occupants is equal to that of the original vehicle (vehicle A). However, vehicle A_1 might not be as safe as second variant (vehicle A_2) of vehicle A, one that is produced by adding to vehicle A the same new safety equipment added to the first variant, but this time without any mass reduction.

Additional comments received from the AISI challenge the agencies' conclusions with regard to vehicle size. While they agree that "the historical relationship between vehicle size, weight, and collision severity may be influenced by design and structural improvements", they assert that "the aggressive schedule for implementing the proposed rule assures that carmakers will be manufacturing smaller, lighter vehicles in order to comply." Porsche and IIHS had similar comments implying that footprint standards will increase the risk that manufacturers will make vehicles smaller. In response, EPA does not feel that the schedule is overly aggressive. The standards and their phase-in period is feasible and economically practical as described in section III.D of the preamble. That same discussion, as well as the supporting analysis in the joint TSD, demonstrates a clear compliance path to meeting the standards based on wider penetration of existing technologies, at reasonable and affordable cost. In addition, the attribute-based approach, along with the shape of footprint curve has been developed with the objective of minimizing the incentive to downsize (since, among other things, downsizing simply creates a more stringent regulatory target corresponding to the downsized footprint) nor to upsize (as that could incur significant redesign costs and also would likely increase the mass of the vehicle which could off-set any benefit in upsizing from a stringency perspective as a higher mass vehicle will produce more CO_2 emissions). EPA consequently does not accept the commenter's assertion. However, as discussed in Sections III.H.1 and IV.G.6 of the preamble, the agencies acknowledge some uncertainty regarding how consumer purchases will change in response to the vehicles designed to meet the MYs 2012-2016 standards. This could potentially affect the mix of vehicles sold in the future, including the mass and footprint distribution.

7.6.3 NHTSA's 2010 Study of Accident Fatalities by Vehicle Size and Weight

In response to comments received and in an effort to follow through on some of its NRPM pledges for consideration in the future, NHTSA has significantly revised its 2003 study on the relationship between vehicle mass and fatalities in the context of this 2012-2016 rulemaking. A copy of this new report, "Relationships Between Fatality Risk, Mass, and Footprint in Model Year 1991-1999 and Other Passenger Cars and LTVs", Charles J. Kahane, NCSA, NHTSA, March 2010, has been placed in the docket for this rulemaking, hereafter referred to as the 2010 Kahane report.[VVV] In the new 2010 Kahane report, based on the original MY 1991-1999 vehicle data set, NHTSA addresses several criticisms, specifically including 2-door vehicles in its passenger car analysis, attempting to separate weight and footprint as independent variables and their associated contributions to vehicle fatalities, and comparing their results to those from DRI. We note that this analysis looks specifically at impacts on fatalities. EPA and NHTSA have not analyzed the impact of mass reduction predicted from this final rule on non-fatal accidents. We also note that the results of the 2010 Kahane analysis, as applied to the mass reductions predicted from this rulemaking, must be viewed in the overall context of our projection of the 2012-2016 new vehicle fleet distribution (See Chapter 1 of the Joint TSD for a discussion of how EPA and NHTSA have developed the

[VVV] NHTSA intends for this 2010 Kahane report to undergo a peer review in accordance with OMB guidance for peer review, and the results of this peer review and any subsequent revisions to the report will be made available to the public upon completion.

projected future new vehicle fleet). EPA acknowledges some uncertainty regarding how consumer purchases may change in response to the vehicles designed to meet the MYs 2012-2016 standards. This could potentially affect the mix of vehicles sold in this time frame, including the mass and footprint distribution – which would impact the projection of fatalities from the 2010 Kahane analysis as applied to this final rule.

The 2010 Kahane report presents three sets of results each with an estimate of fatalities based on the weight reductions projected in the feasibility analysis for the final rule. Each of these results presents a significant departure from the NPRM. The first set of results is a straight regression of result for passenger cars and LTVs. The passenger car data now includes 2-door vehicles, although a decision was made to continue to exclude muscle cars. The second and third sets of results, termed "upper bound scenario" and "lower bound scenario" respectively, are the result of expert opinion and judgment by NHTSA as to how mass may be reduced and the potential effects, both primary for the driver and occupants of a vehicle, and secondary or societal effects. NHTSA was able to perform these analyses with both mass and footprint treated as independent variables in the 2010 study. The unmodified straight regression results now reflect an expected reduction of 301 fatalities for the life of MY 2012-2016 vehicles, down from the absolute worst-case 493 in the CAFE NPRM. The new "upper bound scenario" estimates that there will be 22 additional fatalities as the result of the CAFE rule, and the "lower bound scenario" an 80 fatality decrease[WWW]. These results are consistent with EPA's NPRM claim that fatalities as a result of the rule could be close to zero. However, NHTSA states in the new 2010 Kahane analysis that the potential fatality increases associated with mass reduction in the passenger cars would be to a large extent offset by the benefits of mass reduction in the heavier LTVs. As was stated in the NPRM, EPA continues to believe that weight can be reduced from passenger cars safely through smart design, and other methods which can be used in the model years 2012 to 2016 time frame. This is based on a number of studies in the literature including those from DRI, Wenzel, Ross and Robertson referenced above and elsewhere in this final rule.

Furthermore, in an effort to address public comments that promoted the DRI results as a legitimate alternative to NHTSA's analysis, the 2010 Kahane report presents several conclusions. NHTSA first focused on the issue of "near multicollinearity" of the data. This statistical characteristic can result in increased uncertainty of regression coefficients, which according to sources cited by NHTSA, can result in the "wrong sign or implausible magnitude". There are statistical tests that can be run on data used in regression models to determine the level of multicollinearity between independent variables. NHTSA performed tests on their data set and determined that mass and footprint did exhibit "near multicollinearity". Subsequently, NHTSA applied a 2-step regression, in accordance with DRI's methodology, to its own data and the results showed a corresponding decrease in fatalities for a 100 pound mass reduction. NHTSA did not accept these results for many

[WWW] The "upper-estimate scenario" and "lower-estimate scenario" are based on NHTSA's judgment as a vehicle safety agency, and are not meant to convey a sense of confidence in the precision of the results, but more to convey a sense of bounding for potential safety effects.

reasons, as outlined in the 2010 Kahane report, however their underlying conclusion was that the 2-step regression applied by DRI exacerbated the effects of "near multicollinearity".

The EPA has found one additional peer-reviewed study of historical FARS data. Robertson 2006[371] analyzed somewhat newer model year passenger cars and light-trucks (1999-2002) and used a logistic regression approach similar to the 2003 Kahane and 2005 DRI studies, including consideration of driver gender and age. We note that this peer reviewed paper was published as a commentary in response to previous work published by the author, and this commentary does include new original work. The reference list contained in this 2006 Robertson paper includes the references to the previous work by the author The study found multicollinearity to be a problem for regressions, including vehicle curb-weight and wheelbase, but found turning radius could be substituted as an indicator of vehicle size without introducing significant multicollinearity into the regression analysis. Robertson's analysis tested the hypothesis of reducing vehicle curb-weight to the minimum achievable by the 1999-2002 model year population vs. vehicle size. The regression results showed a societal benefit of a 28% reduction in fatalities for minimization of mass. Mass minimization vs a vehicle size metric is not the same as removing a fixed percent or fixed quantity of vehicle mass and thus the results are not directly comparable to either the 2010 Kahane or 2005 DRI results, but they are directionally consistent with both studies. The analysis showed similar trends to the 2010 Kahane report with increased risk of fatality to drivers of lighter vehicles, which was more than offset by the reduction in risk of fatality to other drivers, similar to Kahane's 2010 results with respect to light trucks and to DRI's results for both light-trucks and passenger cars.

The EPA believe that while NHTSA's new 2010 analysis significantly adds to the literature and understanding of the effects of mass reduction on safety, that there still are many opportunities for further study.

7.6.4 Suggested Next Steps To Increase Our Understanding of the Effects of Vehicle Size and Weight on Fatalities

NHTSA and EPA believe that it is important for the agencies to conduct further study and research into the interaction of mass, size and safety to assist future rulemakings. The agencies intend to begin working collaboratively and to explore with DOE, CARB, and perhaps other stakeholders an interagency/ intergovernmental working group to evaluate all aspects of mass, size and safety. It would also be the goal of this team to coordinate government supported studies and independent research, to the extent possible, to help ensure the work is complementary to previous and ongoing research and to guide further research in this area. DOE's EERE office has long funded extensive research into component advanced vehicle materials and vehicle mass reduction. Other agencies may have additional expertise that will be helpful in establishing a coordinated work plan. The agencies are interested in looking at the weight-safety relationship in a more holistic (complete vehicle) way, and thanks to this CAFE rulemaking NHTSA has begun to bring together parts of the agency—crashworthiness, and crash avoidance rulemaking offices and the agency's Research & Development office—in an interdisciplinary way to better leverage the expertise of the agency. Extending this effort to other agencies will help to ensure that all aspects of the weight-safety relationship are considered completely and carefully with our future research.

The agencies also intend to carefully consider comments received in response to the NPRM in developing plans for future studies and research and to solicit input from stakeholders.

The agencies also plan to watch for safety effects as the U.S. light-duty vehicle fleet evolves in response both to the CAFE/GHG standards and to consumer preferences over the next several years. Additionally, as new and advanced materials and component smart designs are developed and commercialized, and as manufacturers implement them in more vehicles, it will be useful for the agencies to learn more about them and to try to track these vehicles in the fleet to understand the relationship between vehicle design and injury/fatality data. Specifically, the agencies intend to follow up with study and research of the following:

First, NHTSA is in the process of contracting with an independent institution to review the statistical methods that NHTSA and DRI have used to analyze historical data related to mass, size and safety, and to provide recommendation on whether the existing methods or other methods should be used for future statistical analysis of historical data. This study will include an consideration of potential multicollinearity in the historical data and how best to address it in a regression analysis. This study is being initiated because, in response to the NPRM, NHTSA received a number of comments related to the methodology NHTSA used for the NPRM to determine the relationship between mass and safety, as discussed in detail above.

Second, NHTSA and EPA, in consultation with DOE, intend to begin updating the MYs 1991-1999 database on which the safety analyses in the NPRM and final rule are based with newer vehicle data in the next several months. This task will take at least a year to complete. This study is being initiated in response to the NPRM comments related to the use of data from MYs 1991-1999 in the NHTSA analysis, as discussed in the section II.G of the preamble.

Third, in order to assess if the design of recent model year vehicles that incorporate various mass reduction methods affect the relationships among vehicle mass, size and safety, NHTSA and EPA intend to conduct collaborative statistical analysis, beginning in the next several months. The agencies intend to work with DOE to identify vehicles that are using material substitution and smart design. After these vehicles are identified, the agencies intend to assess if there are sufficient data for statistical analysis. If there are sufficient data, statistical analysis would be conducted to compare the relationship among mass, size and safety of these smart design vehicles to vehicles of similar size and mass with more traditional designs. This study is being initiated because, in response to the NPRM, NHTSA received comments related to the use of data from MYs 1991-1999 in the NHTSA analysis that did not include new designs that might change the relationship among mass, size and safety, as discussed in detail above.

NHTSA may initiate a two-year study of the safety of the fleet through an analysis of the trends in structural stiffness and whether any trends identified impact occupant injury response in crashes. Vehicle manufacturers may employ stiffer light weight materials to limit occupant compartment intrusion while controlling for mass that may expose the occupants to higher accelerations resulting in a greater chance of injury in real-world crashes. This study would provide information that would increase the understanding of the effects on safety of newer vehicle designs.

In addition, EPA and NHTSA, possibly in collaboration with DOE, may conduct a longer-term computer modeling-based design and analysis study to help determine the maximum potential for mass reduction in the MYs 2017-2021 timeframe, through direct material substitution and smart design while meeting safety regulations and guidelines, and maintaining vehicle size and functionality. This study may build upon prior research completed on vehicle mass reduction. This study would further explore the comprehensive vehicle effects, including dissimilar material joining technologies, manufacturer feasibility of both supplier and OEM, tooling costs, and crash simulation and perhaps eventual crash testing.

References

References can be found in the EPA DOCKET (EPA-HQ-OAR-2009-0472) or are publicly available.

[1] U.S. EPA (2009). Integrated Science Assessment for Particulate Matter (Final Report). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-08/139F, 2009. Docket EPA-HQ-OAR-2009-0472-11295.

[2] U.S. EPA (2009). Integrated Science Assessment for Particulate Matter (Final Report). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-08/139F, 2009. Section 2.3.1.1. Docket EPA-HQ-OAR-2009-0472-11295.

[3] U.S. EPA (2009). Integrated Science Assessment for Particulate Matter (Final Report). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-08/139F, 2009. Section 2.3.1.2. Docket EPA-HQ-OAR-2009-0472-11295.

[4] U.S. EPA (2009). Integrated Science Assessment for Particulate Matter (Final Report). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-08/139F, 2009. Section 2.3.4. Docket EPA-HQ-OAR-2009-0472-11295.

[5] U.S. EPA (2009). Integrated Science Assessment for Particulate Matter (Final Report). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-08/139F, 2009. Table 2-6. Docket EPA-HQ-OAR-2009-0472-11295.

[6] U.S. EPA (2009). Integrated Science Assessment for Particulate Matter (Final Report). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-08/139F, 2009. Section 2.3.5.1. Docket EPA-HQ-OAR-2009-0472-11295.

[7] U.S. EPA (2009). Integrated Science Assessment for Particulate Matter (Final Report). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-08/139F, 2009. Table 2-6. Docket EPA-HQ-OAR-2009-0472-11295.

[8] 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/. Docket EPA-HQ-OAR-2009-0472-0099, EPA-HQ-OAR-2009-0472-0100, and EPA-HQ-OAR-2009-0472-0101.

[9] 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/. Docket EPA-HQ-OAR-2009-0472-0106.

[10] National Research Council (NRC), 2008. *Estimating Mortality Risk Reduction and Economic Benefits from Controlling Ozone Air Pollution.* The National Academies Press: Washington, D.C. Docket EPA-HQ-OAR-2009-0472-0322.

[11] 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. Docket EPA-HQ-OAR-2009-0472-0264.

[12] 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. Docket EPA-HQ-OAR-2009-0472-0265.

[13] 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. Docket EPA-HQ-OAR-2009-0472-0266.

[14] Lipfert, F.W., Hammerstrom, T. (1992). Temporal patterns in air pollution and hospital admissions. *Environ. Res., 59*,374-399. Docket EPA-HQ-OAR-2009-0472-0267.

[15] 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. Docket EPA-HQ-OAR-2009-0472-0268.

[16] 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/. Docket EPA-HQ-OAR-2009-0472-0099, EPA-HQ-OAR-2009-0472-0100, and EPA-HQ-OAR-2009-0472-0101.

[17] 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/. Docket EPA-HQ-OAR-2009-0472-0099, EPA-HQ-OAR-2009-0472-0100, and EPA-HQ-OAR-2009-0472-0101.

[18] 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.

[19] 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. Docket EPA-HQ-OAR-2009-0472-0269.

[20] 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. Docket EPA-HQ-OAR-2009-0472-0323.

[21] 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. Docket EPA-HQ-OAR-2009-0472-0324.

[22] 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. Docket EPA-HQ-OAR-2009-0472-0099, EPA-HQ-OAR-2009-0472-0100, and EPA-HQ-OAR-2009-0472-0101.

[23] 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. Docket EPA-HQ-OAR-2009-0472-0270.

[24] 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. Docket EPA-HQ-OAR-2009-0472-0360.

[25] 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. Docket EPA-HQ-OAR-2009-0472-0361.

[26] 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/. Docket EPA-HQ-OAR-2009-0472-0106.

[27] 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/. Docket EPA-HQ-OAR-2009-0472-0099, EPA-HQ-OAR-2009-0472-0100, and EPA-HQ-OAR-2009-0472-0101.

[28] 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/. Docket EPA-HQ-OAR-2009-0472-0099, EPA-HQ-OAR-2009-0472-0100, and EPA-HQ-OAR-2009-0472-0101.

[29] 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. Docket EPA-HQ-OAR-2009-0472-0362.

[30] 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. Docket EPA-HQ-OAR-2009-0472-0332.

[31] 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. Docket EPA-HQ-OAR-2009-0472-0363.

[32] 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. Docket EPA-HQ-OAR-2009-0472-0364.

[33] 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). Docket EPA-HQ-OAR-2009-0472-0383.

[34] 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. Docket EPA-HQ-OAR-2009-0472-0380.

[35] 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. Docket EPA-HQ-OAR-2009-0472-0333.

[36] 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/. Docket EPA-HQ-OAR-2009-0472-0099, EPA-HQ-OAR-2009-0472-0100, and EPA-HQ-OAR-2009-0472-0101.

[37] 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. Docket EPA-HQ-OAR-2009-0472-0334.

[38] 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.

[39] 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. Docket EPA-HQ-OAR-2009-0472-0384.

[40] U.S. EPA (2008). *Integrated Science Assessment (ISA) for Sulfur Oxides – Health Criteria* (Final Report). EPA/600/R-08/047F. Washington, DC,: U.S.EPA. Retrieved on March 19, 2009 from http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=198843. Docket EPA-HQ-OAR-2009-0472-0335.

[41] 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. Docket EPA-HQ-OAR-2009-0472-0350.

[42] U.S. EPA, 2010. Integrated Science Assessment for Carbon Monoxide (Final Report). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-09/019F, 2010. http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=218686. Docket EPA-HQ-OAR-2009-0472-0335.

[43] U. S. EPA. (2009) 2002 National-Scale Air Toxics Assessment. http://www.epa.gov/ttn/atw/nata2002/risksum.html Docket EPA-HQ-OAR-2009-0472-11322.

[44] U.S. EPA (2007) Control of Hazardous Air Pollutants from Mobile Sources. 72 FR 8428; February 26, 2007. Docket EPA-HQ-OAR-2009-0472-0271.

[45] 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. Docket EPA-HQ-OAR-2009-0472-0391.

[46] 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. Docket EPA-HQ-OAR-2009-0472-11322.

[47] U.S. EPA (2009) National-Scale Air Toxics Assessment for 2002. http://www.epa.gov/ttn/atw/nata2002. Docket EPA-HQ-OAR-2009-0472-11321.

[48] 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. Docket EPA-HQ-OAR-2009-0472-1659.

[49] 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. Docket EPA-HQ-OAR-2009-0472-0366.

[50] 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. Docket EPA-HQ-OAR-2009-0472-0370.

[51] 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. EPA-HQ-OAR-2009-0472-0367. Docket EPA-HQ-OAR-2009-0472-0367.

[52] U.S. Department of Health and Human Services National Toxicology Program 11th Report on Carcinogens available at: http://ntp.niehs.nih.gov/go/16183.

[53] Aksoy, M. (1989). Hematotoxicity and carcinogenicity of benzene. Environ. Health Perspect. 82: 193-197. EPA-HQ-OAR-2009-0472-0368

[54] Goldstein, B.D. (1988). Benzene toxicity. Occupational medicine. State of the Art Reviews. 3: 541-554. Docket EPA-HQ-OAR-2009-0472-0325.

[55] 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. Docket EPA-HQ-OAR-2009-0472-0326.

[56] 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. Docket EPA-HQ-OAR-2009-0472-0327.

[57] 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. Docket EPA-HQ-OAR-2009-0472-0328.

[58] 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. Docket EPA-HQ-OAR-2009-0472-0329.

[59] Lan, Qing, Zhang, L., Li, G., Vermeulen, R., et al. (2004). Hematotoxically in Workers Exposed to Low Levels of Benzene. Science 306: 1774-1776. Docket EPA-HQ-OAR-2009-0472-0330.

[60] 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. Docket EPA-HQ-OAR-2009-0472-0385.

[61] 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. Docket EPA-HQ-OAR-2009-0472-0386.

[62] 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. Docket EPA-HQ-OAR-2009-0472-1660.

[63] 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. Docket EPA-HQ-OAR-2009-0472-0387.

[64] U.S. Department of Health and Human Services National Toxicology Program 11th Report on Carcinogens available at: http://ntp.niehs.nih.gov/go/16183.

[65] 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. Docket EPA-HQ-OAR-2009-0472-0388.

[66] 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. Docket EPA-HQ-OAR-2009-0472-0389.

[67] 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. Docket EPA-HQ-OAR-2009-0472-0336.

[68] 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. Docket EPA-HQ-OAR-2009-0472-0337.

[69] 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. Docket EPA-HQ-OAR-2009-0472-0338.

[70] Pinkerton, L. E. 2004. Mortality among a cohort of garment workers exposed to formaldehyde: an update. Occup. Environ. Med. 61: 193-200. Docket EPA-HQ-OAR-2009-0472-0339.

[71] 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. Docket EPA-HQ-OAR-2009-0472-0340.

[72] 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. Docket EPA-HQ-OAR-2009-0472-0341.

[73] 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. Docket EPA-HQ-OAR-2009-0472-0342.

[74] 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. Docket EPA-HQ-OAR-2009-0472-0429.

[75] 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. Docket EPA-HQ-OAR-2009-0472-0369.

[76] 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. Docket EPA-HQ-OAR-2009-0472-0371.

[77] 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. Docket EPA-HQ-OAR-2009-0472-0444.

[78] 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. Docket EPA-HQ-OAR-2009-0472-0447.

[79] 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. Docket EPA-HQ-OAR-2009-0472-0447.

[80] 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. Docket EPA-HQ-OAR-2009-0472-0444.

[81] International Agency for Research on Cancer (2006) Formaldehyde, 2-Butoxyethanol and 1-tert-Butoxypropan-2-ol. Monographs Volume 88. World Health Organization, Lyon, France. Docket EPA-HQ-OAR-2009-0472-1164.

[82] 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. Docket EPA-HQ-OAR-2009-0472-1191.

[83] 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. Docket EPA-HQ-OAR-2009-0472-1199.

[84] 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. Docket EPA-HQ-OAR-2009-0472-0390.

[85] U.S. Department of Health and Human Services National Toxicology Program 11th Report on Carcinogens available at: http://ntp.niehs.nih.gov/go/16183.

[86] 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.

[87] 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. Docket EPA-HQ-OAR-2009-0472-0390.

[88] 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. Docket EPA-HQ-OAR-2009-0472-0391.

[89] 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. Docket EPA-HQ-OAR-2009-0472-0392.

[90] 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. Docket EPA-HQ-OAR-2009-0472-0408.

[91] 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. Docket EPA-HQ-OAR-2009-0472-0391.

[92] 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. Docket EPA-HQ-OAR-2009-0472-0393.

[93] Sim VM, Pattle RE. Effect of possible smog irritants on human subjects JAMA165: 1980-2010, 1957. Docket EPA-HQ-OAR-2009-0472-0395.

[94] U.S. EPA (U.S. Environmental Protection Agency). (2003) Toxicological review of acrolein in support of summary information on Integrated Risk Information System (IRIS) National Center for Environmental Assessment, Washington, DC. EPA/635/R-03/003. Available online at: http://www.epa.gov/ncea/iris.

[95] 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. Docket EPA-HQ-OAR-2009-0472-0394.

[96] Integrated Risk Information System File of Acrolein. Office of Research and Development, National Center for Environmental Assessment, Washington, DC. This material is available at http://www.epa.gov/iris/subst/0364.htm. Docket EPA-HQ-OAR-2009-0472-0391.

[97] U.S. EPA (U.S. Environmental Protection Agency). (2003) Toxicological review of acrolein in support of summary information on Integrated Risk Information System (IRIS) National Center for Environmental Assessment, Washington, DC. EPA/635/R-03/003. Available online at: http://www.epa.gov/ncea/iris.

[98] 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. Docket EPA-HQ-OAR-2009-0472-0396.

[99] 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. Docket EPA-HQ-OAR-2009-0472-0372.

[100] 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. Docket EPA-HQ-OAR-2009-0472-0373.

[101] 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. Docket EPA-HQ-OAR-2009-0472-0272.

[102] 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. Docket EPA-HQ-OAR-2009-0472-0273.

[103] 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.

[104] International Agency for Research on Cancer (IARC). (2002). Monographs on the Evaluation of the Carcinogenic Risk of Chemicals for Humans. Vol. 82. Lyon, France. Docket EPA-HQ-OAR-2009-0472-0274.

[105] 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

[106] Zhou, Y.; Levy, J.I. (2007) Factors influencing the spatial extent of mobile source air pollution impacts: a meta-analysis. BMC Public Health 7: 89. doi:10.1186/1471-2458-7-89. Docket EPA-HQ-OAR-2009-0472-11375.

[107] HEI Panel on the Health Effects of Air Pollution. (2010) Traffic-related air pollution: a critical review of the literature on emissions, exposure, and health effects. [Online at www.healtheffects.org]. Docket EPA-HQ-OAR-2009-0472-11382.

[108] Salam, M.T.; Islam, T.; Gilliland, F.D. (2008) Recent evidence for adverse effects of residential proximity to traffic sources on asthma. Current Opin Pulm Med 14: 3-8. Docket EPA-HQ-OAR-2009-0472-11381.

[109] Holguin, F. (2008) Traffic, outdoor air pollution, and asthma. Immunol Allergy Clinics North Am 28: 577-588.

[110] Adar, S.D.; Kaufman, J.D. (2007) Cardiovascular disease and air pollutants: evaluating and improving epidemiological data implicating traffic exposure. Inhal Toxicol 19: 135-149. Docket EPA-HQ-OAR-2009-0472-11376.

[111] Raaschou-Nielsen, O.; Reynolds, P. (2006) Air pollution and childhood cancer: a review of the epidemiological literature. Int J Cancer 118: 2920-2929. Docket EPA-HQ-OAR-2009-0472-11380.

[112] U.S. Census Bureau (2008) American Housing Survey for the United States in 2007. Series H-150 (National Data), Table 1A-6. [Accessed at http://www.census.gov/hhes/www/housing/ahs/ahs07/ahs07.html on January 22, 2009]

[113] Lena, T.S.; Ochieng, V.; Carter, M.; Holguín-Veras, J.; Kinney, P.L. (2002) Elemental carbon and PM2.5 levels in an urban community heavily impacted by truck traffic. Environ Health Perspect 110: 1009-1015. Docket EPA-HQ-OAR-2009-0472-11379.

[114] Wier, M.; Sciammas, C.; Seto, E.; Bhatia, R.; Rivard, T. (2009) Health, traffic, and environmental justice: collaborative research and community action in San Francisco, California. Am J Public Health 99: S499-S504. Docket EPA-HQ-OAR-2009-0472-11373.

[115] Forkenbrock, D.J. and L.A. Schweitzer, Environmental Justice and Transportation Investment Policy. Iowa City: Univerity of Iowa, 1997.

[116] Appatova, A.S.; Ryan, P.H.; LeMasters, G.K.; Grinshpun, S.A. (2008) Proximal exposure of public schools and students to major roadways: a nationwide US survey. J Environ Plan Mgmt. Docket EPA-HQ-OAR-2009-0472-11378.

[117] Green, R.S.; Smorodinsky, S.; Kim, J.J.; McLaughlin, R.; Ostro, B. (2004) Proximity of California public schools to busy roads. Environ Health Perspect 112: 61-66. Docket EPA-HQ-OAR-2009-0472-11377.

[118] Houston, D.; Ong, P.; Wu, J.; Winer, A. (2006) Proximity of licensed child care facilities to near-roadway vehicle pollution. Am J Public Health 96: 1611-1617. Docket EPA-HQ-OAR-2009-0472-11383.

[119] Wu, Y.; Batterman, S. (2006) Proximity of schools in Detroit, Michigan to automobile and truck traffic. J Exposure Sci Environ Epidemiol 16: 457-470. Docket EPA-HQ-OAR-2009-0472-11374.

[120] U.S. EPA (2009). *final PM ISA, pg 9-19 through 9-23*

[121] 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. Docket EPA-HQ-OAR-2009-0472-0343.

[122] 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. Docket EPA-HQ-OAR-2009-0472-0099, EPA-HQ-OAR-2009-0472-0100, and EPA-HQ-OAR-2009-0472-0101.

[123] 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. Docket EPA-HQ-OAR-2009-0472-0344.

[124] 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. Docket EPA-HQ-OAR-2009-0472-0099, EPA-HQ-OAR-2009-0472-0100, and EPA-HQ-OAR-2009-0472-0101.

[125] 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. Docket EPA-HQ-OAR-2009-0472-0345.

[126] 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. Docket EPA-HQ-OAR-2009-0472-0099, EPA-HQ-OAR-2009-0472-0100, and EPA-HQ-OAR-2009-0472-0101.

[127] 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. Docket EPA-HQ-OAR-2009-0472-0099, EPA-HQ-OAR-2009-0472-0100, and EPA-HQ-OAR-2009-0472-0101.

[128] 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. Docket EPA-HQ-OAR-2009-0472-0099, EPA-HQ-OAR-2009-0472-0100, and EPA-HQ-OAR-2009-0472-0101.

[129] 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. Docket EPA-HQ-OAR-2009-0472-0099, EPA-HQ-OAR-2009-0472-0100, and EPA-HQ-OAR-2009-0472-0101.

[130] 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. Docket EPA-HQ-OAR-2009-0472-0346.

[131] Winner, W.E. (1994). Mechanistic analysis of plant responses to air pollution. *Ecological Applications, 4(4),* 651-661. Docket EPA-HQ-OAR-2009-0472-0347.

[132] 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. Docket EPA-HQ-OAR-2009-0472-0099, EPA-HQ-OAR-2009-0472-0100, and EPA-HQ-OAR-2009-0472-0101.

[133] 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. Docket EPA-HQ-OAR-2009-0472-0099, EPA-HQ-OAR-2009-0472-0100, and EPA-HQ-OAR-2009-0472-0101.

[134] 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.

[135] De Steiguer, J., Pye, J., Love, C. (1990). Air Pollution Damage to U.S. Forests. *Journal of Forestry, 88(8),* 17-22. Docket EPA-HQ-OAR-2009-0472-0348.

[136] Pye, J.M. (1988). Impact of ozone on the growth and yield of trees: A review. *Journal of Environmental Quality, 17*, 347-360. Docket EPA-HQ-OAR-2009-0472-0349.

[137] 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. Docket EPA-HQ-OAR-2009-0472-0099, EPA-HQ-OAR-2009-0472-0100, and EPA-HQ-OAR-2009-0472-0101.

[138] 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. Docket EPA-HQ-OAR-2009-0472-0099, EPA-HQ-OAR-2009-0472-0100, and EPA-HQ-OAR-2009-0472-0101.

[139] 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. Docket EPA-HQ-OAR-2009-0472-0374.

[140] 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). Docket EPA-HQ-OAR-2009-0472-0375.

[141] 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. Docket EPA-HQ-OAR-2009-0472-0099, EPA-HQ-OAR-2009-0472-0100, and EPA-HQ-OAR-2009-0472-0101.

[142] 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. Docket EPA-HQ-OAR-2009-0472-0376.

[143] 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. Docket EPA-HQ-OAR-2009-0472-0397.

[144] 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. Docket EPA-HQ-OAR-2009-0472-0398.

[145] 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. Docket EPA-HQ-OAR-2009-0472-0399.

[146] 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. Docket EPA-HQ-OAR-2009-0472-0099, EPA-HQ-OAR-2009-0472-0100, and EPA-HQ-OAR-2009-0472-0101.

[147] 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. Docket EPA-HQ-OAR-2009-0472-0400.

[148] 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. Docket EPA-HQ-OAR-2009-0472-1200.

[149] 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. Docket EPA-HQ-OAR-2009-0472-1201.

[150] 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. Docket EPA-HQ-OAR-2009-0472-1200.

[151] 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. Docket EPA-HQ-OAR-2009-0472-1201.

[152] 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. Docket EPA-HQ-OAR-2009-0472-1202.

[153] U.S. EPA. (2006). *Air Quality Criteria for Ozone and Related Photochemical Oxidants.* EPA/600/R-05/004aF-cF. Docket EPA-HQ-OAR-2009-0472-0099, EPA-HQ-OAR-2009-0472-0100, and EPA-HQ-OAR-2009-0472-0101.

[154] 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. Docket EPA-HQ-OAR-2009-0472-1201.

[155] U.S. EPA (2006). *Air Quality Criteria for Ozone and Related Photochemical Oxidants.* EPA/600/R-05/004aF-cF. Docket EPA-HQ-OAR-2009-0472-0099, EPA-HQ-OAR-2009-0472-0100, and EPA-HQ-OAR-2009-0472-0101.

[156] 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. Docket EPA-HQ-OAR-2009-0472-0106.

[157] 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. Docket EPA-HQ-OAR-2009-0472-1203

[158] U.S. EPA (2009) Final PM ISA

[159] 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. Docket EPA-HQ-OAR-2009-0472-0098.

[160] 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. Docket EPA-HQ-OAR-2009-0472-0014.

[161] 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. Docket EPA-HQ-OAR-2009-0472-0095.

[162] 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. Docket EPA-HQ-OAR-2009-0472-0112.

[163] Galloway, J. N.; Cowling, E. B. (2002). Reactive nitrogen and the world: 200 years of change. Ambio 31: 64–71. Docket EPA-HQ-OAR-2009-0472-0377.

[164] 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. Docket EPA-HQ-OAR-2009-0472-0378 and EPA-HQ-OAR-2009-0472-0378.1.

[165] Smith, W.H. 1991. “Air pollution and Forest Damage.” Chemical Engineering News, 69(45): 30-43. Docket EPA-HQ-OAR-2009-0472-0275.

[166] 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. Docket EPA-HQ-OAR-2009-0472-0276.

[167] 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. Docket EPA-HQ-OAR-2009-0472-1205.

[168] 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. Docket EPA-HQ-OAR-2009-0472-1206.

[169] U.S. EPA (2009). Integrated Science Assessment for Particulate Matter (Final Report). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-08/139F, 2009. Section 9.4.5.2. Docket EPA-HQ-OAR-2009-0472-11295

[170] 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"). Docket EPA-HQ-OAR-2009-0472-1207.

[171] 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. Docket EPA-HQ-OAR-2009-0472-1208.

[172] 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. Docket EPA-HQ-OAR-2009-0472-0091.

[173] National Science and Technology Council (NSTC) 1999. "The Role of Monitoring Networks in the Management of the Nation's Air Quality." Docket EPA-HQ-OAR-2009-0472-1209.

[174] 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. Docket EPA-HQ-OAR-2009-0472-1895.

[175] Rice, K.C. 1999. "Trace Element Concentrations in Streambed Sediment Across the Conterminous United States." Environmental Science & Technology, 33: 2499-2504. Docket EPA-HQ-OAR-2009-0472-1896.

[176] 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. Docket EPA-HQ-OAR-2009-0472-1897.

[177] 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. Docket EPA-HQ-OAR-2009-0472-1908.

[178] 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. Docket EPA-HQ-OAR-2009-0472-1908.

[179] 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. Docket EPA-HQ-OAR-2009-0472-1909.

[180] 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. Docket EPA-HQ-OAR-2009-0472-1910.

[181] 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. Docket EPA-HQ-OAR-2009-0472-0256.

[182] 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. Docket EPA-HQ-OAR-2009-0472-0352.

[183] 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. Docket EPA-HQ-OAR-2009-0472-0354.

[184] 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. Docket EPA-HQ-OAR-2009-0472-0256.

[185] 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. Docket EPA-HQ-OAR-2009-0472-0091.

[186] Van Metre, P.C.; Mahler, B.J.; and Furlong, E.T. 2000. "Urban Sprawl Leaves its PAH Signature." Environmental Science & Technology, 34: 4064-4070. Docket EPA-HQ-OAR-2009-0472-0355.

[187] 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. Docket EPA-HQ-OAR-2009-0472-0359.

[188] Tuhackova, J. et al. (2001) Hydrocarbon deposition and soil microflora as affected by highway traffic. Environmental Pollution, 113: 255-262. Docket EPA-HQ-OAR-2009-0472-0356.

[189] U.S. EPA. 1991. Effects of organic chemicals in the atmosphere on terrestrial plants. EPA/600/3-91/001. Docket EPA-HQ-OAR-2009-0472-0401.

[190] 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. Docket EPA-HQ-OAR-2009-0472-0357.

[191] 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. Docket EPA-HQ-OAR-2009-0472-0357.

[192] Viskari E-L. 2000. Epicuticular wax of Norway spruce needles as indicator of traffic pollutant deposition. Water, Air, and Soil Pollut. 121:327-337. Docket EPA-HQ-OAR-2009-0472-1128.

[193] Ugrekhelidze D, F Korte, G Kvesitadze. 1997. Uptake and transformation of benzene and toluene by plant leaves. Ecotox. Environ. Safety 37:24-29. Docket EPA-HQ-OAR-2009-0472-1142.

[194] 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. Docket EPA-HQ-OAR-2009-0472-0358.

[195] Byun, D.W., Ching, J. K.S. (1999). *Science algorithms of the EPA models-3 community multiscale air quality (CMAQ) modeling system*. Washington, DC: U.S. Environmental Protection Agency, Office of Research and Development. Docket EPA-HQ-OAR-2009-0472-1915

[196] Byun, D.W., 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. *Journal of Applied Mechanics Reviews, 59(2),* 51-77. Docket EPA-HQ-OAR-2009-0472-1916

[197] 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. Docket EPA-HQ-OAR-2009-0472-1917

[198] Hogrefe, C., Biswas, J., Lynn, B., Civerolo, K., Ku, J.Y., Rosenthal, J., et al. (2004). Simulating regional-scale ozone climatology over the eastern United States: model evaluation results. *Atmospheric Environment, 38(17),* 2627-2638. Docket EPA-HQ-OAR-2009-0472-11350

[199] Lin, M., Oki, T., Holloway, T., Streets, D.G., Bengtsson, M., Kanae, S. (2008). Long-range transport of acidifying substances in East Asia-Part I: Model evaluation and sensitivity studies. *Atmospheric Environment, 42(24),* 5939-5955. Docket EPA-HQ-OAR-2009-0472-11341

[200] U.S. Environmental Protection Agency. (2008). *Technical support document for the final locomotive/marine rule: Air quality modeling analyses.* Research Triangle Park, N.C.: U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Air Quality Assessment Division. Docket EPA-HQ-OAR-2009-0472-11329

[201] 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. Docket EPA-HQ-OAR-2009-0472-2104

[202] 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. Docket EPA-HQ-OAR-2009-0472-2104

[203] Byun, D.W., Ching, J. K.S. (1999). *Science algorithms of EPA Models-3 Community Multiscale Air Quality (CMAQ) modeling system*, EPA/600/R-99/030, Office of Research and Development). Please also see: http://www.cmascenter.org/. Docket EPA-HQ-OAR-2009-0472-1915

[204] Le Sager, P. Yantosca, B., Carouge, C. (2008). *GEOS-CHEM v8-01-02 User's Guide*, Atmospheric Chemistry Modeling Group, Harvard University, Cambridge, MA, December 18, 2008. Docket EPA-HQ-OAR-2009-0472-11344

[205] U.S. EPA, (2004), *Procedures for Estimating Future PM2.5 Values for the CAIR Final Rule by Application of the (Revised) Speciated Modeled Attainment Test (SMAT)- Updated 11/8/04.* Docket EPA-HQ-OAR-2009-0472-11327

[206] U.S. EPA, (2008), *Control of Emissions from Nonroad Spark-Ignition Engines and Equipment, Technical Support Document.* EPA 454/R-08-005. Docket EPA-HQ-OAR-2009-0472-11330

[207] U.S. EPA (2007) *Guidance on the Use of Models and Other Analyses For Demonstrating Attainment of Air Quality Goals for Ozone, PM2.5, and Regional Haze;* EPA-454/B-07-002; Research Triangle Park, NC; April 2007. Docket EPA-HQ-OAR-2009-0472-11328

[208] Yarwood G, Rao S, Yocke M, Whitten GZ (2005) Updates to the Carbon Bond Chemical Mechanism: CB05. Final Report to the US EPA, RT-0400675, December 8, 2005. http://www.camx.com/publ/pdfs/CB05_Final_Report_120805.pdf. Docket EPA-HQ-OAR-2009-0472-0111

[209] Dodge, M.C., 2000. Chemical oxidant mechanisms for air quality modeling: critical review. Atmospheric Environment 34, 2103-2130. Docket EPA-HQ-OAR-2009-0472-11338

[210] Atkinson, R., Baulch, D.L., Cox, R.A., Crowley, J.N., Hampson, R.F. Jr., Hynes, R.G., Jenkin, M.E., Kerr, J.A., Rossi, M.J., Troe, J. (2005) Evaluated Kinetic and Photochemical Data for Atmospheric Chemistry - IUPAC Subcommittee on Gas Kinetic Data Evaluation for Atmospheric Chemistry. July 2005 web version. http://www.iupac-kinetic.ch.cam.ac.uk/index.html. Docket EPA-HQ-OAR-2009-0472-11333

[211] Atkinson, R., Baulch, D.L., Cox, R.A., Crowley, J.N., Hampson, R.F. Jr., Hynes, R.G., Jenkin, M.E., Kerr, J.A., Rossi, M.J., Troe, J. (2005) Evaluated Kinetic and Photochemical Data for Atmospheric Chemistry - IUPAC Subcommittee on Gas Kinetic Data Evaluation for Atmospheric Chemistry. July 2005 web version. http://www.iupac-kinetic.ch.cam.ac.uk/index.html. Docket EPA-HQ-OAR-2009-0472-11333

[212] Atkinson, R., Baulch, D.L., Cox, R.A., Crowley, J.N., Hampson, R.F. Jr., Hynes, R.G., Jenkin, M.E., Kerr, J.A., Rossi, M.J., Troe, J. (2005) Evaluated Kinetic and Photochemical Data for Atmospheric Chemistry - IUPAC Subcommittee on Gas Kinetic Data Evaluation for Atmospheric Chemistry. July 2005 web version. http://www.iupac-kinetic.ch.cam.ac.uk/index.html. Docket EPA-HQ-OAR-2009-0472-11333

[213] Atkinson, R., Baulch, D.L., Cox, R.A., Crowley, J.N., Hampson, R.F. Jr., Hynes, R.G., Jenkin, M.E., Kerr, J.A., Rossi, M.J., Troe, J. (2005) Evaluated Kinetic and Photochemical Data for Atmospheric Chemistry - IUPAC Subcommittee on Gas Kinetic Data Evaluation for Atmospheric Chemistry. July 2005 web version. http://www.iupac-kinetic.ch.cam.ac.uk/index.html. Docket EPA-HQ-OAR-2009-0472-11333

[214] Sander, S.P., Friedl, R.R., Golden, D.M., Kurylo, M.J., Huie, R.E., Orkin, V.L., Moortgat, G.K., Ravishankara, A.R., Kolb, C.E., Molina, M.J., Finlayson-Pitts, B.J. (2003) Chemical Kinetics and Photochemical Data for use in Atmospheric Studies, Evaluation Number 14. NASA Jet Propulsion Laboratory http://jpldataeval.jpl.nasa.gov/index.html. Docket EPA-HQ-OAR-2009-0472-11320

[215] Sander, S.P., Friedl, R.R., Golden, D.M., Kurylo, M.J., Huie, R.E., Orkin, V.L., Moortgat, G.K., Ravishankara, A.R., Kolb, C.E., Molina, M.J., Finlayson-Pitts, B.J. (2003) Chemical Kinetics and Photochemical Data for use in Atmospheric Studies, Evaluation Number 14. NASA Jet Propulsion Laboratory http://jpldataeval.jpl.nasa.gov/index.html. Docket EPA-HQ-OAR-2009-0472-11320

[216] Yarwood, G., Rao, S., Yocke, M., Whitten, G.Z., 2005. Updates to the Carbon Bond Mechanism: CB05. Final Report to the US EPA, RT-0400675. Yocke and Company, Novato, CA. Docket EPA-HQ-OAR-2009-0472-0111

[217] Luecken, D.J., Phillips, S., Sarwar, G., Jang, C., 2008b. Effects of using the CB05 vs. SAPRC99 vs. CB4 chemical mechanism on model predictions: Ozone and gas-phase photochemical precursor concentrations. Atmospheric Environment 42, 5805-5820. Docket EPA-HQ-OAR-2009-0472-11343

[218] Sander, S.P., Friedl, R.R., Golden, D.M., Kurylo, M.J., Huie, R.E., Orkin, V.L., Moortgat, G.K., Ravishankara, A.R., Kolb, C.E., Molina, M.J., Finlayson-Pitts, B.J., 2003. Chemical Kinetics and Photochemical Data for use in Atmospheric Studies, Evaluation Number 14. NASA Jet Propulsion Laboratory. Docket EPA-HQ-OAR-2009-0472-11320

[219] Sander, S.P., Friedl, R.R., Golden, D.M., Kurylo, M.J., Huie, R.E., Orkin, V.L., Moortgat, G.K., Ravishankara, A.R., Kolb, C.E., Molina, M.J., Finlayson-Pitts, B.J., 2003. Chemical Kinetics and Photochemical Data for use in Atmospheric Studies, Evaluation Number 14. NASA Jet Propulsion Laboratory. Docket EPA-HQ-OAR-2009-0472-11320

[220] Atkinson R, Arey J (2003) Atmospheric Degradation of Volatile Organic Compounds. Chem Rev 103: 4605-4638. Docket EPA-HQ-OAR-2009-0472-11334

[221] Atkinson, R., Baulch, D.L., Cox, R.A., Crowley, J.N., Hampson, R.F. Jr., Hynes, R.G., Jenkin, M.E., Kerr, J.A., Rossi, M.J., Troe, J. (2005) Evaluated Kinetic and Photochemical Data for Atmospheric Chemistry - IUPAC Subcommittee on Gas Kinetic Data Evaluation for Atmospheric Chemistry. July 2005 web version. http://www.iupac-kinetic.ch.cam.ac.uk/index.html. Docket EPA-HQ-OAR-2009-0472-11333

[222] Atkinson, R., Baulch, D.L., Cox, R.A., Crowley, J.N., Hampson, R.F. Jr., Hynes, R.G., Jenkin, M.E., Kerr, J.A., Rossi, M.J., Troe, J. (2005) Evaluated Kinetic and Photochemical Data for Atmospheric Chemistry - IUPAC Subcommittee on Gas Kinetic Data Evaluation for Atmospheric Chemistry. July 2005 web version. http://www.iupac-kinetic.ch.cam.ac.uk/index.html. Docket EPA-HQ-OAR-2009-0472-11333

[223] Edney, E. O., T. E. Kleindienst, M. Lewandowski, and J. H. Offenberg, 2007. Updated SOA chemical mechanism for the Community Multi-Scale Air Quality model, EPA 600/X-07/025, U.S. EPA, Research Triangle Park, NC. Docket EPA-HQ-OAR-2009-0472-11345

[224] Carlton, A.G., B. J. Turpin, K. Altieri, S. Seitzinger, R. Mathur, S. Roselle, R. J. Weber, (2008), CMAQ model performance enhanced when in-cloud SOA is included: comparisons of OC predictions with measurements, Environ. Sci. Technol. 42 (23), 8798–8802. Docket EPA-HQ-OAR-2009-0472-11336

[225] Lewandowski M, M Jaoui , JH Offenberg , TE Kleindienst, EO Edney, RJ Sheesley, JJ Schauer (2008) Primary and secondary contributions to ambient PM in the midwestern United States, Environ Sci Technol 42(9):3303-3309. http://pubs.acs.org/cgi-bin/article.cgi/esthag/2008/42/i09/html/es0720412.html. Docket EPA-HQ-OAR-2009-0472-11340

[226] Kleindienst TE, M Jaoui, M Lewandowski, JH Offenberg, EO Edney (2007) Estimates of the contributions of biogenic and anthropogenic hydrocarbons to secondary organic aerosol at

a southeastern U.S. location, Atmos Environ 41(37):8288-8300. Docket EPA-HQ-OAR-2009-0472-11356

[227] Offenberg JH, CW Lewis, M Lewandowski, M Jaoui, TE Kleindienst, EO Edney (2007) Contributions of Toluene and □-pinene to SOA Formed in an Irradiated Toluene/□-pinene,NO_x/Air Mixture: Comparison of Results Using ^{14}C Content and SOA Organic Tracer Methods, Environ Sci Technol 41: 3972-3976. Docket EPA-HQ-OAR-2009-0472-11318

[228] Pandis, S.N., Harley, R.A., Cass, G.R., Seinfeld, J.H. (1992) Secondary organic aerosol formation and transport. Atmos Environ 26, 2269–2282. Docket EPA-HQ-OAR-2009-0472-11319

[229] Takekawa, H. Minoura, H. Yamazaki, S. (2003) Temperature dependence of secondary organic aerosol formation by photo-oxidation of hydrocarbons. Atmos Environ 37: 3413–3424. Docket EPA-HQ-OAR-2009-0472-11358

[230] Kleeman, M.J., Ying, Q., Lu, J., Mysliwiec, M.J., Griffin, R.J., Chen, J., Clegg, S. (2007) Source apportionment of secondary organic aerosol during a severe photochemical smog episode. Atmos Environ 41: 576–591. Docket EPA-HQ-OAR-2009-0472-11313

[231] Robinson, A. L.; Donahue, N. M.; Shrivastava, M.; Weitkamp, E. A.; Sage, A. M.; Grieshop, A. P.; Lane, T. E.; Pierce, J. R.; Pandis, S. N. (2007) Rethinking organic aerosol: Semivolatile emissions and photochemical aging. Science 315: 1259-1262. Docket EPA-HQ-OAR-2009-0472-11357

[232] Byun DW, Schere, KL (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: 51-76. Docket EPA-HQ-OAR-2009-0472-1916

[233] U. S. EPA (2002) National Air Quality and Emissions Trends Report, 2001. EPA 454/K-02-001, September 2002. http://www.epa.gov/air/airtrends/aqtrnd01/summary.pdf. Docket EPA-HQ-OAR-2009-0472-0092

[234] U. S. EPA. (2009) 2002 National-Scale Air Toxics Assessment. http://www.epa.gov/ttn/atw/nata2002/risksum.html. Docket EPA-HQ-OAR-2009-0472-11321

[235] U. S. EPA (2007) Regulatory Impact Analysis for the Control of Hazardous Air Pollutants from Mobile Sources Rule, Chapter 3, Air Quality and Resulting Health and Welfare Effects of Air Pollution from Mobile Sources. 72 FR 8428, February 26, 2007. http://www.epa.gov/otaq/regs/toxics/420r07002.pdf. Docket EPA-HQ-OAR-2009-0472-0107

[236] Kleindienst, T.E. (2008) Hypothetical SOA Production from Ethanol Photooxidation. Memo to the Docket EPA-HQ-OAR-2005-0161. Docket EPA-HQ-OAR-2009-0472-11314

237 Turpin, B.J., Huntzicker, J.J., Larson, S.M., Cass, G.R. (1991) Los Angeles Summer Midday Particulate Carbon: Primary and Secondary Aerosol. Environ Sci Technol 25: 1788-1793. Docket EPA-HQ-OAR-2009-0472-11359

238 Turpin, B.J., Huntzicker, J.J. (1995) Identification of Secondary Organic Aerosol Episodes and Quantitation of Primary and Secondary Organic Aerosol Concentrations During SCAQS. Atmos Environ 29(23): 3527-3544. Docket EPA-HQ-OAR-2009-0472-11360

239 Bae M-S, Schauer JJ, Turner JR (2006) Estimation of the Monthly Average Ratios of Organic Mass to Organic Carbon for Fine Particulate Matter at an Urban Site, Aerosol Sci Technol 40(12): 1123-1139. http://dx.doi.org/10.1080/02786820601004085. Docket EPA-HQ-OAR-2009-0472-11335

240 Kleindienst TE, M Jaoui, M Lewandowski, JH Offenberg, EO Edney (2007) Estimates of the contributions of biogenic and anthropogenic hydrocarbons to secondary organic aerosol at a southeastern U.S. location. Atmos Environ 41(37):8288-8300. Docket EPA-HQ-OAR-2009-0472-11356

241 Offenberg JH, CW Lewis, M Lewandowski, M Jaoui, TE Kleindienst, EO Edney (2007) Contributions of Toluene and □-pinene to SOA Formed in an Irradiated Toluene/□-pinene,NO_x/Air Mixture: Comparison of Results Using ^{14}C Content and SOA Organic Tracer Methods, Environ Sci Technol 41: 3972-3976. Docket EPA-HQ-OAR-2009-0472-11318

242 Claeys M, R Szmigielski, I Kourtchev, P Van der Veken, R Vermeylen, W Maenhaut, M Jaoui, TE Kleindienst, M Lewandowski, JH Offenberg, EO Edney (2007) Hydroxydicarboxylic acids: Markers for secondary organic aerosol from the photooxidation of □-pinene. Environ Sci Technol 41(5): 1628-1634. Docket EPA-HQ-OAR-2009-0472-11337

243 Edney EO, TE Kleindienst, M Jaoui, M Lewandowski, JH Offenberg, W Wang, M Claeys (2005) Formation of 2-methyl tetrols and 2-methylglyceric acid in secondary organic aerosol from laboratory irradiated isoprene/NO_X/SO_2/air mixtures and their detection in ambient $PM_{2.5}$ samples collected in the Eastern United States. Atmos Environ 39: 5281-5289. Docket EPA-HQ-OAR-2009-0472-11339

244 Jaoui M, TE Kleindienst, M Lewandowski, JH Offenberg, EO Edney (2005) Identification and quantification of aerosol polar oxygenated compounds bearing carboxylic or hydroxyl groups. 2. Organic tracer compounds from monoterpenes. Environ Sci Technol 39: 5661-5673. Docket EPA-HQ-OAR-2009-0472-11352

245 Kleindienst TE, TS Conver, CD McIver, EO Edney (2004) Determination of secondary organic aerosol products from the photooxidation of toluene and their implications in ambient $PM_{2.5}$. J Atmos Chem 47: 70-100. Docket EPA-HQ-OAR-2009-0472-11315

246 Kleindienst TE, TS Conver, CD McIver, EO Edney (2004) Determination of secondary organic aerosol products from the photooxidation of toluene and their implication in ambient $PM_{2.5}$, J Atmos Chem 47: 70-100. Docket EPA-HQ-OAR-2009-0472-11315

[247] Izumi L, T Fukuyama (1990) Photochemical aerosol formation from aromatic hydrocarbons in the presence of NO_x, Atmos Environ 24A: 1433. Docket EPA-HQ-OAR-2009-0472-11351

[248] Martin-Reviego M, K Wirtz (2005) Is benzene a precursor for secondary organic aerosol? Environ Sci Technol 39: 1045-1054. Docket EPA-HQ-OAR-2009-0472-11343

[249] Ng, N. L., Kroll, J. H., Chan, A. W. H., Chabra, P. S., Flagan, R. C., Seinfield, J. H., Secondary organic aerosol formation from *m*-xylene, toluene, and benzene, Atmospheric Chemistry and Physics Discussion, 7, 3909-3922, 2007. Docket EPA-HQ-OAR-2009-0472-11316

[250] Lewandowski M, M Jaoui , JH Offenberg , TE Kleindienst, EO Edney, RJ Sheesley, JJ Schauer (2008) Primary and secondary contributions to ambient PM in the midwestern United States, Environ Sci Technol 42(9):3303-3309. http://pubs.acs.org/cgi-bin/article.cgi/esthag/2008/42/i09/html/es0720412.html. Docket EPA-HQ-OAR-2009-0472-11340

[251] Kleindienst TE, M Jaoui, M Lewandowski, JH Offenberg, EO Edney (2007) Estimates of the contributions of biogenic and anthropogenic hydrocarbons to secondary organic aerosol at a southeastern U.S. location. Atmos Environ 41(37):8288-8300. Docket EPA-HQ-OAR-2009-0472-11356

[252] Henze DK, JH Seinfeld (2006) Global secondary organic aerosol from isoprene oxidation. Geophys Res Lett 33: L09812. doi:10.1029/2006GL025976. Docket EPA-HQ-OAR-2009-0472-11347

[253] Henze DK.;J Seinfeld (2006) Global secondary organic aerosol from isoprene oxidation. Geophys. Res. Lett 33 L09812. doi:10.1029/2006GL025976. Docket EPA-HQ-OAR-2009-0472-11347

[254] Jaoui M, M Lewandowski, TE Kleindienst, JH Offenberg, EO Edney (2007) β - Caryophyllinic acid: An atmospheric tracer for β-caryophyllene secondary organic aerosol. Geophys Res Lett 34: L05816. doi:10.1029/2006GL028827. Docket EPA-HQ-OAR-2009-0472-1917

[255] Griffin RJ, DR Cocker III, RC Flagan, JH Seinfeld (1999) Organic aerosol formation from oxidation of biogenic hydrocarbons, J Geophys Res 104: 3555-3567. Docket EPA-HQ-OAR-2009-0472-11346

[256] Ng NL, JH Kroll, AWH Chan, PS Chabra, RC Flagan, JH Seinfeld (2007) Secondary organic aerosol formation from m-xylene, toluene, and benzene. Atmos Chem Phys 7: 3909-3922. Docket EPA-HQ-OAR-2009-0472-11316

[257] Hildebrandt1, L., Donahue1, N. M, Pandis1, S. N. (2009) High formation of secondary organic aerosol from the photo-oxidation of toluene. Atmos Chem Phys 9: 2973-2986. Docket EPA-HQ-OAR-2009-0472-11349

[258] Atkinson, R., Baulch, D.L., Cox, R.A., Crowley, J.N., Hampson, R.F. Jr., Hynes, R.G., Jenkin, M.E., Kerr, J.A., Rossi, M.J., Troe, J. (2005) Evaluated Kinetic and Photochemical Data for Atmospheric Chemistry - IUPAC Subcommittee on Gas Kinetic Data Evaluation for Atmospheric Chemistry. July 2005 web version. http://www.iupac-kinetic.ch.cam.ac.uk/index.html. Docket EPA-HQ-OAR-2009-0472-11333

[259] Sander, S.P., Friedl, R.R., Golden, D.M., Kurylo, M.J., Huie, R.E., Orkin, V.L., Moortgat, G.K., Ravishankara, A.R., Kolb, C.E., Molina, M.J., Finlayson-Pitts, B.J. (2003) Chemical Kinetics and Photochemical Data for use in Atmospheric Studies, Evaluation Number 14. NASA Jet Propulsion Laboratory. http://jpldataeval.jpl.nasa.gov/index.html. Docket EPA-HQ-OAR-2009-0472-11320

[260] Finlayson-Pitts BJ, Pitts JN Jr. (1986) Atmospheric Chemistry: Fundamentals and Experimental Techniques, Wiley, New York.

[261] Yarwood G, Rao S, Yocke M, Whitten GZ (2005) Updates to the Carbon Bond Chemical Mechanism: CB05. Final Report to the US EPA, RT-0400675, December 8, 2005. http://www.camx.com/publ/pdfs/CB05_Final_Report_120805.pdf. Docket EPA-HQ-OAR-2009-0472-0111

[262] http://www.cmascenter.org/help/model_docs/cmaq/4.7/RELEASE_NOTES.txt

[263] 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.

[264] PM Standards Revision – 2006: Timeline. Retrieved on March 19, 2009 from http://www.epa.gov/oar/particlepollution/naaqsrev2006.html#timeline

[265] EPA 2010, Renewable Fuel Standard Program (RFS2) Regulatory Impact Analysis. EPA-420-R-10-006. February 2010. Docket EPA-HQ-OAR-2009-0472-11332. see also 75 FR 14670, March 26, 2010.

[266] EPA 2010, Renewable Fuel Standard Program (RFS2) Regulatory Impact Analysis. EPA-420-R-10-006. February 2010. Sections 3.4.2.1.2 and 3.4.3.3. Docket EPA-HQ-OAR-2009-0472-11332

[267] 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.

[268] U. S. Environmental Protection Agency (2007). Control of Hazardous Air Pollutants from Mobile Sources; Final Rule. 72 FR 8434, February 26, 2007. Docket EPA-HQ-OAR-2009-0472-0271, 0271.1 and 0271.2

[269] U. S. Environmental Protection Agency (2007). Control of Hazardous Air Pollutants from Mobile Sources; Final Rule. 72 FR 8434, February 26, 2007. Docket EPA-HQ-OAR-2009-0472-0271, 0271.1 and 0271.2

[270] U. S. EPA. (2009) 2002 National-Scale Air Toxics Assessment. http://www.epa.gov/ttn/atw/nata2002/. Docket EPA-HQ-OAR-2009-0472-11321

[271] U. S. EPA. (2009) 2002 National-Scale Air Toxics Assessment. http://www.epa.gov/ttn/atw/nata2002/risksum.html. Docket EPA-HQ-OAR-2009-0472-11322

[272] U.S. EPA. U.S. EPA's 2008 Report on the Environment (Final Report). U.S. Environmental Protection Agency, Washington, D.C., EPA/600/R-07/045F (NTIS PB2008-112484). Docket EPA-HQ-OAR-2009-0472-11298. Updated data available online at: http://cfpub.epa.gov/eroe/index.cfm?fuseaction=detail.viewInd&ch=46&subtop=341&lv=list.listByChapter&r=201744

[273] 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. Docket EPA-HQ-OAR-2009-0472-0096

[274] U.S. Environmental Protection Agency. (2006). *Final Regulatory Impact Analysis (RIA) for the Proposed National Ambient Air Quality Standards for Particulate Matter*. Prepared by: Office of Air and Radiation. Retrieved March, 26, 2009 at http://www.epa.gov/ttn/ecas/ria.html. EPA-HQ-OAR-2009-0472-0240

[275] 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. Retrieved March, 26, 2009 at http://www.epa.gov/ttn/ecas/ria.html. EPA-HQ-OAR-2009-0472-0238

[276] U.S. Environmental Protection Agency (U.S. EPA). 2009. 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>. EPA-HQ-OAR-2009-0472-0241

[277] U.S. Environmental Protection Agency (U.S. EPA). 2010. Final 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/FinalNO2RIAfulldocument.pdf. Accessed March 15. EPA-HQ-OAR-2009-0472-0237

[278] U.S. Environmental Protection Agency. 2009. Regulatory Impact Analysis: Control of Emissions of Air Pollution from Category 3 Marine Diesel Engines. EPA-420-R-09-019, December 2009. Prepared by Office of Air and Radiation.

http://www.epa.gov/otaq/regs/nonroad/marine/ci/420r09019.pdf. Accessed February 9, 2010. EPA-HQ-OAR-2009-0472-0283

279 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. EPA-HQ-OAR-2009-0472-0244

280 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. EPA-HQ-OAR-2009-0472-0382

281 GeoLytics Inc. (2002). Geolytics CensusCD® 2000 Short Form Blocks. CD-ROM Release 1.0. GeoLytics, Inc. East Brunswick, NJ. Available: http://www.geolytics.com/ [accessed 29 September 2004]

282 Woods & Poole Economics Inc. 2008. Population by Single Year of Age CD. CD-ROM. Woods & Poole Economics, Inc. Washington, D.C. EPA-HQ-OAR-2009-0472-0011

283 U.S. Environmental Protection Agency. (2006). *Air quality criteria for ozone and related photochemical oxidants (second external review draft).* Research Triangle Park, NC: National Center for Environmental Assessment; report no. EPA/600R-05/004aB-cB, 3v. Available: http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=137307[March 2006] EPA-HQ-OAR-2009-0472-0099, EPA-HQ-OAR-2009-0472-0100, EPA-HQ-OAR-2009-0472-0101

284 U.S. Environmental Protection Agency, 2004. *Air Quality Criteria for Particulate Matter Volume II of II.* National Center for Environmental Assessment, Office of Research and Development, U.S. Environmental Protection Agency, Research Triangle Park, NC EPA/600/P-99/002bF. EPA-HQ-OAR-2009-0472-0097

285 World Health Organization (WHO). (2003). *Health Aspects of Air Pollution with Particulate Matter, Ozone and Nitrogen Dioxide: Report on a WHO Working Group.* World Health Organization. Bonn, Germany. EUR/03/5042688.

286 Anderson HR, Atkinson RW, Peacock JL, Marston L, Konstantinou K. (2004). *Meta-analysis of time-series studies and panel studies of Particulate Matter (PM) and Ozone (O3): Report of a WHO task group.* Copenhagen, Denmark: World Health Organization.

287 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. EPA-HQ-OAR-2009-0472-1662

288 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. EPA-HQ-OAR-2009-0472-0233

289 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. EPA-HQ-OAR-2009-0472-1678

[290] 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. EPA-HQ-OAR-2009-0472-0222

[291] 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. EPA-HQ-OAR-2009-0472-0231

[292] 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. EPA-HQ-OAR-2009-0472-0236

[293] 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. EPA-HQ-OAR-2009-0472-0263

[294] 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. EPA-HQ-OAR-2009-0472-1661

[295] 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. EPA-HQ-OAR-2009-0472-0242

[296] 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. EPA-HQ-OAR-2009-0472-0382

[297] 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. EPA-HQ-OAR-2009-0472-0432

[298] 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. EPA-HQ-OAR-2009-0472-0239

[299] Schwartz J. (1995). Short term fluctuations in air pollution and hospital admissions of the elderly for respiratory disease. *Thorax.* 50(5):531-538.

[300] Schwartz J. (1994a). PM(10) Ozone, and Hospital Admissions For the Elderly in Minneapolis St Paul, Minnesota. *Arch Environ Health.* 49(5):366-374. EPA-HQ-OAR-2009-0472-1673

[301] Schwartz J. (1994b). Air Pollution and Hospital Admissions For the Elderly in Detroit, Michigan. *Am J Respir Crit Care Med.* 150(3):648-655. EPA-HQ-OAR-2009-0472-1674

[302] 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. EPA-HQ-OAR-2009-0472-1673

[303] 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. EPA-HQ-OAR-2009-0472-0223

[304] 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.

[305] 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. EPA-HQ-OAR-2009-0472-1674

[306] 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. EPA-HQ-OAR-2009-0472-1664

[307] 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. EPA-HQ-OAR-2009-0472-0318

[308] 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. EPA-HQ-OAR-2009-0472-0234

[309] 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. EPA-HQ-OAR-2009-0472-1663

[310] 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. EPA-HQ-OAR-2009-0472-0246

[311] 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. EPA-HQ-OAR-2009-0472-0318

[312] 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. EPA-HQ-OAR-2009-0472-0225

[313] 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. EPA-HQ-OAR-2009-0472-1672

[314] 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.

[315] 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.

[316] 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. EPA-HQ-OAR-2009-0472-1671

[317] Ostro, B.D. (1987). Air Pollution and Morbidity Revisited: A Specification Test. *Journal of Environmental Economics Management* 14:87-98. EPA-HQ-OAR-2009-0472-1670

[318] 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. EPA-HQ-OAR-2009-0472-1675

[319] Chen L, Jennison BL, Yang W, Omaye ST. (2000). Elementary school absenteeism and air pollution. *Inhal Toxicol* 12(11):997-1016. EPA-HQ-OAR-2009-0472-0224

[320] Ostro, B.D. and S. Rothschild. (1989). Air Pollution and Acute Respiratory Morbidity: An Observational Study of Multiple Pollutants. *Environmental Research* 50:238-247. EPA-HQ-OAR-2009-0472-0364

[321] 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. EPA-HQ-OAR-2009-0472-4664

[322] National Research Council (NRC). (2002). *Estimating the Public Health Benefits of Proposed Air Pollution Regulations.* Washington, DC: The National Academies Press.

[323] Abt Associates, Inc. October 2005. *Methodology for County-level Mortality Rate Projections.* Memorandum to Bryan Hubbell and Zachary Pekar, U.S. EPA.

[324] U.S. Environmental Protection Agency. (2009). *Regulatory Impact Analysis: National Emission Standards for Hazardous Air Pollutants from the Portland Cement Manufacturing Industry*. Office of Air and Radiation. Retrieved on May 4, 2009, from http://www.epa.gov/ttn/ecas/regdata/RIAs/portlandcementria_4-20-09.pdf EPA-HQ-OAR-2009-0472-0241

[325] Viscusi, W.K., W.A. Magat, and J. Huber. (1991). Pricing Environmental Health Risks: Survey Assessments of Risk-Risk and Risk-Dollar Trade-Offs for Chronic Bronchitis. *Journal of Environmental Economics and Management* 21:32-51.

[326] Cropper, M.L., and A.J. Krupnick. (1990). *The Social Costs of Chronic Heart and Lung Disease.* Resources for the Future. Washington, DC. Discussion Paper QE 89-16-REV.

[327] 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. EPA-HQ-OAR-2009-0472-1666

[328] 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. EPA-HQ-OAR-2009-0472-1669

[329] Agency for Healthcare Research and Quality (AHRQ). (2000). HCUPnet, Healthcare Cost and Utilization Project. Rockville, MD. Accessed April 10, 2009, from http://hcupnet.ahrq.gov/

[330] 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. EPA-HQ-OAR-2009-0472-1667

[331] 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. EPA-HQ-OAR-2009-0472-1668

[332] Industrial Economics, Incorporated (IEc). (1994). Memorandum to Jim DeMocker, Office of Air and Radiation, Office of Policy Analysis and Review, U.S. Environmental Protection Agency. March 31.

[333] 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. EPA-HQ-OAR-2009-0472-0243

[334] Neumann, J.E., M.T. Dickie, and R.E. Unsworth. (1994). *Linkage Between Health Effects Estimation and Morbidity Valuation in the Section 812 Analysis—Draft Valuation Document.* Industrial Economics Incorporated (IEc) Memorandum to Jim DeMocker, U.S. Environmental Protection Agency, Office of Air and Radiation, Office of Policy Analysis and Review. March 31.

[335] Tolley, G.S. et al. January (1986). *Valuation of Reductions in Human Health Symptoms and Risks. University of Chicago*. Final Report for the U.S. Environmental Protection Agency.

[336] Council of Economic Advisors. (2005). *The Annual Report of the Council of Economic Advisors. In: Economic Report of the President.* Table B-60. U.S. Government Printing Office: Washington, DC.

[337] National Research Council (NRC). (2002). *Estimating the Public Health Benefits of Proposed Air Pollution Regulations.* The National Academies Press: Washington, D.C.

[338] U.S. Environmental Protection Agency, (2004a). *Final Regulatory Analysis: Control of Emissions from Nonroad Diesel Engines.* EPA420-R-04-007. Prepared by Office of Air and Radiation. Retrieved on April 10, 2009, from http://www.epa.gov/nonroad-diesel/2004fr/420r04007.pdf. EPA-HQ-OAR-2009-0472-0140

[339] U.S. Environmental Protection Agency, (2005). *Regulatory Impact Analysis for the Clean Air Interstate Rule.* EPA 452/-03-001. Prepared by Office of Air and Radiation. Retrieved on April 10, 2009, from http://www.epa.gov/interstateairquality/tsd0175.pdf.

[340] U.S. Environmental Protection Agency, (2006). *Regulatory Impact Analysis for the PM NAAQS.* EPA Prepared by Office of Air and Radiation. Retrieved on April 10, 2009, from http://www.epa.gov/ttn/ecas/regdata/RIAs/Chapter%205--Benefits.pdf. EPA-HQ-OAR-2009-0472-0240

Regulatory Impact Analysis

[341] Industrial Economics, Inc. (2006). *Expanded Expert Judgment Assessment of the Concentration-Response Relationship Between PM2.5 Exposure and Mortality.* Prepared for EPA Office of Air Quality Planning and Standards, September. Retrieved on April 10, 2009, from http://www.epa.gov/ttn/ecas/regdata/Uncertainty/pm_ee_report.pdf. EPA-HQ-OAR-2009-0472-0242

[342] National Research Council (NRC), 2008. Estimating Mortality Risk Reduction and Economic Benefits from Controlling Ozone Air Pollution. The National Academies Press: Washington, D.C. EPA-HQ-OAR-2009-0472-0322

[343] National Research Council (NRC). 2002. Estimating the Public Health Benefits of Proposed Air Pollution Regulations. The National Academies Press: Washington, D.C.

[344] 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. Available at http://www.epa.gov/ttn/ecas/ria.html. EPA-HQ-OAR-2009-0472-0240

[345] U.S. Environmental Protection Agency (U.S. EPA). 2008. 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>. EPA-HQ-OAR-2009-0472-0238

[346] U.S. Environmental Protection Agency (U.S. EPA). 2009. 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>. EPA-HQ-OAR-2009-0472-0241

[347] U.S. Environmental Protection Agency (U.S. EPA). 2010. Final 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/FinalNO2RIAfulldocument.pdf. Accessed March 15, 2010. EPA-HQ-OAR-2009-0472-0237

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

[349] 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. EPA-HQ-OAR-2009-0472-0229

[350] 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. EPA-HQ-OAR-2009-0472-0263

[351] 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. EPA-HQ-OAR-2009-0472-1661

[352] 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. EPA-HQ-OAR-2009-0472-0242

[353] 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 EPA-HQ-OAR-2009-0472-0242

[354] 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. EPA-HQ-OAR-2009-0472-1677

[355] 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. EPA-HQ-OAR-2009-0472-0245

[356] 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. EPA-HQ-OAR-2009-0472-0235

[357] 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>. EPA-HQ-OAR-2009-0472-0232

[358] IPCC WGI, 2007. The baseline temperature increases by 2100 from our MiniCAM-MAGICC runs are 1.8°C to 4.5°C.

[359] IPCC. 2007. *Climate Change 2007 - Synthesis Report Contribution of Working Groups I, II and III to the Fourth Assessment Report of the IPCC.*

[360] Interagency Working Group on Social Cost of Carbon, U.S. Government, with participation by Council of Economic Advisers, Council on Environmental Quality, Department of Agriculture, Department of Commerce, Department of Energy, Department of Transportation, Environmental Protection Agency, National Economic Council, Office of Energy and Climate Change, Office of Management and Budget, Office of Science and Technology Policy, and Department of Treasury, "Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866," February 2010, available in docket EPA-HQ-OAR-2009-0472.

[361] "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

[362] "2008/9 Blueprint for Sustainability – Our Future Works" Ford Motor Company. Last accessed on the Internet on March 24, 2010 at the following URL: http://www.ford.com/go/sustainability and available in Docket EPA-HQ-OAR-2009-0472.

[363] "Japan's new diet plan: Slim down, ounce by ounce" Automotive News, July 7, 2008.

[364] "Mazda: Don't believe the hot air being emitted by hybrid hype" Automotive News, March 30, 2009.

[365] "Improved aerodynamics, lightweight construction, tyres and drive technology - BlueEFFICIENCY in the C-Class: Fuel consumption reduced by 12 per cent" Daimler Press Release, February 28, 2008. Last accessed on the Internet on March 24, 2010 at the following URL: http://media.daimler.com/dcmedia/0-921-1050602-1-1050604-1-0-0-0-0-1-11701-854934-0-1-0-0-0-0-0.html and available in Docket EPA-HQ-OAR-2009-0472.

[366] "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.

[367] "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

[368] "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

[369] "Supplemental Results on the Independent Effects of Curb Weight, Wheelbase and Track on Fatality Risk", Dynamic Research, Inc., DRI-TR-05-01, May 2005

[370] "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.

[371] "Blood and Oil: Vehicle Characteristics in Relation to Fatality Risk and Fuel Economy", L.S. Robertson, American Journal of Public Health, Vol. 96, No. 11, November 2006.

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.5 of the preamble to the rule 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 compares two effects. On the one hand, the vehicles will become more expensive, which would, by itself, discourage sales. On the other hand, the vehicles will have improved fuel economy and thus lower operating costs, which makes them more attractive to consumers. If consumers do not accurately compare the value of fuel savings with the increased cost of fuel economy technology in their vehicle purchase decisions, as discussed in Preamble III.H.1, they will continue to behave in this way after this rule. If auto makers have accurately gauged how consumers consider fuel economy when purchasing vehicles and have provided the amount that consumers want in vehicles, then consumers should not be expected to want the more fuel-efficient vehicles. After all, auto makers would have provided as much fuel economy as consumers want. If, on the other hand, auto makers underestimated consumer demand for fuel economy, as suggested by some commenters and discussed in Preamble Section III.H.1 and RIA Section 8.1.2, then this rule may lead to production of more desirable vehicles, and vehicle sales may increase. This assumption implies that auto makers have missed some profit-making opportunities. The results presented in this analysis depend on the assumption that more fuel efficient vehicles that yield net consumer benefits over five years would not otherwise be offered on the vehicle market due to market failures on the part of vehicle manufacturers. If vehicles that achieve the fuel economy standards prescribed by today's rulemaking would already be available, but consumers chose not to purchase them, then this rulemaking would not result in an increase in vehicle sales, because it does not alter how consumers make decisions about which vehicles to purchase

The analysis starts with the increase in costs estimated by the OMEGA model. We assume that these costs are fully passed along to consumers. This assumption is appropriate for cost increases in perfectly competitive markets. In less than perfectly competitive markets, though, it is likely that the cost increase is split between consumers and automakers, and the price is not likely to increase as much as costs.[1] 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, insurance, and financing 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[2] 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.[3] (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.[4] The sales tax per state was then multiplied by the 2006 population of the state;[5] 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 February 9, 2010, the national average interest rate for a 5 year new car loan was 6.54 percent.[6] Converting the up-front payment to an annual value paid over five years results in a consumer paying 24.1% of the up-front amount every year. The present value of these five payments results in an increase of 10.3% of the cost, using a 3% discount rate; with a 7% discount rate, the increase is -1.2%. NHTSA's RIA notes that 70% of auto purchases use financing; applying that fraction to this cost increase results in an addition of 7.2% in financing costs with a 3% discount rate, and -0.9% for a 7% discount rate.

The average resale price of a vehicle after 5 years is about 35%[7] 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 + 0.072 – 0.302) = 0.914 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 - 0.009 – 0.250) = 0.876 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 6.3 of this

RIA 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[8]: 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 new vehicles in the past. 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	67,500	0.7	62,100	1.1
2013	76,000	0.8	190,200	3.2
2014	114,000	1.1	254,900	4.3
2015	222,200	2.1	352,800	6.1
2016	360,500	3.3	488,000	8.6

Table 8-1 shows 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). This approach may not accurately reflect the role of fuel savings in consumers' purchase decisions, as the discussion in Preamble Section III.H.1 suggests. If consumers consider fuel savings in a different fashion than modeled here, then this approach will not accurately reflect the impact of this rule on vehicle sales.

Table 8-2 Vehicle Sales Impacts Using a 7% Discount Rate

	CHANGE IN CAR SALES	% CHANGE	CHANGE IN TRUCK SALES	% CHANGE
2012	62,800	0.7	58,300	1
2013	70,500	0.7	92,300	1.5
2014	106,100	1	127,700	2.1
2015	208,400	2	194,200	3.3
2016	339,400	3.1	280,000	4.9

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. Some of the factors that might affect consumer vehicle purchases include changing market conditions, changes in vehicle characteristics that might accompany improvements in fuel economy, or consumers considering a different "payback period" for their fuel economy purchases. These complications add considerable uncertainty to our vehicle sales impact analysis.

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 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 rule.

This rule will lead automakers to change characteristics – in particular, the fuel economy -- of the vehicles they produce. These changes will affect the cost of manufacturing the vehicle; as a result, the prices of the vehicles will also change.

In response to these changes, the number and types of vehicles sold is likely to change. When consumers buy vehicles, they consider both their personal characteristics (such as age, family composition, income, and their vehicle needs) and the characteristics of vehicles (e.g., vehicle size, fuel economy, and price). In response to the changes in vehicle characteristics, consumers will reconsider their purchases. Increases in fuel economy are likely to be attractive to consumers, but increases in price, as well as 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,[9] Greene et al.,[10] and McManus.[11]

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,[12] Bento et al.,[13] and Train and Winston.[14]

While discrete choice modeling appears to be the primary method for consumer choice modeling, others (such as Kleit[15] and Austin and Dinan[16]) 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.[17] 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.[18]

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[19] and the New Vehicle Market Model developed by NERA Economic Consulting[20] 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;[21] others consider the choice between new vehicles and an outside good (possibly including a used vehicle);[22] others explicitly consider the relationship between the new and used vehicle markets.[23] Some models include consideration of vehicle miles traveled,[24] 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;[25] 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,[26] 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,[27] the market acceptability of alternative-fuel vehicles,[28] the effects of introduction and exit of vehicles from markets,[29] causes of the decline in market shares of U.S. automakers,[30] and the effects of gasoline taxes[31] and "feebates"[32] (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[33] 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[34] 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:[35] since consumers pay for gallons of fuel, then this measure can assess fuel savings relatively directly.[36] Yet other models multiply fuel consumption per mile by the cost of fuel to get the price of driving a mile,[37] or they divide fuel economy by fuel cost to get miles per dollar.[38] 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: Recent research[39] presents results that higher fuel prices play a major role in that decision.

Greene and Liu,[40] in a paper published in 1988, reviewed 10 papers using consumer vehicle choice models and estimated for each one how much consumers would be willing to pay at time of purchase to reduce vehicle operating costs by $1 per year. They found that people were willing to pay between $0.74 and $25.97 for a $1 decrease in annual operating costs for a vehicle. This is clearly a very wide range: while the lowest estimate suggests that people are not willing to pay $1 once to get $1 per year reduced costs of operating their vehicles, the maximum suggests a willingness to pay 35 times as high. For comparison, the present value of saving $1 per year for 15 years at a 3% discount rate is $11.94, while a 7% discount rate produces a present value of $8.78. While this study is quite old, it suggests that, at least as of that time, consumer vehicle choice models produced widely varying estimates of the value of reduced vehicle operating costs.

A new review from David Greene[41] suggests continued lack of convergence on the value of increased fuel economy to consumers. Of 27 studies, willingness to pay for fuel economy as a percent of the expected value of fuel savings varied from highly positive to highly negative. Significant numbers of studies found that consumers overvalued fuel economy, undervalued fuel economy, or roughly valued fuel economy correctly relative to fuel savings. Part of the difficulty may be, as these papers note, that fuel economy may be correlated (either positively or negatively) with other vehicle attributes, such as size, power, or quality, not all of which may be included in the analyses; as a result, "fuel economy" may in fact represent several characteristics at the same time. Indeed, Gramlich[42] includes both fuel cost (dollars per mile) and miles per gallon in his analysis, with the argument that miles per gallon measures other undesirable quality attributes, while fuel cost picks up the consumer's demand for improved fuel economy. Greene finds that, while some of the variation may be explainable due to issues in some of the studies, the variation shows up in studies that appear to be well conducted. As a result, further work needs to be conducted before it is possible to identify one value that represents the role of fuel economy in consumer purchase decisions.

Some studies[43] 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[44] 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[45] 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? While existing research does not offer full answers, it is important to attempt to explore these questions, because under certain assumptions, the purely private benefits of fuel economy (fuel savings, time savings, increases in driving time) are likely to be accompanied by private losses. If there is no such offset, or if it is small or insignificant, the reason lies in some kind of market failure.

A detailed literature attempts to identify possible market failures that would justify the assumption that the degree of consumer welfare loss is relatively small. 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,[46] since consumers appear to undervalue a wide range of investments in energy conservation. Some possible explanations for the paradox[47] include:

- Consumers put little weight on benefits from fuel economy in the future and show high discount rates;

- Consumers do not find the benefits from fuel economy to be sufficiently salient at the time of purchase, even if it would be in consumers' economic interest to take account of those benefits;

- Consumers consider other attributes more important than fuel economy at the time of vehicle purchase, especially if fuel economy is a relatively "shrouded" attribute;

- Consumers have difficulty in calculating expected fuel savings;

- Consumers may use imprecise rules of thumb when deciding how much fuel economy to purchase;

- Fuel savings in the future are uncertain, while at the time of purchase the increased costs of fuel-saving technologies are certain and immediate;

- Consumers may not be able to find the vehicles they want with improved fuel economy;

- 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.

Both theoretical and empirical research suggests that, in the context of fuel economy and elsewhere, many consumers do not make energy-efficient investments even when those investments would pay off in the relatively short-term.[48] This conclusion is in line with related findings that consumers may underweight benefits and costs that are less salient or that will be realized only in the future.[49] At the same time, it is worth noting that many of these behaviors can be accounted for in standard economic models. For instance, accounting for uncertainty in future fuel savings is a common practice. For some consumers, high observed discount rates may reflect the illiquidity of investments in fuel economy or high opportunity costs of such investments where consumers are carrying high-interest-rate debt. There is disagreement in the literature about the degree to which these explanations contribute to understanding the Energy Paradox, and additional empirical investigation is still needed.

The producer side of this paradox is much less studied. Hypotheses for underprovision of fuel economy by producers, related to those involving consumers, include:

- Producers put more effort into attributes that consumers have regularly sought in the past, such as size and power, than into fuel and time 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 and time savings 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 underestimated 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 savings from fuel economy improvements. 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, helping to answer some of the central questions about relevant effects on consumer welfare. 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,[50] 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.[51] 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.[52] 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 complication associated with consumer choice modeling is accurate prediction of producers' responses to the rule. Auto makers not only predict consumers' preferences for vehicles; they also may seek to influence those preferences through marketing and advertising.[53] In addition, auto makers are commonly considered to have market power; they can influence the prices that consumers pay to increase their profits. As a result, the price increases that consumers face may reflect strategic factors that could make them higher or lower than the technology costs. Including these market features into consumer vehicle choice models is a complex undertaking. Not all consumer vehicle choice models include a producer model, and those that do may not include much detail, due to computational limits. Technology costs still represent an accurate measure of the opportunity cost of resources to society, but they may overestimate or underestimate the effect on the prices that consumers face. Firms with market power usually pass along less than full cost increases, in order not to reduce sales very much. As a result, for most vehicles the increased technology costs may not equal the price increases that consumers will see.

An additional feature of consumer choice models, as noted above, is that they can be used to calculate consumer surplus impacts on vehicle purchase decisions. 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.

Principles of welfare analysis can be useful for understanding the role of consumer vehicle choice models in benefit-cost analysis. Consumer welfare is commonly measured as the change in income that would leave the consumer as well off in the presence of the change (in this case, the increase in fuel economy and vehicle price) as in the absence of the change; this amount is known as compensating variation, since the consumer is compensated for the change.[A] If the vehicle has not changed other than those two characteristics, then a consumer has the choices of (i) paying the higher price for the vehicle, (ii) choosing to buy a different vehicle, or (iii) not buying a new vehicle. The only reason the consumer would decide to pay the higher price, (i), is if this option is preferable to the other two options. If the consumer cares nothing about the increased fuel economy but is given an amount of money equal to the price increase, she is at least as well off as before the price increase: she can still buy the original vehicle (which has improved fuel economy but is otherwise identical), or she can still choose options (ii) or (iii). Thus, the price increase due to the rule is an upper bound on the consumer's welfare loss, if no other vehicle characteristics of interest to the consumer has changed. If the consumer actually appreciates the improved fuel economy, the welfare loss is even smaller. However, if the vehicle has changed due to the fuel economy increase in ways other than price and fuel economy, or if there are additional costs associated with these vehicles not included in the analysis, then there may be additional welfare impacts that are not included in the technology cost estimates.

At this point, it is unclear whether two consumer vehicle choice models given the same scenario would produce similar results in either prediction of changes in the vehicles

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[A] A closely related concept, equivalent variation, measures the change in income that would be a perfect substitute for the increased fuel economy and vehicle cost. These measures differ based on whether the basis for evaluation is the consumer's utility before the change (compensating variation) or the consumer's utility after the change (equivalent variation). In practice, the difference between these two measures is typically very small for marketed goods.

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.

Given the current limitations in modeling the role of fuel economy in vehicle purchase decisions, and limitations in modeling market responses to the new regulations, in this rulemaking EPA compares the fuel and other savings that consumers will receive with the technology costs of the vehicles. The regulations have been carefully designed so that the full range of vehicle choices in the marketplace could be maintained; rigorous technological feasibility, cost, and lead-time analysis has shown that the standards could be met while maintaining current levels of other vehicle attributes. For these reasons, EPA believes that consumers will enjoy significant savings that substantially outweigh any likely consumer welfare losses. Nonetheless, EPA continues to consider these questions, and 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, the estimates of consumers' willingness to pay for increased fuel economy, and overall efects on consumer welfare.

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 future rules.

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 these 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 $948 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 6 for details on fuel savings). But how many months or years would pass before the fuel savings exceed the upfront cost of $948?

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 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 RIA. 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 joint TSD. As can be seen in the table, it will take under 3 years (2 years and 7 months at a 3% discount rate, 2 years and 9 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 49,000 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 ($)	Cumulative Discounted Fuel Savings at 3% ($)	Cumulative Discounted Fuel Savings at 7% ($)
1	$1,018	$3.07	17,850	18,186	$2,437	$2,013	$424	$418	$410
2		$3.13	17,297	17,623	$2,410	$1,990	$420	$820	$790
3		$3.19	16,789	17,105	$2,377	$1,963	$414	$1,204	$1,139
4		$3.22	16,133	16,437	$2,310	$1,908	$402	$1,567	$1,457

[a] Increased cost of the rule is $948; 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 2010 Early Release reference case fuel price including taxes.
[c] VMT is calculated as the weighted car/truck VMT with cars estimated to account for 66% of the fleet and trucks 34%; 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 per 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 February 9, 2010, the national average interest rate for a 5 year new car loan was 6.54 percent. If the increased vehicle cost is spread out over 5 years at 6.54 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 $177 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 $15 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 ($)	Annual Discounted Net Savings at 3% ($)	Annual Discounted Net Savings at 7% ($)
1	$245	$3.07	17,850	18,186	$2,437	$2,013	$424	$177	$173
2	$245	$3.13	17,297	17,623	$2,410	$1,990	$420	$167	$158
3	$245	$3.19	16,789	17,105	$2,377	$1,963	$414	$157	$142
4	$245	$3.22	16,133	16,437	$2,310	$1,908	$402	$142	$124
5	$245	$3.27	15,451	15,742	$2,244	$1,853	$391	$127	$107
6	$0	$3.29	14,668	14,944	$2,148	$1,774	$374	$318	$258

[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 6.54 percent.
[b] AEO 2010 Early Release reference case fuel price including taxes.
[c] VMT is calculated as the weighted car/truck VMT with cars estimated to account for 66% of the fleet and trucks 34%; 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 per 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 $3,100 at a 3% discount rate, or $2,300 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	$1,018	$4,306	$3,303
Credit[a]	$1,140	$4,306	$3,166
7% discount rate			
Cash	$1,018	$3,381	$2,396
Credit[a]	$1,040	$3,381	$2,340

[a] Assumes a 5 year loan at 6.54 percent.

[b] VMT is calculated as the weighted car/truck VMT with cars estimated to account for 66% of the fleet and trucks 34%; VMT shown here includes survival fraction and, for the control case, rebound VMT.
[c] Fuel savings here were calculated using AEO 2010 Early Release reference case fuel price including taxes.

8.2 Energy Security Impacts

This chapter will only describe the energy security analysis that was conducted beyond that described in Chapter 4 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 of the joint 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.[54] 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.[55] The reduced oil estimates were derived from the OMEGA model, as explained in Chapter 5 of EPA's RIA. EPA used the same assumption that NHTSA used in its Corporate Average Fuel Economy and CAFE Reform for MY 2008-2011 Light Trucks rule, which assumed each gallon of fuel saved reduces total U.S. imports of crude oil or refined products by 0.95 gallons[B56] . Section 5.3 of this RIA contains a discussion regarding caveats

[B] 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 for the fuel savings estimated due to implementation of this rule. Section III.H. 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	$0.57
2020	$2.17
2030	$4.55
2040	$6.00

8.3 Other Impacts

There are other impacts associated with the GHG emissions standards and associated reduced fuel consumption. Lower fuel consumption would, presumably, result in fewer trips to the filling station to refuel and, thus, time saved. The rebound effect, discussed in detail in Chapter 4 of the 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 these standards, but they are nevertheless important to include. We summarize the value of these other impacts in section 8.4.4 of this RIA. Please refer to the joint TSD for more information about these impacts and how EPA and NHTSA use them in their analyses.

8.3.1 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

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 reduce total U.S. imports of crude petroleum or refined fuel by 0.95 gallons.

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.[57]

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.[58,59]

8.3.2 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).[60] 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 joint TSD. Again, the negative effect that rebound driving has on the fuel consumption savings associated with the GHG standards is included in the fuel economy savings presented in section 8.5 of this RIA. 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.

8.3.3 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.[61] 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).[62, 63] 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

8.3.4 Summary of Other Impacts

Table 8-10 summarizes the other economic impacts discussed in sections 8.3.1 through 8.3.3.

Table 8-10 Other Impacts Associated with the Light-Duty Vehicle GHG Program (Millions of 2007 dollars)

YEAR	VALUE OF REDUCED REFUELING	VALUE OF INCREASED DRIVING	ACCIDENTS, NOISE, CONGESTION
2012	$100	$200	-$100
2013	$300	$400	-$200
2014	$500	$700	-$400
2015	$700	$1,200	-$700
2016	$1,100	$1,800	-$1,000
2017	$1,500	$2,400	-$1,400
2018	$1,800	$3,000	-$1,700
2019	$2,100	$3,600	-$2,000
2020	$2,400	$4,200	-$2,300
2021	$2,700	$4,700	-$2,600
2022	$3,000	$5,300	-$2,900
2023	$3,300	$5,800	-$3,200
2024	$3,600	$6,200	-$3,400
2025	$3,800	$6,700	-$3,700
2026	$4,000	$7,200	-$3,900
2027	$4,200	$7,600	-$4,100
2028	$4,400	$8,100	-$4,300
2029	$4,600	$8,500	-$4,500
2030	$4,800	$8,800	-$4,600
2031	$4,900	$9,200	-$4,800
2032	$5,100	$9,600	-$4,900
2033	$5,300	$10,000	-$5,100
2034	$5,400	$10,400	-$5,200
2035	$5,600	$10,900	-$5,400
2036	$5,700	$11,300	-$5,500
2037	$5,900	$11,700	-$5,700
2038	$6,000	$12,100	-$5,800
2039	$6,200	$12,500	-$5,900
2040	$6,300	$13,000	-$6,100
2041	$6,500	$13,500	-$6,300
2042	$6,600	$13,900	-$6,400
2043	$6,800	$14,400	-$6,600
2044	$7,000	$14,900	-$6,700
2045	$7,100	$15,500	-$6,900
2046	$7,300	$16,000	-$7,100
2047	$7,500	$16,600	-$7,200
2048	$7,700	$17,200	-$7,400
2049	$7,800	$17,800	-$7,600
2050	$8,000	$18,400	-$7,800
NPV, 3%	$87,900	$171,500	-$84,800
NPV, 7%	$40,100	$75,500	-$38,600

8.4 Summary of Costs and Benefits

In this section we present a summary of costs, benefits, and net benefits of the rule. 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 3 and 7 percent discount rates. In this table, fuel savings are calculated using pre-tax fuel prices.

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	$15,600	$15,800	$17,400	$19,000	$345,900	$191,900
Fuel Savings [a]	-$35,700	-$79,800	-$119,300	-$171,200	-$1,545,600	-$672,600
Quantified Annual Costs	-$20,100	-$64,000	-$101,900	-$152,200	-$1,199,700	-$480,700

[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 four SCC values considered by EPA. As discussed in [the SCC TSD for this final rule], the models used to estimate SCC may not capture the economic effects of all possible adverse consequences of climate change and may therefore lead to underestimates of the SCC.

In addition the monetized GHG benefits presented below exclude the value of reductions in non-CO_2 GHG emissions (HFC, CH_4, N_2O) expected under this final rule. Although EPA has not monetized the benefits of reductions in non-CO_2 GHGs, the value of these reductions should not be interpreted as zero. Rather, the reductions in non-CO_2 GHGs will contribute to this rule's climate benefits, as explained in Section III.F.2. The technical support document, *Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866*, (i.e., SCC TSD) notes the difference between the social cost of non-CO_2 emissions and CO_2 emissions, and specifies a goal to develop methods to value non-CO_2 emissions in future analyses.[64]

Table 8-12 Use Estimated Societal Benefits Associated with the Light-Duty Vehicle GHG Program (Millions of 2007 dollars)

BENEFITS	2020	2030	2040	2050	NPV, 3%[A]	NPV, 7%[A]
Reduced CO_2 Emissions at each assumed SCC value[b,c]						
Avg SCC at 5%	$900	$2,700	$4,600	$7,200	$34,500	$34,500
Avg SCC at 3%	$3,700	$8,900	$14,000	$21,000	$176,700	$176,700
Avg SCC at 2.5%	$5,800	$14,000	$21,000	$30,000	$299,600	$299,600
95th percentile SCC at 3%	$11,000	$27,000	$43,000	$62,000	$538,500	$538,500
Criteria Pollutant Benefits[d,e,f,g]	B	$1,200-$1,300	$1,200-$1,300	$1,200-$1,300	$21,000	$14,000
Energy Security Impacts (price shock)	$2,200	$4,500	$6,000	$7,600	$81,900	$36,900
Reduced Refueling	$2,400	$4,800	$6,300	$8,000	$87,900	$40,100
Value of Increased Driving[h]	$4,200	$8,800	$13,000	$18,400	$171,500	$75,500
Accidents, Noise, Congestion	-$2,300	-$4,600	-$6,100	-$7,800	-$84,800	-$38,600
Quantified Annual Benefits at each assumed SCC value[b,c]						
Avg SCC at 5%	$7,400	$17,500	$25,100	$34,700	$312,000	$162,400
Avg SCC at 3%	$10,200	$23,700	$34,500	$48,500	$454,200	$304,600
Avg SCC at 2.5%	$12,300	$28,800	$41,500	$57,500	$577,100	$427,500
95th percentile SCC at 3%	$17,500	$41,800	$63,500	$89,500	$816,000	$666,400

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

[b] Monetized GHG benefits exclude the value of reductions in non-CO_2 GHG emissions (HFC, CH_4 and N_2O) expected under this final rule. Although EPA has not monetized the benefits of reductions in these non-CO_2 emissions, the value of these reductions should not be interpreted as zero. Rather, the reductions in non-CO_2 GHGs will contribute to this rule's climate benefits, as explained in Section III.F.2. The SCC TSD notes the difference between the social cost of non-CO_2 emissions and CO_2 emissions, and specifies a goal to develop methods to value non-CO_2 emissions in future analyses.

[c] Section 7.5 notes that SCC increases over time. Corresponding to the years in this table, the SCC estimates range as follows: for Average SCC at 5%: $5-$16; for Average SCC at 3%: $21-$45; for Average SCC at 2.5%: $35-$65; and for 95th percentile SCC at 3%: $65-$136. Section 7.5 also presents these SCC estimates.

[d] Note that "B" indicates unquantified criteria pollutant benefits in the year 2020. For the final rule, we only modeled the rule's PM2.5- and ozone-related impacts in the calendar year 2030. For the purposes of estimating a stream of future-year criteria pollutant benefits, we assume that the benefits out to 2050 are equal to, and no less than, those modeled in 2030 as reflected by the stream of estimated future emission reductions. The NPV of criteria pollutant-related benefits should therefore be considered a conservative estimate of the potential benefits associated with the final rule.

[e] The benefits presented in this table include an estimate of PM-related premature mortality derived from Laden et al., 2006, and the ozone-related premature mortality estimate derived from Bell et al., 2004. If the benefit estimates were based on the ACS study of PM-related premature mortality (Pope et al., 2002) and the Levy et al., 2005 study of ozone-related premature mortality, the values would be as much as 70% smaller.

[f] The calendar year benefits presented in this table assume either a 3% discount rate in the valuation of PM-related premature mortality ($1,300 million) or a 7% discount rate ($1,200 million) to account for a twenty-year segmented cessation lag. Note that the benefits estimated using a 3% discount rate were used to calculate the NPV using a 3% discount rate and the benefits estimated using a 7% discount rate were used to calculate the NPV using a 7% discount rate. For benefits totals presented at each calendar year, we used the mid-point of the criteria pollutant benefits range ($1,250).

[g] Note that the co-pollutant impacts presented here do not include the full complement of endpoints that, if quantified and monetized, would change the total monetized estimate of impacts. The full complement of

human health and welfare effects associated with PM and ozone remain unquantified because of current limitations in methods or available data. We have not quantified a number of known or suspected health effects linked with ozone and PM for which appropriate health impact functions are not available or which do not provide easily interpretable outcomes (e.g., changes in heart rate variability). Additionally, we are unable to quantify a number of known welfare effects, including reduced acid and particulate deposition damage to cultural monuments and other materials, and environmental benefits due to reductions of impacts of eutrophication in coastal areas.
[h] 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 four SCC values considered by EPA.

Table 8-13 Quantified Net Benefits Associated with the Light-Duty Vehicle GHG Program[a] (Millions of 2007 dollars)

	2020	2030	2040	2050	NPV, 3%	NPV, 7%
Quantified Annual Costs	-$20,100	-$64,000	-$101,900	-$152,200	-$1,199,700	-$480,700
Quantified Annual Benefits at each assumed SCC value[b,c]						
Avg SCC at 5%	$7,400	$17,500	$25,100	$34,700	$312,000	$162,400
Avg SCC at 3%	$10,200	$23,700	$34,500	$48,500	$454,200	$304,600
Avg SCC at 2.5%	$12,300	$28,800	$41,500	$57,500	$577,100	$427,500
95th percentile SCC at 3%	$17,500	$41,800	$63,500	$89,500	$816,000	$666,400
Quantified Net Benefits at each assumed SCC value[b,c]						
Avg SCC at 5%	$27,500	$81,500	$127,000	$186,900	$1,511,700	$643,100
Avg SCC at 3%	$30,300	$87,700	$136,400	$200,700	$1,653,900	$785,300
Avg SCC at 2.5%	$32,400	$92,800	$143,400	$209,700	$1,776,800	$908,200
95th percentile SCC at 3%	$37,600	$105,800	$165,400	$241,700	$2,015,700	$1,147,100

[a] Fuel impacts were calculated using pre-tax fuel prices.
[b] Monetized GHG benefits exclude the value of reductions in non-CO_2 GHG emissions (HFC, CH_4 and N_2O) expected under this final rule. Although EPA has not monetized the benefits of reductions in these non-CO_2 emissions, the value of these reductions should not be interpreted as zero. Rather, the reductions in non-CO_2 GHGs will contribute to this rule's climate benefits, as explained in Section III.F.2. The SCC TSD notes the difference between the social cost of non-CO_2 emissions and CO_2 emissions, and specifies a goal to develop methods to value non-CO_2 emissions in future analyses.
[c] Section 7.5 notes that SCC increases over time. Corresponding to the years in this table, the SCC estimates range as follows: for Average SCC at 5%: $5-$16; for Average SCC at 3%: $21-$45; for Average SCC at 2.5%: $35-$65; and for 95th percentile SCC at 3%: $65-$136. Section 7.5 also presents these SCC estimates. Note also that net present value of reduced CO2 emissions is calculated differently than other benefits. The same discount rate used to discount the value of damages from future emissions (SCC at 5, 3, 2.5 percent) is used to calculate net present value of SCC for internal consistency. Refer to the SCC TSD for more detail.

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 presented in Table 8-11 through Table 8-13, 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 Chapter 5 of this RIA. 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 8-15 include 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 four SCC values considered by EPA.

Table 8-14 Estimated Societal Benefits Associated with the Lifetimes of 2012-2016 Model year Vehicles (Millions of 2007 dollars; 3% Discount Rate)

MONETIZED VALUES	2012MY	2013MY	2014MY	2015MY	2016MY	SUM
Cost of Noise, Accident, Congestion ($)	-$1,100	-$1,600	-$2,100	-$2,900	-$3,900	-$11,600
Pretax Fuel Savings ($)	$16,100	$23,900	$32,200	$46,000	$63,500	$181,800
Energy Security ($) (price shock) [a]	$900	$1,400	$1,800	$2,500	$3,500	$10,100
Value of Reduced Refueling time ($)	$1,100	$1,600	$2,100	$3,000	$4,000	$11,900
Value of Additional Driving ($)	$2,400	$3,400	$4,400	$6,000	$7,900	$24,000
Value of $PM_{2.5}$ related Health Impacts ($)[b,c,d]	$700	$900	$1,300	$1,800	$2,400	$7,000
Reduced CO_2 Emissions at each assumed SCC value [e,f]						
Avg SCC at 5%	$400	$500	$700	$1,000	$1,300	$3,800
Avg SCC at 3%	$1,700	$2,400	$3,100	$4,400	$5,900	$17,000
Avg SCC at 2.5%	$2,700	$3,900	$5,200	$7,200	$9,700	$29,000
95^{th} percentile SCC at 3%	$5,100	$7,300	$9,600	$13,000	$18,000	$53,000
Total Benefits at each assumed SCC value [e,f]						
Avg SCC at 5%	$20,500	$30,100	$40,400	$57,400	$78,700	$227,000
Avg SCC at 3%	$21,800	$32,000	$42,800	$60,800	$83,300	$240,200
Avg SCC at 2.5%	$22,800	$33,500	$44,900	$63,600	$87,100	$252,200
95^{th} percentile SCC at 3%	$25,200	$36,900	$49,300	$69,400	$95,400	$276,200

[a] Note that, due to a calculation error in the rule, the energy security impacts for the model year analysis were roughly half what they should have been.

[b] 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, EPA was unable to conduct a full-scale air quality modeling analysis associated with the vehicle model year lifetimes for the final rule.

[c] 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.

[d] 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.

[e] Monetized GHG benefits exclude the value of reductions in non-CO_2 GHG emissions (HFC, CH_4 and N_2O) expected under this final rule. Although EPA has not monetized the benefits of reductions in these non-CO_2 emissions, the value of these reductions should not be interpreted as zero. Rather, the reductions in non-CO_2 GHGs will contribute to this rule's climate benefits, as explained in Section III.F.2. The SCC TSD notes the difference between the social cost of non-CO_2 emissions and CO_2 emissions, and specifies a goal to develop methods to value non-CO_2 emissions in future analyses.

[f] Section 7.5 notes that SCC increases over time. Corresponding to the years in this table, the SCC estimates range as follows: for Average SCC at 5%: $5-$16; for Average SCC at 3%: $21-$45; for Average SCC at 2.5%: $35-$65; and for 95^{th} percentile SCC at 3%: $65-$136. Section 7.5 also presents these SCC estimates. Note that net present value of reduced CO2 emissions is calculated differently than other benefits. The same discount rate used to discount the value of damages from future emissions (SCC at 5, 3, 2.5 percent) is used to calculate net present value of SCC for internal consistency. Refer to the SCC TSD for more detail.

Table 8-15 Estimated Societal Benefits Associated with the Lifetimes of 2012-2016 Model year Vehicles (Millions of 2007 dollars; 7% Discount Rate)

MONETIZED VALUES	2012MY	2013MY	2014MY	2015MY	2016MY	SUM
Cost of Noise, Accident, Congestion ($)	-$900	-$1,200	-$1,600	-$2,300	-$3,100	-$9,200
Pretax Fuel Savings ($)	$12,500	$18,600	$25,100	$36,000	$49,600	$141,900
Energy Security ($) (price shock) [a]	$800	$1,100	$1,400	$2,000	$2,700	$8,000
Value of Reduced Refueling time ($)	$900	$1,300	$1,700	$2,400	$3,200	$9,400
Value of Additional Driving ($)	$1,900	$2,700	$3,500	$4,700	$6,200	$19,000
Value of $PM_{2.5}$ related Health Impacts ($)[b,c,d]	$500	$800	$1,000	$1,400	$1,900	$5,600
Reduced CO_2 Emissions at each assumed SCC value [e,f]						
Avg SCC at 5%	$400	$500	$700	$1,000	$1,300	$3,800
Avg SCC at 3%	$1,700	$2,400	$3,100	$4,400	$5,900	$17,000
Avg SCC at 2.5%	$2,700	$3,900	$5,200	$7,200	$9,700	$29,000
95th percentile SCC at 3%	$5,100	$7,300	$9,600	$13,000	$18,000	$53,000
Total Benefits at each assumed SCC value [e,f]						
Avg SCC at 5%	$16,100	$23,800	$31,800	$45,200	$61,800	$178,500
Avg SCC at 3%	$17,400	$25,700	$34,200	$48,600	$66,400	$191,700
Avg SCC at 2.5%	$18,400	$27,200	$36,300	$51,400	$70,200	$203,700
95th percentile SCC at 3%	$20,800	$30,600	$40,700	$57,200	$78,500	$227,700

[a] Note that, due to a calculation error in the rule, the energy security impacts for the model year analysis were roughly half what they should have been.

[b] 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, EPA was unable to conduct a full-scale air quality modeling analysis associated with the vehicle model year lifetimes for the final rule.

[c] 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.

[d] 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.

[e] Monetized GHG benefits exclude the value of reductions in non-CO_2 GHG emissions (HFC, CH_4 and N_2O) expected under this final rule. Although EPA has not monetized the benefits of reductions in these non-CO_2 emissions, the value of these reductions should not be interpreted as zero. Rather, the reductions in non-CO_2 GHGs will contribute to this rule's climate benefits, as explained in Section III.F.2. The SCC TSD notes the difference between the social cost of non-CO_2 emissions and CO_2 emissions, and specifies a goal to develop methods to value non-CO_2 emissions in future analyses.

[f] Section 7.5 notes that SCC increases over time. Corresponding to the years in this table, the SCC estimates range as follows: for Average SCC at 5%: $5-$16; for Average SCC at 3%: $21-$45; for Average SCC at 2.5%: $35-$65; and for 95th percentile SCC at 3%: $65-$136. Section 7.5 also presents these SCC estimates. Note that net present value of reduced CO2 emissions is calculated differently than other benefits. The same discount rate used to discount the value of damages from future emissions (SCC at 5, 3, 2.5 percent) is used to calculate net present value of SCC for internal consistency. Refer to the SCC TSD for more detail.

Table 8-16. Quantified Net Benefits Associated with the Lifetimes of 2012-2016 Model Year Vehicles (Millions of 2007 dollars; 3% Discount Rate)

	2012MY	2013MY	2014MY	2015MY	2016MY	SUM
Quantified Annual Costs (excluding fuel savings)[a]	$4,900	$8,000	$10,300	$12,700	$15,600	$51,500
Quantified Annual Benefits at each assumed SCC value[b,c]						
Avg SCC at 5%	$20,500	$30,100	$40,400	$57,400	$78,700	$227,000
Avg SCC at 3%	$21,800	$32,000	$42,800	$60,800	$83,300	$240,200
Avg SCC at 2.5%	$22,800	$33,500	$44,900	$63,600	$87,100	$252,200
95th percentile SCC at 3%	$25,200	$36,900	$49,300	$69,400	$95,400	$276,200
Quantified Net Benefits at each assumed SCC value[b,c]						
Avg SCC at 5%	$15,600	$22,100	$30,100	$44,700	$63,100	$175,500
Avg SCC at 3%	$16,900	$24,000	$32,500	$48,100	$67,700	$188,700
Avg SCC at 2.5%	$17,900	$25,500	$34,600	$50,900	$71,500	$200,700
95th percentile SCC at 3%	$20,300	$28,900	$39,000	$56,700	$79,800	$224,700

[a] Quantified annual costs as shown here are the increased costs for new vehicles in each given model year. Since those costs are assumed to occur in the given model year (i.e., not over a several year time span), the discount rate does not affect the costs.

[b] Monetized GHG benefits exclude the value of reductions in non-CO_2 GHG emissions (HFC, CH_4 and N_2O) expected under this final rule. Although EPA has not monetized the benefits of reductions in these non-CO_2 emissions, the value of these reductions should not be interpreted as zero. Rather, the reductions in non-CO_2 GHGs will contribute to this rule's climate benefits, as explained in Section III.F.2. The SCC TSD notes the difference between the social cost of non-CO_2 emissions and CO_2 emissions, and specifies a goal to develop methods to value non-CO_2 emissions in future analyses.

[c] Section 7.5 notes that SCC increases over time. Corresponding to the years in this table, the SCC estimates range as follows: for Average SCC at 5%: $5-$16; for Average SCC at 3%: $21-$45; for Average SCC at 2.5%: $35-$65; and for 95th percentile SCC at 3%: $65-$136. Section 7.5 also presents these SCC estimates. Note that net present value of reduced CO2 emissions is calculated differently than other benefits. The same discount rate used to discount the value of damages from future emissions (SCC at 5, 3, 2.5 percent) is used to calculate net present value of SCC for internal consistency. Refer to the SCC TSD for more detail.

Table 8-17 Quantified Net Benefits Associated with the Lifetimes of 2012-2016 Model Year Vehicles (Millions of 2007 dollars; 7% Discount Rate)

	2012MY	2013MY	2014MY	2015MY	2016MY	SUM
Quantified Annual Costs (excluding fuel savings)[a]	$4,900	$8,000	$10,300	$12,700	$15,600	$51,500
Quantified Annual Benefits at each assumed SCC value[b,c]						
Avg SCC at 5%	$16,100	$23,800	$31,800	$45,200	$61,800	$178,500
Avg SCC at 3%	$17,400	$25,700	$34,200	$48,600	$66,400	$191,700
Avg SCC at 2.5%	$18,400	$27,200	$36,300	$51,400	$70,200	$203,700
95th percentile SCC at 3%	$20,800	$30,600	$40,700	$57,200	$78,500	$227,700
Quantified Net Benefits at each assumed SCC value[b,c]						
Avg SCC at 5%	$11,200	$15,800	$21,500	$32,500	$46,200	$127,000
Avg SCC at 3%	$12,500	$17,700	$23,900	$35,900	$50,800	$140,200
Avg SCC at 2.5%	$13,500	$19,200	$26,000	$38,700	$54,600	$152,200
95th percentile SCC at 3%	$15,900	$22,600	$30,400	$44,500	$62,900	$176,200

[a] Quantified annual costs as shown here are the increased costs for new vehicles in each given model year. Since those costs are assumed to occur in the given model year (i.e., not over a several year time span), the discount rate does not affect the costs.

[b] Monetized GHG benefits exclude the value of reductions in non-CO_2 GHG emissions (HFC, CH_4 and N_2O) expected under this final rule. Although EPA has not monetized the benefits of reductions in these non-CO_2 emissions, the value of these reductions should not be interpreted as zero. Rather, the reductions in non-CO_2 GHGs will contribute to this rule's climate benefits, as explained in Section III.F.2. The SCC TSD notes the difference between the social cost of non-CO_2 emissions and CO_2 emissions, and specifies a goal to develop methods to value non-CO_2 emissions in future analyses.

[c] Section 7.5 notes that SCC increases over time. Corresponding to the years in this table, the SCC estimates range as follows: for Average SCC at 5%: $5-$16; for Average SCC at 3%: $21-$45; for Average SCC at 2.5%: $35-$65; and for 95th percentile SCC at 3%: $65-$136. Section 7.5 also presents these SCC estimates. Note that net present value of reduced CO2 emissions is calculated differently than other benefits. The same discount rate used to discount the value of damages from future emissions (SCC at 5, 3, 2.5 percent) is used to calculate net present value of SCC for internal consistency. Refer to the SCC TSD for more detail.

References

[1] 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 (Docket EPA-HQ-OAR-2009-0472-0007).

[2] 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 (Docket EPA-HQ-OAR-2009-0472-0008).

[3] 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 (Docket EPA-HQ-OAR-2009-0472-0009).

[4] Solheim, Mark, 2006"State Car Tax Rankings," http://www.kiplinger.com/features/archives/2006/04/cartax.html, accessed April 23, 2009 (Docket EPA-HQ-OAR-2009-0472-0010).

[5] 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 (Docket EPA-HQ-OAR-2009-0472-0011).

[6]"Auto Loan Interest Rate", EPA-HQ-OAR-2009-0472-11575 http://auto-loan.interest.com, 1/22/10.

[7] 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 (Docket EPA-HQ-OAR-2009-0472-0013).

[8] Kleit A.N., 1990, "The Effect of Annual Changes in Automobile Fuel Economy Standards," Journal of Regulatory Economics 2: 151-172 (Docket EPA-HQ-OAR-2009-0472-0015); McCarthy, Patrick S., 1996. "Market Price and Income Elasticities of New Vehicle Demands." Review of Economics and Statistics 78: 543-547 (Docket EPA-HQ-OAR-2009-0472-0016); Goldberg, Pinelopi K., 1998. "The Effects of the Corporate Average Fuel Efficiency Standards in the US," Journal of Industrial Economics 46(1): 1-33 (Docket EPA-HQ-OAR-2009-0472-0017); Greene, David L., "Feebates, Footprints and Highway Safety," Transportation Research Part D 14 (2009): 375-384 (Docket EPA-HQ-OAR-2009-0472-0019).

[9] 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 (Docket EPA-HQ-OAR-2009-0472-0021); 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 (Docket EPA-HQ-OAR-2009-0472-0017).

[10] 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 (Docket EPA-HQ-OAR-2009-0472-0022); 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 (Docket EPA-HQ-OAR-2009-0472-0023).

[11] McManus, Walter M., "Can Proactive Fuel Economy Strategies Help Automakers Mitigate Fuel-Price Risks?" University of Michigan Transportation Research Institute, September 14, 2006 (Docket EPA-HQ-OAR-2009-0472-0024).

[12] Berry, Steven, James Levinsohn, and Ariel Pakes, "Automobile Prices in Market Equilibrium," Econometrica 63(4) (July 1995): 841-940 (Docket EPA-HQ-OAR-2009-0472-0025); 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 (Docket EPA-HQ-OAR-2009-0472-0026).

[13] 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 (Docket EPA-HQ-OAR-2009-0472-0029).

[14] 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 (Docket EPA-HQ-OAR-2009-0472-0030).

[15] Kleit, Andrew N., "Impacts of Long-Range Increases in the Fuel Economy (CAFE) Standard," Economic Inquiry 42(2) (April 2004): 279-294 (Docket EPA-HQ-OAR-2009-0472-0031).

[16] 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 (Docket EPA-HQ-OAR-2009-0472-0032).

[17] 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 (Docket EPA-HQ-OAR-2009-0472-0029); 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 (Docket EPA-HQ-OAR-2009-0472-0030).

[18] E.g., Berry, Steven, James Levinsohn, and Ariel Pakes, "Automobile Prices in Market Equilibrium," Econometrica 63(4) (July 1995): 841-940 (Docket EPA-HQ-OAR-2009-0472-0025).

[19] 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 (Docket EPA-HQ-OAR-2009-0472-0022).

[20] 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 (Docket EPA-HQ-OAR-2009-0472-0033).

[21] 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 (Docket EPA-HQ-OAR-2009-0472-0030).

[22] E.g., Berry, Steven, James Levinsohn, and Ariel Pakes, "Automobile Prices in Market Equilibrium," Econometrica 63(4) (July 1995): 841-940 (Docket EPA-HQ-OAR-2009-0472-0025).

[23] 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 (Docket EPA-HQ-OAR-2009-0472-0029).

[24] 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 (Docket EPA-HQ-OAR-2009-0472-0029); 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 (Docket EPA-HQ-OAR-2009-0472-0034).

[25] 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 (Docket EPA-HQ-OAR-2009-0472-0035).

[26] Berry, Steven, James Levinsohn, and Ariel Pakes, "Automobile Prices in Market Equilibrium," Econometrica 63(4) (July 1995): 841-940 (Docket EPA-HQ-OAR-2009-0472-0025).

[27] 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 (Docket EPA-HQ-OAR-2009-0472-0021).

[28] Brownstone, David, and Kenneth Train, "Forecasting New Product Penetration with Flexible Substitution Patterns," Journal of Econometrics 89 (1999): 109-129 (Docket EPA-HQ-OAR-2009-0472-0036); 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 (Docket EPA-HQ-OAR-2009-0472-00357); 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 (Docket EPA-HQ-OAR-2009-0472-0038); 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 (Docket EPA-HQ-OAR-2009-0472-0039).

[29] Petrin, Amil, "Quantifying the Benefits of New Products: The Case of the Minivan," Journal of Political Economy 110 (2002): 705-729 (Docket EPA-HQ-OAR-2009-0472-0040); 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 (Docket EPA-HQ-OAR-2009-0472-0026).

[30] 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 (Docket EPA-HQ-OAR-2009-0472-0030).

[31] 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 (Docket EPA-HQ-OAR-2009-0472-0029); 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 (Docket EPA-HQ-OAR-2009-0472-0034).

[32] 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 (Docket EPA-HQ-OAR-2009-0472-0023); 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 (Docket EPA-HQ-OAR-2009-0472-0034); Greene, David L., "Feebates, Footprints and Highway Safety," Transportation Research Part D (2009) (in press) (Docket EPA-HQ-OAR-2009-0472-0019).

[33] 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 (Docket EPA-HQ-OAR-2009-0472-0032).

[34] Turrentine, Thomas S., and Kenneth S. Kurani, "Car Buyers and Fuel Economy?" Energy Policy 35 (2007): 1213-1223 (Docket EPA-HQ-OAR-2009-0472-0041).

[35] E.g., Espey, Molly, and Santosh Nair, 2005. "Automobile Fuel Economy: What Is It Worth?" Contemporary Economic Policy 23: 317-323 (Docket EPA-HQ-OAR-2009-0472-0042).

[36] Larrick, Richard P., and Jack B. Soll, 2008. "The MPG Illusion," Science 320(5883): 1593-1594 (Docket EPA-HQ-OAR-2009-0472-0043).

[37] 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 (Docket EPA-HQ-OAR-2009-0472-0021).

[38] E.g., Berry, Steven, James Levinsohn, and Ariel Pakes, "Automobile Prices in Market Equilibrium," Econometrica 63(4) (July 1995): 841-940 (Docket EPA-HQ-OAR-2009-0472-0025).

[39] 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) (Docket EPA-HQ-OAR-2009-0472-0044); Li, Shanjun, Christopher Timmins, and Roger H. von Haefen, 2009. "How Do Gasoline Prices Affect Fleet Fuel Economy?" American Economic Journal: Economic Policy 1(2): 113-137; Congressional Budget Office (2008). Effects of Gasoline Prices on Driving Behavior and Vehicle Markets. The Congress of the United States, Pub. No. 2883; West. Sarah (2007). "The Effect of Gasoline Prices on the Demand for Sport Utility Vehicles." Working Paper. Macalester College, http://www.macalester.edu/~wests/SarahWestMEA2007.pdf, accessed 1/25/10.

[40] Greene, David L., and Jin-Tan Liu, 1988. "Automotive Fuel Economy Improvements and Consumers' Surplus," Transportation Research Part A 22A (3): 203-218 (Docket EPA-HQ-OAR-2009-0472-0045).

[41] Greene, David L. (2010). "How Consumers Value Fuel Economy: A Literature Review." EPA Report EPA-420-R-10-008. (Docket EPA-HQ-OAR-2009-0472-11575).

[42] 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 (Docket EPA-HQ-OAR-2009-0472-0046).

[43] 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 (Docket EPA-HQ-OAR-2009-0472-0046); 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 (Docket EPA-HQ-OAR-2009-0472-0054).

[44] For instance, Kleit, Andrew N., "Impacts of Long-Range Increases in the Fuel Economy (CAFE) Standard," Economic Inquiry 42(2) (April 2004): 279-294 (Docket EPA-HQ-OAR-2009-0472-0031); 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 (Docket EPA-HQ-OAR-2009-0472-0032); 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) (Docket EPA-HQ-OAR-2009-0472-0047); 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) (Docket EPA-HQ-OAR-2009-0472-0048).

[45] 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 (Docket EPA-HQ-OAR-2009-0472-0032).

[46] IEA. 2007. "Mind the Gap: Quantifying Principal-Agent Problems in Energy Efficiency." Paris, France: International Energy Agency (Docket EPA-HQ-OAR-2009-0472-0049); 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 (Docket EPA-HQ-OAR-2009-0472-0050); 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 (Docket EPA-HQ-OAR-2009-0472-0051); 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 (Docket EPA-HQ-OAR-2009-0472-0052).

[47] Helfand, Gloria, and Ann Wolverton (2009). "Evaluating the Consumer Response to Fuel Economy: A Review of the Literature." U.S. Environmental Protection Agency, National Center for Environmental Economics Working Paper 2009-4, available at http://yosemite.epa.gov/EE/epa/eed.nsf/WPNumber/2009-04?OpenDocument, accessed 1/25/10 (Docket EPA-HQ-OAR-2009-0472-11520).

[48] Jaffe, A.B., and R.N Stavins (1994). "The Energy Paradox and the Diffusion of Conservation Technology." Resource and Energy Economics 16(2): 91-122 (Docket EPA-HQ-OAR-2009-0472-11415); Allcott, Hunt, and Nathan Wozny, "Gasoline Prices, Fuel Economy, and the Energy Paradox," working paper, available at http://web.mit.edu/allcott/www/Allcott%20and%20Wozny%202010%20-%20Gasoline%20Prices,%20Fuel%20Economy,%20and%20the%20Energy%20Paradox.pdf (Docket EPA-HQ-OAR-2009-0472-11554).

[49] Barber, Brad, Terrance Odean, and Lu Zheng. "Out of Sight, Out of Mind: The Effects of Expenses on Mutual Fund Flows." Journal of Business 78(6) (2005): 2095-2119 (Docket EPA-HQ-OAR-2009-0472-11555).

[50] 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 (Docket EPA-HQ-OAR-2009-0472-0053).

[51] Berry, Steven, James Levinsohn, and Ariel Pakes (July 1995). "Automobile Prices in Market Equilibrium," Econometrica 63(4): 841-940 (Docket EPA-HQ-OAR-2009-0472-0025).

[52] 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 (Docket EPA-HQ-OAR-2009-0472-0023).

[53] Rex, Emma, and Henrikke Baumann (2007). "Beyond ecolabels: what green marketing can learn from conventional marketing." Journal of Cleaner Production 15: 567-576.

[54] *Peer Review Report Summary: Estimating the Energy Security Benefits of Reduced U.S. Oil Imports*, ICF, Inc., September 2007.

[55] 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.

[56] Preliminary RIA in support of the "Corporate Average Fuel Economy Standards For MY 2011 - 2015 Passenger Cars and Light Trucks", April 2008

[57] See http://ostpxweb.dot.gov/policy/Data/VOT97guid.pdf and http://ostpxweb.dot.gov/policy/Data/VOTrevision1_2-11-03.pdf

[58] California Environmental Protection Agency, Air Resources Board. Draft Assessment of the Real-World Impacts of Commingling California Phase 3 Reformulated Gasoline. August 2003

[59] 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.

[60] These benefits are included in the value of fuel savings reported in Tables VIII-5 through VIII-9.

[61] 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).

[62] *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).

[63] 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).

[64] Interagency Working Group on Social Cost of Carbon, U.S. Government, with participation by Council of Economic Advisers, Council on Environmental Quality, Department of Agriculture, Department of Commerce, Department of Energy, Department of Transportation, Environmental Protection Agency, National Economic Council, Office of Energy and Climate Change, Office of Management and Budget, Office of Science and Technology Policy, and Department of Treasury, "*Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866*," February 2010, available in docket EPA-HQ-OAR-2009-0472.

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. 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. This requirement does not apply if the agency certifies that the rule will not have a significant economic impact on a substantial number of small entities.

The following discussion provides an overview of small entities in the vehicle market. Small entities include small businesses, small organizations, and small governmental jurisdictions. For the purposes of assessing the impacts of the rule on small entities, a small entity is defined as: (1) a small business that meets the definition for business based on the Small Business Administration's (SBA) size standards (see Table 9-1); (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 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 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 this assessment, EPA identified a total of about 47 vehicle entities, 33 of which are vehicle manufacturers. Of a total of 33 manufacturers, two 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 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 exempting them will have a negligible impact on the GHG emissions reductions from the standards.

EPA has not conducted a Regulatory Flexibility Analysis or a SBREFA SBAR Panel for the rule because we are certifying that the rule would not have a significant economic impact on a substantial number of small entities. EPA is exempting manufacturers, domestic and foreign, meeting SBA's size definitions of small business as described in 13 CFR 121.201. EPA will 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 exemption will have a negligible impact on the GHG emissions reductions from the final standards.[A]

To ensure that EPA is aware of which companies would be exempt, EPA proposed to require 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. EPA has reconsidered the need for this additional submission under the regulations and is deleting it as not necessary. We already have

[A] It should be noted that EPA is deferring CO_2 standards for small volume manufacturers with annual sales less than 5,000 vehicles. See preamble section III.B.6. This deferral is not dependent on whether the entity in question meets the SBA definition of small entity.

information on the limited number of small entities that we expect would receive the benefits of the exemption, and do not need the proposed regulatory requirement to be able to effectively implement this exemption for those parties who in fact meet its terms. 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. The net effect is that these entities are not regulated by the light duty vehicle greenhouse gas rule.

Responses to comments that the rule has an adverse impact on small entity stationary sources which are not regulated by the rule can be found at Section 5.14 of the Response to Comments.