Control of Hazardous Air Pollutants from Mobile Sources

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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List of Acronyms

µg/kg-day	Micrograms per kilogram day
µg/m^3	Microgram per cubic meter
AAM	Alliance of Automobile Manufacturers
ABT	Averaging, Banking, and Trading
ACS	American Cancer Society
AEO	Annual Energy Outlook (an EIA publication)
AGO	Atmospheric Gas Oil (a refinery stream)
ALTP	Absolute Level Trigger Point
AMS/EPA	Regulatory Model AERMOD
ANS	Alaska North Slope
APHEA	Air Pollution and Health: A European Approach
API	American Petroleum Institute
AQCD	Air Quality Criteria Document
AQMTSD	Air Quality Modeling Technical Support Document
ARB	(California) Air Resources Board
ASPEN	Assessment System for Population Exposure Nationwide
ASTM	American Society of Testing Materials
ATB	Atmospheric Tower Bottoms (a refinery stream)
ATSDR	Agency for Toxic Substances and Disease Registry
ATV	All-Terrain Vehicles
BBL	Barrel
BC	Black Carbon
BenMAP	Environmental Benefits Mapping and Analysis Program
BPCD	Barrels Per Calendar Day
BPD	Barrels Per Day
BTEX	Benzene, Toluene, Ethylbenzene, and Xylene isomers
BTX	Benzene, Toluene, and Xylene isomers
BZ	Benzene
C	Celsius
C6 or C_6	A hydrocarbon molecule with a specified number of carbon atoms, in this case 6 carbons
CA	California
CAA	Clean Air Act
CAIR	Clean Air Interstate Rule
California EPA	California Environmental Protection Agency
CAMR	Clean Air Mercury Rule
CAMx	Comprehensive Air Quality Model with Extension
CAND	Clean Air Nonroad Diesel
CARB	California Air Resources Board
CASAC	Clean Air Science Advisory Committee
CAVR	Clean Air Visibility Rule
CB	Chronic Bronchitis
CD	Criteria Document
CDC	Center for Disease Control
CE10	Gasoline with 10 percent ethanol content
CEA	Cost-Effectiveness Analysis
CFEIS	Certification and Fuel Economy Information System
CFR	Code of Federal Regulations
CG	Conventional Gasoline
CHAD	Consolidated Human Activity Database
CHD	Coronary Heart Disease
CI	Compression Ignition
CIIT	Chemical Industry Institute of Toxicology
CIMT	Carotid Intima-Media Thickness

CM15	Gasoline with 15 percent methanol content
CMAI	Chemical Market Associates Incorporated
CMAQ	Community Multiscale Air Quality Model
CNG	Compressed Natural Gas
CNS	Central Nervous System
CO	Carbon Monoxide
CO2	Carbon Dioxide
COI	Cost-of-Illness
COPD	Chronic Obstructive Pulmonary Disease
COV	Coefficient of Variation
C-R	Concentration-Response
CRC E-55/E-59	Coordinating Research Council Emission Test Program for Heavy Duty Trucks
CUA	Cost-Utility Analysis
DCS	Distributed Control System
DEOG	Diesel Exhaust Organic Gases
DF	Deterioration Factor
DOE	Department of Energy
DPM	Diesel Particulate
E&C	Engineering and Construction
E10	Gasoline Blend with Nominal 10 volume percent Ethanol
E200	Percent of Fuel Evaporated at 200 Degrees F (ASTM D 86)
E300	Percent of Fuel Evaporated at 300 Degrees F (ASTM D 86)
EAC	Early Action Compact
EC/OC	Elemental/Organic Carbon
ECM	Engine Control Module
EGU	Electrical Generating Utility
EIA	Economic Impact Analysis
EIA	Energy Information Administration (part of the U.S. Department of Energy)
EIM	Economic Impact Model
EMS-HAP	Emissions Modeling System for Hazardous Air Pollutants
EO	Executive Order
EPA	Environmental Protection Agency
EPEFE	European Programme on Emissions, Fuels, and Engine Technology
EPAct	Energy Policy Act of 2005
ETBE	Ethyl Tertiary Butyl Ether
ETC	Electronic Throttle Control
ETS	Environmental Tobacco Smoke
EU	European Union
EVOH	Ethylene vinyl alcohol
F	Fahrenheit
FACES	Fresno Asthmatic Children's Environment Study
FBP	Feed Boiling Point (also Final Boiling Point)
FCC	Fluidized Catalytic Cracker
FCCU	Fluidized Catalytic Cracking Unit
FEL	Family Emission Level
FEV	Functional Expiratory Volume
FHWA	Federal Highway Administration
FOEB	Fuel Oil Equivalent Barrel
FRM	Final Rulemaking
FRTP	Fixed Reduction Trigger Point
FTC	Federal Trade Commission
FTP	Federal Test Procedure
g/gal/day	Grams per gallon per day
GDP	Gross Domestic Product
GIS	Geographic Information System
GM	General Motors

GPA	Geographic Phase-in Area
GVW	Gross Vehicle Weight
GVWR	Gross Vehicle Weight Rating
H_2	Hydrogen gas
HAD	Diesel Health Assessment Document
HAP	Hazardous Air Pollutant
HAPEM5	Hazardous Air Pollutant Exposure Model version 5
HC	Hydrocarbon
HCO	Heavy Cycle Oil (a refinery stream)
HDN	Naphtha Hydrotreater (also Hydro-Denitrogenation Unit)
HDPE	High density polyethylene
HDS	Hydro-Desulfurization Unit
HDT	Hydrotreater
HEGO	(Heated) Exhaust Gas Oxygen
HHC	Heavy Hydrocrackate
HHDDT	Heavy Heavy-Duty Diesel Truck
HI	Hazard Index
HLDT	Heavy Light-Duty Truck
HQ	Hazard Quotient
HSR	Heavy Straight Run (a refinery stream)
HVGO	Heavy Vacuum Gas Oil (a refinery stream)
IBP	Initial Boiling Point
ICAO	International Civil Aviation Organization
ICD-9	International Classification of Diseases - Ninth Revision
ICI	Independent Commercial Importer
IFP	Institute Francais du Petrole
IMO	International Maritime Organization
IMPROVE	Interagency Monitoring of Protected Visual Environments
IRFA	Initial Regulatory Flexibility Analysis
IRIS	Integrated Risk Information System
ISBL	Inside Battery Limits
ISC	Integrated Source Complex
ISCST	Industrial Source Complex Short Term
JAMA	Journal of the American Medical Association
K	Thousand
KBBL	Thousand barrels
Kfoeb/day	Thousands of Fuel Oil Equivalent Barrels per Day
KWH	Kilowatt Hour
LB	Pound
LCG	Light Cracked Gasoline
LCN	Light Coker Naphtha
LCO	Light Cycle Oil (a refinery stream)
LDGT	Light Duty Gasoline Truck
LDGV	Light Duty Gasoline Vehicle
LDT	Light-Duty Truck
LDV	Light-Duty Vehicle
LEV I	Low Emission Vehicle I
LEV II	Low Emission Vehicle II
LEV	Low Emission Vehicle
LHC	Light Hydrocrackate
LLDT	Light Light-Duty Truck
LLE	Liquid-Liquid Extraction
LNS	Light Naphtha Splitter
LP	Linear Programming (a type of refinery model)
LPG	Liquefied Petroleum Gas
LRS	Lower Respiratory Symptom

LSR	Light Straight Run (a refinery stream)
MACT	Maximum Available Control Technology
MAF	(Engine) Mass Air Flow
MAP	(Engine) Manifold Absolute Pressure
MC	Motorcycle
MDPV	Medium-Duty Passenger Vehicle
mg/m^3	Milligrams per cubic meter
MHDDT	Diesel-Fueled Medium Heavy-Duty Truck
MHDT	Medium Heavy-Duty Truck
MI	Myocardial Infarction
MILY	Morbidity Inclusive Life Years
MLE	Maximum Likelihood Estimate
MM	Million
MNCPES	Minnesota Children's Pesticide Exposure Study
MOBILE6.2	EPA's Highway Vehicle Emission Model
MON	Motor Octane Number
MRAD	Minor Restricted Activity Days
MRL	Minimum Risk Level
MSAT	Mobile Source Air Toxics
MSAT1	2001 Mobile Source Air Toxics Rule
MTBE	Methyl Tertiary-Butyl Ether
NAAQS	National Ambient Air Quality Standards
NAICS	North American Industrial Classification System
NAS	National Academy of Science
NATA	National Scale Air Toxics Assessment
NATTS	National Air Toxics Trends Sites
NCI	National Cancer Institute
NCLAN	National Crop Loss Assessment Network
NEI	National Emissions Inventory
NEMS	National Energy Modeling System
NESCAUM	Northeast States for Coordinated Air Use Management
NESHAP	National Emissions Standards for Hazardous Air Pollutants
NHAPS	National Human Activity Pattern Survey
NHEXAS	National Human EXposure Assessment Survey
NIOSH	National Institute for Occupational Safety and Health
NLEV	National Low Emission Vehicle
NMHC	Non-Methane Hydrocarbons
NMIM	National Mobile Inventory Model (EPA software tool)
NMIM2005	National Mobile Inventory Model Released in 2005
NMMAPS	National Mortality, Morbidity and Air Pollution
NMOG	Non-Methane Organic Gases
NO_2	Nitrogen Dioxide
NONROAD	EPA's Non-road Engine Emission Model
NONROAD2005	EPA's Non-road Engine Emission Model Released in 2005
NO_x	Oxides of Nitrogen
NPRA	National Petroleum Refiners Association
NPRM	Notice of Proposed Rulemaking
NRC	National Research Council
NSTC	National Science and Technology Council
O&M	Operating and maintenance
OBD	On-board Diagnostics
OEHHA	Office of Environmental Health Hazard Assessment
OGJ	Oil and Gas Journal
OMB	Office of Management and Budget
OP	Original Production
OSHA	U.S. Department of Labor Occupational Safety and Health Organization

OTAQ	Office of Transportation and Air Quality
PADD	Petroleum Administration for Defense District
PAH	Polycyclic Aromatic Hydrocarbon
PC	Particle Count
PC	Passenger car
PFC	Portable Fuel Containers
PFT	perfluorocarbon tracer
PM	Particulate Matter
PM/NMHC	Particulate Matter to Non-Methane Hydrocarbon Ratio
PM_{10}	Coarse Particle
$PM_{2.5}$	Fine Particle
POM	Polycyclic Organic Matter
PONA	Paraffin, Olefin, Naphthene, Aromatic
PPM	Parts Per Million
PRTP	Percentage Reduction Trigger Point
PSI	Pounds per Square Inch
PSR	Power Systems Research
QALY	Quality-Adjusted Life Year
R&D	Research and Development
RAMS	Regional Atmospheric Modeling System
RBOB	Reformulated Blendstock for Oxygenate Blending
RECS	Residential Energy Consumption Survey
REMSAD	Regional Modeling System for Aerosols and Deposition
RfC	Reference Concentration
RfD	Oral reference dose
RFG	Reformulated Gasoline
RFS	Renewable Fuels Standard
RIA	Regulatory Impact Analysis
RIOPA	Relationship Between Indoor, Outdoor and Personal Air
ROI	Return on Investment
RON	Research Octane Number
RPM	Revolutions Per Minute
RSM	Response Surface Metamodel
RVP	Reid Vapor Pressure
SAB	Science Advisory Board
SAB-HES	Science Advisory Board - Health Effects Subcommittee
SAE	Society of Automotive Engineers
SBA	Small Business Administration
SBAR Panel, or ‘the Panel’	Small Business Advocacy Review Panel
SBREFA	Small Business Regulatory Enforcement Fairness Act of 1996
SCF	Standard Cubic Foot
SECA	SO_x Emission Control Area
SER	Small Entity Representative
SFTP	Supplemental Federal Test Procedure
SHED	Sealed Housing for Evaporative Determination
SI	Spark Ignition
SIP	State Implementation Plan
SOA	Secondary Organic Aerosols
SPECIATE	EPA's repository of Total Organic Compound (TOC) & Particulate Matter (PM) speciated profiles
SUV	Sports-Utility Vehicle
SVM	Small Vehicle Manufacturer
SVOC	Semi-Volatile Organic Compound
SwRI	Southwest Research Institute
TDM	Travel Demand Model
TEACH	Toxic Exposure Assessment – Columbia/Harvard

TEAM	Total Exposure Assessment Methodology
THC	Total Hydrocarbon
TMP	2,2,4-Trimethylpentane
TWA	Time-weighted Average
TSP	Total Suspended Particulate Matter
TWC	Three-Way Catalyst
UC	Unified Cycle Emission Test Procedure from ARB
UCL	Upper Confidence Limit
ULSD	Ultra-Low Sulfur Diesel
URE	Unit Risk Estimate
URS	Upper Respiratory Symptom
UV	Ultraviolet
UVb	Ultraviolet-b
VGO	Vacuum Gas Oil (a refinery stream)
VMT	Vehicle Miles Traveled
VOC	Volatile Organic Compound
VSL	Value of a Statistical Life
VTB	Vacuum Tower Bottoms (a refinery stream)
WLD	Work Loss Days
WTP	Willingness-to-Pay

Executive Summary

EPA is adopting new standards to reduce emissions of mobile source air toxics (MSATs) including benzene and overall hydrocarbons from motor vehicles, motor vehicle fuels, and portable fuel containers (PFCs). This Regulatory Impact Analysis provides technical, economic, and environmental analyses of the new emission standards. The anticipated emission reductions will significantly reduce exposure to harmful pollutants and also provide assistance to states and regions facing ozone and particulate air quality problems that are causing a range of adverse health effects, especially in terms of respiratory impairment and related illnesses.

Chapter 1 reviews information related to the health effects of mobile source air toxics. Chapter 2 provides emissions inventory estimates, including estimates of anticipated emissions reductions. Chapter 3 presents air quality, and resulting health and welfare effects, associated with air toxics, ozone, and particulate matter (PM). Chapter 4 contains an overview of the affected refiners and manufacturers, including a description of the range of products involved and their place in the market. Chapters 5 through 7 summarize the available information supporting the specific standards we are adopting, providing a technical justification for the feasibility of the standards for vehicles, fuels, and PFCs, respectively. Chapters 8 through10 present cost estimates of complying with the new standards or vehicles, fuels, and PFCs, respectively. Chapter 11 compares the costs and the emission reductions to generate an estimate of the cost per ton of pollutant removed. Chapters 12 and 13 describe the estimated societal costs and benefits of the rulemaking. Chapter 14 presents our Regulatory Flexibility Analysis, as called for in the Regulatory Flexibility Act.

The following paragraphs briefly describe the standards that we are finalizing and the estimated impacts.

Emissions Standards

Vehicles

We are adopting new standards for both exhaust and evaporative emissions from passenger vehicles. The new exhaust emissions standards will significantly reduce non-methane hydrocarbon (NMHC) emissions from passenger vehicles at cold temperatures. These hydrocarbons include many mobile source air toxics (including benzene), as well as VOC.

The current NMHC standards are typically tested at 75˚ F, and recent research and analysis indicates that these standards are not resulting in robust control of NMHC at lower temperatures. (There is an existing cold temperature standard, but it applies only to CO.) We believe that cold temperature NMHC control can be substantially improved using the same technological approaches that are generally already being used in the Tier 2 vehicle fleet to meet the stringent standards at 75˚ F. We project that these cold-temperature NMHC controls will also result in lower direct PM emissions at cold temperatures.

Accordingly, we are requiring that light-duty vehicles, light-duty trucks, and medium-duty passenger vehicles be subject to a new NMHC exhaust emissions standard at 20˚ F.

Vehicles at or below 6,000 pounds gross vehicle weight rating (GVWR) will be subject to a sales-weighted fleet average NMHC level of 0.3 grams/mile. Vehicles between 6,000 and 8,500 pounds GVWR and medium-duty passenger vehicles will be subject to a sales-weighted fleet average NMHC level of 0.5 grams/mile. For lighter vehicles, the standard will phase in between 2010 and 2013. For heavier vehicles, the new standards will phase in between 2012 and 2015. We are also adopting a credit program and other provisions designed to provide flexibility to manufacturers, especially during the phase-in periods. These provisions are designed to allow the earliest possible phase-in of standards and help minimize costs and ease the transition to new standards.

We are also adopting a set of nominally more stringent evaporative emission standards for all light-duty vehicles, light-duty trucks, and medium-duty passenger vehicles. The new standards are equivalent to California's Low Emission Vehicle II (LEV II) standards, and they reflect the evaporative emissions levels that are already being achieved nationwide. The standards will codify the approach that manufacturers are already taking for 50-state evaporative systems, and thus the standards will prevent backsliding in the future. The new evaporative emission standards begin in 2009 for lighter vehicles and in 2010 for the heavier vehicles.

Gasoline Fuel Standards

We are requiring that beginning January 1, 2011, refiners and fuel importers will meet a refinery average gasoline benzene content standard of 0.62% by volume on all their gasoline, both reformulated and conventional (except for California, which is already covered by a similar relatively stringent state program).

This new fuel standard will result in air toxics emissions reductions that are greater than required under all existing gasoline toxics programs. As a result, EPA is establishing that upon full implementation in 2011, the regulatory provisions for the benzene control program will become the single regulatory mechanism used to implement the reformulated gasoline (RFG) and Anti-dumping annual average toxics requirements. The current RFG and Anti-dumping annual average provisions will be replaced by the new benzene control program. The MSAT2 benzene control program will also replace the MSAT1 requirements. In addition, the program will satisfy certain fuel MSAT conditions of the Energy Policy Act of 2005. In all of these ways, we will significantly consolidate and simplify the existing national fuel-related MSAT regulatory program.

We are also allowing that refiners could generate benzene credits and use or transfer them as a part of a nationwide averaging, banking, and trading (ABT) program. From 2007-2010 refiners can generate benzene credits by taking early steps to reduce gasoline benzene levels. Beginning in 2011 and continuing indefinitely, refiners can generate credits by producing gasoline with benzene levels below the 0.62 vol% refinery average standard. Refiners can apply the credits towards company compliance, "bank" the credits for later use, or transfer ("trade") them to other refiners nationwide (outside of California) under the new program. Under this program, refiners can use credits to achieve compliance with the benzene content standard. In addition, to the 0.62 vol% standards, refiners must also meet a maximum average benzene standard of 1.3 vol% beginning on July 1, 2012. A refinery's or importer's actual annual average gasoline benzene levels may not exceed this maximum average standard.

Portable Fuel Container Controls

Portable fuel containers (PFCs) include gasoline containers (gas cans) and kerosene and diesel containers. PFCs are consumer products used to refuel a wide variety of equipment, including lawn and garden equipment, generators, heaters, recreational equipment, and passenger vehicles that have run out of gas. We are adopting standards that will reduce hydrocarbon emissions from evaporation, permeation, and spillage. These standards will significantly reduce benzene and other toxics, as well as VOC more generally. VOC is an ozone precursor. We are also applying the new requirements to kerosene and diesel containers, which are identical to gas cans except for their color and could be used for gasoline.

We are adopting a performance-based standard of 0.3 grams per gallon per day of hydrocarbons, based on the emissions from the can over a diurnal test cycle. The standard will apply to PFCs manufactured on or after January 1, 2009. We are also adopting test procedures and a certification and compliance program, in order to ensure that PFCs will meet the emission standard over a range of in-use conditions. The new requirements will result in the best available control technologies, such as durable permeation barriers, automatically closing spouts, and cans that are well-sealed.

California implemented an emissions control program for PFCs in 2001, and since then, several other states have adopted the program. In 2005, California adopted a revised program, which will take effect July 1, 2007. The revised California program is very similar to the program we are adopting. Although a few aspects of the program we are adopting are different, we believe manufacturers will be able to meet both EPA and California requirements with the same container designs.

Projected Impacts

The following paragraphs and tables summarize the projected emission reductions and costs associated with the emission standards. See the detailed analysis later in this document for further discussion of these estimates.

Emissions Reductions

Toxics

sources as well due to lower benzene levels in gasoline. Annual benzene emissions from

Table 1: Estimated Reductions in Benzene Emissions from New Control Measures by Sector, 2020 and 2030 (tons per year)

	2020	2030
Fuels	17,618	19,643
Vehicles	27,097	45,037
PFCs	718	814
Total	42,760	61,035

Table 2: Estimated Reductions in MSAT Emissions from New Control Measures by Sector, 2020 and 2030 (tons per year)

	2020	2030
Fuels	17,618	19,643
Vehicles	177,007	294,284
PFCs	18,553	21,036
Total	210,303	330,844

VOC

VOC emissions will be reduced by the hydrocarbon emission standards for both light-duty vehicles and PFCs. Annual VOC emission reductions from these sources will be about 34% lower in 2030 because of the new rule.

Table 3: Estimated Reductions in VOC Emissions from Light-Duty Gasoline Vehicles and PFCs, 2020 and 2030 (tons per year)

	2020	2030
Vehicles	529,363	882,762
PFCs	216,294	245,255

Total	745,658	1,128,017

PM$_{2.5}$

We expect that only the vehicle control will reduce emissions of direct PM$_{2.5}$. As shown in Table 4, we expect this control to reduce direct PM$_{2.5}$ emissions by about 19,000 tons in 2030. In addition, the VOC reductions from the vehicle and PFC standards will also reduce secondary formation of PM$_{2.5.}$

Table 4. Estimated National Reductions in Direct PM$_{2.5}$ Exhaust Emissions from Light-Duty Gasoline Vehicles and Trucks, 2020 and 2030 (tons per year)

	2020	**2030**
PM$_{2.5}$ Reductions from Vehicle Standards (tons)	11,646	19,421

Costs

Fuels

The refinery model estimates that the benzene standard will cost 0.27 cents per gallon, averaged over the entire U.S. gasoline pool. (When averaged only over those refineries which are assumed to take steps to reduce their benzene levels, the average cost will be 0.40 cents per gallon.) This per-gallon cost will result from an industry-wide investment in capital equipment of $1,110 million to reduce gasoline benzene levels. This will amount to an average of $14 million in capital investment in each refinery that adds such equipment. The aggregate costs for the fuel program for 2020 and 2030 are provided in Table 5. The increase in costs is due to the projected increase in gasoline usage.

Table 5. Estimated Aggregate Annual Cost for the Benzene Standard, 2020 and 2030

	2020	**2030**
Fuels program	$398 million	$441 million

Vehicles

We project that the average incremental costs associated with the new cold temperature standards will be less than $1 per vehicle. We are not projecting changes to vehicle hardware as a result of the new standard. Costs are associated with vehicle R&D and recalibration as well as facilities upgrades to handle additional development testing under cold conditions. Also, we are not anticipating additional costs for the new evaporative emissions standard. We expect that manufacturers will continue to produce 50-state evaporative systems that meet LEV II standards. Therefore, harmonizing with California's LEV-II evaporative emission standards will streamline certification and be an "anti-backsliding" measure. It also will codify the approach manufacturers have already indicated they are taking for 50-state evaporative systems.

We also estimated annual aggregate costs associated with the new cold temperature emissions standards. These costs are projected to increase with the phase-in of standards and peak in 2014 at about $13.4 million per year, then decrease as the fixed costs are fully amortized. As shown in Table 6, we project the costs will be fully amortized by 2020.

Table 6. Estimated Aggregate Annual Cost for the Vehicle Standards, 2020 and 2030

	2020	2030
Vehicles program	$0	$0

PFCs

Table 7 summarizes the projected near-term and long-term per unit average costs to meet the new emission standards. Long-term impacts on PFCs are expected to decrease as manufacturers fully amortize their fixed costs. The table also shows our projections of average fuel savings over the life of the PFC when used with gasoline.

Table 7 Estimated Average PFC Costs and Lifetime Fuel Savings

	Cost
Near-Term Costs	$2.69
Long-Term Costs	$1.52
Gasoline Savings (NPV)	$4.24

We have also estimated aggregate costs and gasoline fuel savings which are projected to peak in 2013 at about $61 million and then drop to about $33 million once fixed costs are recovered. The aggregate annual costs and gasoline savings estimates for 2020 and 2030 are provided in Table 8.

Table 8. Estimated Aggregate Annual Cost and Gasoline Savings for the PFC Standards, 2020 and 2030

	2020	**2030**
PFC Costs	$37,542,748	$45,764,401
PFC Gasoline Savings	$109,589,064	$124,264,434

Cost Per Ton

We have calculated the cost per ton of HC, benzene, total MSATs, and PM emissions reductions associated with the new fuel, vehicle, and PFC programs. We have calculated the costs per ton using the net present value of the annualized costs of the program, including PFC gasoline fuel savings, from 2009 through 2030 and the net present value of the annual emission reductions through 2030. We have also calculated the cost per ton of emissions reduced in the year 2020 and 2030 using the annual costs and emissions reductions in that year alone. This number represents the long-term cost per ton of emissions reduced. For fuels, the cost per ton estimates include costs and emission reductions that will occur from all motor vehicles and nonroad engines fueled with gasoline as well as PFCs and gasoline distribution.

We have not attempted to apportion costs across these various pollutants for purposes of the cost per ton calculations since there is no distinction in the technologies, or associated costs, used to control the pollutants. Instead, we have calculated costs per ton by assigning all costs to each individual pollutant. If we apportioned costs among the pollutants, the costs per ton presented here would be proportionally lowered depending on what portion of costs were assigned to the various pollutants. The results of the analysis are provided in Tables 9 through 12.

The cost per ton estimates for each individual program are presented separately in the tables below, and are part of the justification for each of the programs. For informational purposes, we also present the cost per ton for the three programs combined.

Table 9. HC Aggregate Cost per Ton and Long-Term Annual Cost Per Ton ($2003)

	Discounted Lifetime Cost per ton at 3%	Discounted Lifetime Cost per ton at 7%	Long-Term Cost per Ton in 2020	Long-Term Cost per Ton in 2030
Vehicles	$14	$18	$0	$0
PFCs (without fuel savings)	$240	$270	$170	$190
PFCs (with fuel savings)	$0	$0	$0	$0
Combined (with fuel savings)	$0	$0	$0	$0

Table 10. Benzene Aggregate Cost per Ton and Long-Term Annual Cost Per Ton ($2003)

	Discounted Lifetime Cost per ton at 3%	Discounted Lifetime Cost per ton at 7%	Long-Term Cost per Ton in 2020	Long-Term Cost per Ton in 2030
Fuels	$22,400	$23,100	$22,600	$22,500
Vehicles	$270	$360	$0	$0
PFCs (without fuel savings)	$74,500	$82,900	$52,200	$56,200
PFCs (with fuel savings)	$0	$0	$0	$0
Combined (with fuel savings)	$8,200	$8,600	$7,600	$5,900

Table 11 MSAT Aggregate Cost per Ton and Long-Term Annual Cost Per Ton ($2003)

	Discounted Lifetime Cost per ton at 3%	Discounted Lifetime Cost per ton at 7%	Long-Term Cost per Ton in 2020	Long-Term Cost per Ton in 2030
Fuels	$22,400	$23,100	$22,600	$22,500
Vehicles	$42	$54	$0	$0
PFCs (without fuel savings)	$2,800	$3,100	$2,000	$2,200
PFCs (with fuel savings)	$0	$0	$0	$0
Combined (with fuel savings)	$1,700	$1,800	$1,600	$1,100

Table 12 Direct PM Aggregate Cost per Ton and Long-Term Annual Cost Per Ton ($2003)

	Discounted Lifetime Cost per ton at 3%	Discounted Lifetime Cost per ton at 7%	Long-Term Cost per Ton in 2020	Long-Term Cost per Ton in 2030
Vehicles	$650	$870	$0	$0

Benefits

This analysis projects significant benefits throughout the period from initial implementation of the new standards through 2030. When translating emission benefits to health effects and monetized values, however, we only quantify the PM-related benefits associated with the new cold temperature vehicle standards. The reductions in PM from the cold temperature vehicle standards will result in significant reductions in premature deaths and other serious human health effects, as well as other important public health and welfare effects. Table 13 provides the estimated monetized benefits of the cold temperature vehicle standards for 2020 and 2030. We estimate that in 2030, the benefits we are able to monetize are expected to be approximately $6.3 billion using a 3 percent discount rate and $5.7 billion using a 7 percent discount rate, assuming a background PM threshold of 3 $\mu g/m^3$ in the calculation of PM mortality. There are no compliance costs associated with the cold temperature vehicle program after 2019; vehicle compliance costs are primarily research and development, and facility costs are expected to be recovered by manufacturers over the first ten years of the program beginning in 2010. Total costs of the entire MSAT rule, which include both the PFC, vehicle, and fuel standards, are $400 million in 2030 (in 2003$, including fuel savings).

The $PM_{2.5}$ benefits are scaled based on relative changes in direct PM emissions between this rule and the proposed Clean Air Nonroad Diesel (CAND) rule. As explained in Section 12.2.1 of the RIA, the $PM_{2.5}$ benefits scaling approach is limited to those studies, health impacts, and assumptions that were used in the proposed CAND analysis. As a result, PM-related premature mortality is based on the updated analysis of the American Cancer Society cohort (ACS; Pope et al., 2002). However, it is important to note that since the CAND rule, EPA's Office of Air and Radiation (OAR) has adopted a different format for its benefits analysis in which characterization of the uncertainty in the concentration-response function is integrated into the main benefits analysis. Within this context, additional data sources are available, including a recent expert elicitation and updated analysis of the Six-Cities Study cohort (Laden et al., 2006). Please see the PM NAAQS RIA for an indication of the sensitivity of our results to use of alternative concentration-response functions.

The analysis presented here assumes a PM threshold of 3 μg/m3, equivalent to background. Through the RIA for the Clean Air Interstate Rule (CAIR), EPA's consistent approach had been to model premature mortality associated with PM exposure as a nonthreshold effect; that is, with harmful effects to exposed populations modeled regardless of the absolute level of ambient PM concentrations. This approach had been supported by advice from EPA's technical peer review panel, the Science Advisory Board's Health Effects Subcommittee (SAB-HES). However, EPA's most recent $PM_{2.5}$ Criteria Document concludes that "the available evidence does not either support or refute the existence of thresholds for the effects of PM on mortality across the range of concentrations in the studies," (p. 9-44). Furthermore, in the RIA for the PM NAAQS we used a threshold of 10 μg/m3 based on recommendations by the Clean Air Scientific Advisory Committee (CASAC) for the Staff Paper analysis. We consider the impact of a potential, assumed threshold in the PM-mortality concentration response function in Section 12.6.2.2 of the RIA

Table 13 Estimated Monetized PM-Related Health Benefits of the Mobile Source Air Toxics Standards: Cold Temperature Controls

	Total Benefits[a, b, c] (billions 2003$)	
	2020	**2030**
Using a 3% discount rate	$3.3 + B	$6.3 + B
Using a 7% discount rate	$3.0 + B	$5.7 + B

[a] Benefits include avoided cases of mortality, chronic illness, and other morbidity health endpoints. PM-related mortality benefits estimated using an assumed PM threshold at background levels (3 μg/m^3). There is uncertainty about which threshold to use and this may impact the magnitude of the total benefits estimate. For a more detailed discussion of this issue, please refer to Section 12.6 of the RIA.

[b] For notational purposes, unquantified benefits are indicated with a "B" to represent the sum of additional monetary benefits and disbenefits. A detailed listing of unquantified health and welfare effects is provided in Table 12.1-2 of the RIA.

[c] Results reflect the use of two different discount rates: 3 and 7 percent, which are 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.

Economic Impact Analysis

We prepared an Economic Impact Analysis (EIA) to estimate the economic impacts of the emission control program on the PFC, gasoline fuel, and light-duty vehicle markets. Our estimates of the net social costs of the program for 2020 and 2030 are provided in Table 14 below. These estimates reflect the estimated costs associated with the gasoline, PFC, and vehicle controls and the expected gasoline fuel savings from better evaporative controls on PFCs. The results of the economic impact modeling performed for the gasoline fuel and PFC control programs suggest that the social costs of those two programs are expected to be about $440.1 million in 2020 with consumers of these products expected to bear about 58 percent of these costs. We estimate fuel savings of about $80.7 million in 2020 that will accrue to consumers. There are no social costs associated with the vehicle program in 2020.

Table 14 Net Social Costs Estimates for the Program (Millions of 2003$)

	2020	**2030**
Net Social Costs	$359.4	$400.0

Impact on Small Businesses

We prepared a Regulatory Flexibility Analysis, which evaluates the potential impacts of new standards and fuel controls of this rule on small entities. As a part of this analysis, we interacted with several small entities representing the various affected sectors and convened a Small Business Advocacy Review Panel to gain feedback and advice from these representatives. This feedback was used to develop regulatory alternatives to address the impacts of the rule on small businesses. Small entities raised general concerns related to potential difficulties and costs of meeting the upcoming standards.

The Panel consisted of members from EPA, the Office of Management and Budget, and the Small Business Administration’s Office of Advocacy. We are adopting most of the Panel’s recommendations. These provisions will reduce the burden on small entities that will be subject to this rule’s requirements. We have included provisions that give small light-duty vehicle manufacturers, small gasoline refiners, and small PFC manufacturers several compliance options aimed specifically at reducing the burden on these small entities. In general, for vehicles and fuels, the options are similar to small entity provisions adopted in prior rulemakings where EPA set vehicle and fuel standards. The options included for small PFC manufacturers are unique to this rulemaking since we are adopting PFC standards for the first time.

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Chapter 1: Mobile Source Air Toxics Health Information

1.1. What Are MSATs?

Section 202(l) refers to “hazardous air pollutants from motor vehicles and motor vehicle fuels.” We use the term “mobile source air toxics (MSATs)” to refer to compounds that are emitted by mobile sources and have the potential for serious adverse health effects. There are a variety of ways in which to identify compounds that have the potential for serious adverse health effects. For example, EPA’s Integrated Risk Information System (IRIS) is EPA’s database containing information on human health effects that may result from exposure to various chemicals in the environment. In addition, Clean Air Act section 112(b) contains a list of hazardous air pollutants that EPA is required to control through regulatory standards; other agencies or programs such as the Agency for Toxic Substances and Disease Registry and the California EPA have developed health benchmark values for various compounds; and the International Agency for Research on Cancer and the National Toxicology Program have assembled evidence of substances that cause cancer in humans and issue judgments on the strength of the evidence. Each source of information has its own strengths and limitations. For example, there are inherent limitations on the number of compounds that have been investigated sufficiently for EPA to conduct an IRIS assessment. There are some compounds that are not listed or not quantitatively assessed in IRIS but are considered to be hazardous air pollutants under Clean Air Act section 112(b) and are regulated by the Agency (e.g., propionaldehyde, 2,2,4-trimethylpentane).

1.1.1. Compounds Emitted by Mobile Sources and Identified in IRIS

In its 2001 MSAT rule, EPA identified a list of 21 MSATs. We listed a compound as an MSAT if it was emitted from mobile sources, and if the Agency had concluded in IRIS that the compound posed a potential cancer hazard and/or if IRIS contained an inhalation reference concentration or ingestion reference dose for the compound. Since 2001, EPA has conducted an extensive review of the literature to produce a list of the compounds identified in the exhaust or evaporative emissions from onroad and nonroad equipment, using baseline as well as alternative fuels (e.g., biodiesel, compressed natural gas).[1] This list, the Master List of Compounds Emitted by Mobile Sources (“Master List”), currently includes approximately 1,000 compounds. It is available in the public docket for this rule and on the web (http://www.epa.gov/otaq/toxics.htm). Table 1.1.-1 lists those compounds from the Master List that currently meet those 2001 MSAT criteria, based on the current IRIS.

Table 1.1.-1 identifies all of the compounds from the Master List that are present in IRIS with (a) a cancer hazard identification of known, probable, or possible human carcinogens (under the 1986 EPA cancer guidelines) or carcinogenic to humans, likely to be carcinogenic to humans, or suggestive evidence of carcinogenic potential (under the 2005 EPA cancer guidelines); and/or (b) an inhalation reference concentration or an ingestion reference dose. Although all these compounds have been detected in emissions from mobile sources, many are emitted in trace amounts and data are not adequate to develop an inventory. Those compounds for which we have developed an emissions inventory are summarized in Chapter 2 Table 2.2.-1. There are

several compounds for which IRIS assessments are underway and therefore are not included in Table 1.1.-1. These compounds are: cerium, copper, ethanol, ethyl tertiary butyl ether (ETBE), platinum, propionaldehyde, and 2,2,4-trimethylpentane.

The fact that a compound is listed in Table 1.1.-1 does not imply a risk to public health or welfare at current levels, or that it is appropriate to adopt controls to limit the emissions of such a compound from motor vehicles or their fuels. In conducting any such further evaluation, pursuant to sections 202(a) or 211(c) of the Act, EPA would consider whether emissions of the compound from motor vehicles cause or contribute to air pollution which may reasonably be anticipated to endanger public health or welfare.

Table 1.1.-1. Compounds Emitted by Mobile Sources That Are Listed in IRIS*

1,1,1,2-Tetrafluoroethane	Cadmium	Manganese
1,1,1-Trichloroethane	Carbon disulfide	Mercury, elemental
1,1-Biphenyl	Carbon tetrachloride	Methanol
1,2-Dibromoethane	Chlorine	Methyl chloride
1,2-Dichlorobenzene	Chlorobenzene	Methyl ethyl ketone (MEK)
1,3-Butadiene	Chloroform	Methyl isobutyl ketone (MIBK)
2,4-Dinitrophenol	Chromium III	Methyl tert-butyl ether (MTBE)
2-Methylnaphthalene	Chromium VI	Molybdenum
2-Methylphenol	Chrysene	Naphthalene
4-Methylphenol	Crotonaldehyde	Nickel
Acenaphthene	Cumene (isopropyl benzene)	Nitrate
Acetaldehyde	Cyclohexane	N-Nitrosodiethylamine
Acetone	Cyclohexanone	N-Nitrosodimethylamine
Acetophenone	Di(2-ethylhexyl)phthalate	N-Nitroso-di-n-butylamine
Acrolein (2-propenal)	Dibenz[a,h]anthracene	N-Nitrosodi-N-propylamine
Ammonia	Dibutyl phthalate	N-Nitrosopyrrolidine
Anthracene	Dichloromethane	Pentachlorophenol
Antimony	Diesel PM and Diesel exhaust organic gases	Phenol
Arsenic, inorganic	Diethyl phthalate	Phosphorus
Barium and compounds	Ethylbenzene	Phthalic anhydride
Benz[a]anthracene	Ethylene glycol monobutyl ether	Pyrene
Benzaldehyde	Fluoranthene	Selenium and compounds
Benzene	Fluorene	Silver

Benzo[a]pyrene (BaP)	Formaldehyde	Strontium
Benzo[b]fluoranthene	Furfural	Styrene
Benzo[k]fluoranthene	Hexachlorodibenzo-p-dioxin, mixture (dioxin/furans)	Tetrachloroethylene
Benzoic acid	n-Hexane	Toluene
Beryllium and compounds	Hydrogen cyanide	Trichlorofluoromethane
Boron (Boron and Borates only)	Hydrogen sulfide	Vanadium
Bromomethane	Indeno[1,2,3-cd]pyrene	Xylenes
Butyl benzyl phthalate	Lead and compounds (inorganic)	Zinc and compounds

*Compounds listed in IRIS as known, probable, or possible human carcinogens and/or pollutants for which the Agency has calculated a reference concentration or reference dose.

1.1.2. Compounds Emitted by Mobile Sources and Included on Section 112(b) List of Hazardous Air Pollutants

Clean Air Act section 112(b) contains a list of hazardous air pollutants that EPA is required to control through regulatory standards. As discussed above, there are some compounds emitted by mobile sources that are not listed in IRIS but are considered to be hazardous air pollutants under Clean Air Act section 112(b) and are regulated by the Agency such as propionaldehyde and 2,2,4-trimethylpentane. Compounds emitted by mobile sources that are Clean Air Act section 112(b) hazardous air pollutants are listed in Table 1.1.-2. Although all these compounds have been detected in emissions from mobile sources, many are emitted in trace amounts and data are not adequate to develop an inventory. Those compounds for which we have developed an emissions inventory are summarized in Table 2.2.-1.

Table 1.1.-2. Compounds Emitted by Mobile Sources That Are Listed in CAA Section 112(b)

1,1,2-Trichloroethane	Carbon disulfide	Methyl ethyl ketone
1,2-Dibromoethane	Carbon tetrachloride	Methyl tert-butyl ether
1,3-Butadiene	Chlorine	Methylchloride
2,2,4-Trimethylpentane	Chlorobenzene	Naphthalene
2,3,7,8-Tetrachlorodibenzo-p-dioxin	Chloroform	Nickel compounds
2,4-Dinitrophenol	Chromium (III and VI)	N-Nitrosodimethylamine

2-Methylphenol (o-cresol)	Cumene	Pentachlorophenol
4-Methylphenol (p-cresol)	Di(2-ethylhexyl)phthalate (DEHP)	Phenol
Acetaldehyde	Dibutylphthalate	Phosphorus
Acetophenone	Dichloromethane	Phthalic anhydride
Acrolein	Ethyl benzene	Polycyclic organic matter*
Antimony compounds	Formaldehyde	Propionaldehyde
Arsenic compounds	Hexane	Selenium compounds
Benzene	Hydrogen cyanide ("Cyanide compounds in Section 112(b))	Styrene
Beryllium	Lead compounds	Tetrachloroethylene
Biphenyl	Manganese	Toluene
Bromomethane	Mercury compounds	Xylenes (isomers and mixture)
Cadmium compounds	Methanol	

*Includes organic compounds with more than one benzene ring, and which have a boiling point greater than or equal to 100.5 C.

1.1.3. Other Sources of Information on Compounds with Potential Serious Adverse Health Effects

Additional sources of information are available to characterize the potential for cancer or noncancer health effects from toxic air pollutants. These include the Agency for Toxic Substances and Disease Registry list of minimal risk levels (http://www.atsdr.cdc.gov/mrls.html), California EPA list of Reference Exposure Levels (http://www.oehha.ca.gov/risk/ChemicalDB/index.asp), International Agency for Research on Cancer lists of carcinogenic compounds (http://www.iarc.fr/ENG/Databases/index.php), the National Toxicology Program list of carcinogenic compounds (http://ntp-server.niehs.nih.gov/), and the U.S. EPA Emergency Planning and Community Right-to-Know Act list of extremely hazardous substances (http://yosemite.epa.gov/oswer/ceppoehs.nsf/content/BackGround). EPA relies on these sources of information, as appropriate, for certain types of analyses.[2]

1.1.4. Which Mobile Source Emissions Pose the Greatest Health Risk at Current Levels?

The 1999 National-Scale Air Toxics Assessment (NATA) provides some perspective on which mobile source emissions pose the greatest risk at current estimated ambient levels.[A] We also conducted a national-scale assessment for future years, which is discussed more fully in Chapters 2 and 3 of the RIA. The limitations and uncertainties associated with NATA are discussed in Section 3.2.1.3 of the RIA. Our understanding of what emissions pose the greatest risk will evolve over time, based on our understanding of the ambient levels and health effects associated with the compounds.[B]

1.1.4.1. Risk Drivers in 1999 National-Scale Air Toxics Assessment

The 1999 NATA evaluates 177 hazardous air pollutants currently listed under CAA section 112(b), as well as diesel PM. NATA is described in greater detail in Chapters 2 and 3 of this RIA. Additional information can also be obtained from the NATA website (http://www.epa.gov/ttn/atw/nata1999). Based on the assessment of inhalation exposures associated with outdoor sources of these hazardous air pollutants, NATA has identified cancer and noncancer risk drivers on a national and regional scale (Table 1.1.-3). A cancer risk driver on a national scale is a hazardous air pollutant for which at least 25 million people are exposed to risk greater than ten in one million. Benzene is the only compound identified in the 1999 NATA as a national cancer risk driver.[C] A cancer risk driver on a regional scale is a hazardous air pollutant for which at least one million people are exposed to risk greater than ten in one million or at least 10,000 people are exposed to risk greater than 100 in one million. Twelve compounds (or groups of compounds in the case of POM) were identified as regional cancer risk drivers. The 1999 NATA concludes that diesel particulate matter is among the substances that pose the greatest relative risk, although the cancer risk cannot be quantified.

A noncancer risk driver at the national scale is a hazardous air pollutant for which at least 25 million people are exposed at a concentration greater than the inhalation reference concentration. The RfC is an estimate (with uncertainty spanning perhaps an order of magnitude) of a daily exposure to the human population (including sensitive subgroups) that is likely to be without appreciable risk of deleterious effects during a lifetime. Acrolein is the only compound identified in the 1999 NATA as a national noncancer risk driver.[D] A noncancer risk driver on a regional scale is defined as a hazardous air pollutant for which at least 10,000 people are exposed to an ambient concentration greater than the inhalation reference concentration.

[A] It is, of course, not necessary for EPA to show that a compound is a national or regional risk driver to show that its emission from motor vehicles may reasonably cause or contribute to endangerment of public health or welfare. A showing that motor vehicles contribute some non-trivial percentage of the inventory of a compound known to be associated with adverse health effects would normally be sufficient. Cf. Bluewater Network v. EPA, 370 F. 3d 1, 15 (D.C. Cir. 2004).

[B] The discussion here considers risks other than those attributed to ambient levels of criteria pollutants.

[C] Benzene was assigned an overall confidence level of "higher" based on consideration of the combined uncertainties from the modeling estimates.

[D] Acrolein was assigned an overall confidence level of "lower" based on consideration of the combined uncertainties from the modeling estimates.

Sixteen regional-scale noncancer risk drivers were identified in the 1999 NATA (see Table 1.1.-3.).

Table 1.1.-3. National and Regional Cancer and Noncancer Risk Drivers in 1999 NATA

Cancer [1]	**Noncancer**
National drivers [2]	**National drivers** [4]
Benzene^{H}	Acrolein^{L}
Regional drivers [3]	**Regional drivers** [5]
Arsenic compounds^{L}	Antimony^{H}
Benzidine^{L}	Arsenic compounds^{L}
1,3-Butadiene^{L}	1,3-Butadiene^{L}
Cadmium compounds^{L}	Cadmium compounds^{L}
Carbon tetrachloride^{H}	Chlorine^{L}
Chromium VI^{L}	Chromium VI^{L}
Coke oven^{M}	Diesel PM^{M}
Ethylene oxide^{H}	Formaldehyde^{M}
Hydrazine^{M}	Hexamethylene 1-6-diisocyanate^{M}
Naphthalene^{M}	Hydrazine^{H}
Perchloroethylene^{M}	Hydrochloric acid^{L}
Polycyclic organic matter^{M}	Maleic anhydride^{L}
	Manganese compounds^{L}
	Nickel compounds^{L}
	2,4-Toluene diisocyanate^{L}
	Triethylamine^{L}

[1] The list of cancer risk drivers does not include diesel particulate matter. However, the 1999 NATA concluded that it was one of the pollutants that posed the greatest relative cancer risk.

[2] At least 25 million people exposed to risk >10 in 1 million

[3] At least 1 million people exposed to risk >10 in 1 million or at least 10,000 people exposed to risk >100 in 1 million

[4] At least 25 million people exposed to a hazard quotient > 1.0

[5] At least 10,000 people exposed to a hazard quotient > 1

EPA has assigned an overall confidence level for each pollutant in NATA based on consideration of the combined uncertainties from emissions estimation, ambient concentration modeling, and exposure modeling. These judgments refer to the relative confidence between two air toxics compounds. A judgment of "Higher" (H) means the confidence is higher for this compound than for compounds assigned a "Medium" (M) or "Lower" (L).

It should be noted that varying levels of confidence are associated with risk estimates for individual pollutants, based on the quality of the data used to estimate emissions, ambient concentrations and exposure. For the pollutants included in NATA, EPA rated its confidence inrisk estimates, based on the quality of the data used for emissions, air quality, and exposure modeling, as high, medium, or lower. EPA has a high level of confidence in the data for benzene, medium confidence in the data for formaldehyde, but lower confidence in data for 1,3-butadiene and acrolein.

1.1.4.2. 1999 NATA Risk Drivers with Significant Mobile Source Contribution

Among the national and regional-scale cancer and noncancer risk drivers identified in the 1999 NATA, seven compounds have significant contributions from mobile sources: benzene, 1,3-butadiene, formaldehyde, acrolein, polycyclic organic matter (POM), naphthalene, and diesel particulate matter and diesel exhaust organic gases (Table 1.1.-4.). For example, mobile sources contribute 68% of the national benzene inventory, with 49% from on-road sources and 19% from nonroad sources based on 1999 NATA data.

Table 1.1.-4. Mobile Source Contribution to 1999 NATA Risk Drivers

1999 NATA Risk Drivers	Percent Contribution from All Mobile Sources	Percent Contribution from On-road Mobile Sources
Benzene^H	68%	49%
1,3-Butadiene^L	58%	41%
Formaldehyde^M	47%	27%
Acrolein^L	25%	14%
Polycyclic organic matter*^{M}	6%	3%
Naphthalene^M	27%	21%
Diesel PM and Diesel exhaust organic gases^M	100%	38%

*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, fluorene, and acenaphthene.

EPA has assigned an overall confidence level for each pollutant in NATA based on consideration of the combined uncertainties from emissions estimation, ambient concentration modeling, and exposure modeling. These judgments refer to the relative confidence between two air toxics compounds. A judgment of "Higher" (H) means the confidence is higher for this compound than for compounds assigned a "Medium" (M) or "Lower" (L).

1.2. Dose-Response and Agency Risk Assessment Practice

This section describes EPA's formal process for conducting risk assessment. The EPA framework for assessing and managing risks reflects the risk assessment and risk management paradigm set forth by the National Academy of Sciences in 1983[3] which was incorporated into the 1986 EPA risk guidance[4] and revised in 2005 in the EPA Guidelines for Carcinogen Risk Assessment and Supplemental Guidance for Assessing Susceptibility from Early-Life Exposure to Carcinogens.[5] The paradigm divides the risk assessment and management process into four general phases. The first three phases (exposure assessment, dose-response assessment, and risk characterization) comprise risk assessment. The fourth phase, risk management, involves evaluation of information provided by the risk assessment to the environmental manager who makes a risk management decision.

An exposure assessment is the quantitative or qualitative evaluation of contact to a specific pollutant and includes such characteristics as intensity, frequency, and duration of contact. The numerical output of an exposure assessment may be either exposure or dose, depending on the purpose of the evaluation and available data.

The dose-response assessment produces two sequential analyses. The first analysis is the hazard identification, which identifies contaminants that are suspected to pose health hazards, describes the specific forms of toxicity (e.g., neurotoxicity, carcinogenicity, etc.) that they may cause, and evaluates the conditions under which these forms of toxicity might be expressed in exposed humans. The types of effects that are relevant to a particular chemical (e.g., cancer, noncancer) are determined as part of the hazard identification.

The second analysis is the human health dose-response assessment, which generally describes the characterization of the relationship between the concentration, exposure, or dose of a pollutant and the resultant health effects. Dose-response assessment methods generally consist of two parts. First is the evaluation of the experimentally observed relationship between health effects and the concentration, exposure and/or dose of a particular compound, and second is the extrapolation from the observed range to lower doses and risks.

1.2.1. Cancer

The term 'cancer' is used to describe a group of related diseases that affect a variety of organs and tissues. Cancer results from a combination of genetic damage and nongenetic factors that favor the growth of damaged cells. The EPA document, *Guidelines for Carcinogen Risk Assessment*[6] (2005) provides guidance on hazard identification for carcinogens. The approach recognizes three broad categories of data: (1) human data (primarily, epidemiological); (2) results of long-term experimental animal bioassays; and (3) supporting data, including a variety of short-term tests for genotoxicity and other relevant properties. The 2005 Guidelines for hazard identification recommend that an agent's human carcinogenic potential be described in a weight-of-evidence narrative. The narrative summarizes the full range of available evidence and describes any conditions associated with conclusions about an agent's hazard potential (e.g., carcinogenic by some routes of exposure and not others). To provide additional clarity and consistency in weight-of-evidence narratives, the Guidelines suggest a set of weight-of-evidence descriptors to accompany the narratives. The five descriptors are: Carcinogenic to Humans, Likely to be Carcinogenic to Humans, Suggestive Evidence of Carcinogenic Potential, Inadequate Information to Assess Carcinogenic Potential, and Not Likely to be Carcinogenic to Humans. These descriptors replace those based on the EPA 1986 Risk Assessment Guidelines which classified a compound as Group A: Carcinogenic to Humans, Group B: Probably Carcinogenic to Humans, Group C: Possibly Carcinogenic to Humans, Group D: Not Classifiable as to Human Carcinogenicity, or Group E: Evidence of Noncarcinogenicity for Humans.

A quantitative assessment is performed depending on the weight-of-evidence and the suitability of the available information regarding a relationship between the dose of a compound and the effect it causes (dose-response data). Dose-response models are used to calculate unit risk estimates (URE). Inhalation cancer risks are quantified by EPA using the unit risk, which represent the excess lifetime cancer risk estimated to result from continuous lifetime exposure to an agent at a concentration of 1 $\mu g/m^3$ in air. These unit risks are typically upper-bound estimates, although where there are adequate epidemiological data, the unit risk may be based on a maximum likelihood estimate (MLE). Except for benzene and chromium, where risks are based on maximum likelihood dose-response values, risks from mobile source air toxics should all be considered upper-bound values. This means they are plausible upper limits to risks. True risks could be greater, but are likely to be lower, and could be zero. A discussion of the confidence in a quantitative cancer risk estimate is provided in the IRIS file for each compound. The discussion of the confidence in the cancer risk estimate includes an assessment of the source of the data (human or animal), uncertainties in dose estimates, choice of the model used to fit the exposure and response data and how uncertainties and potential confounders are handled.

The 2005 Guidelines include Supplemental Guidance for Assessing Susceptibility from Early-Life Exposure to Carcinogens.[7] The Supplemental Guidance is part of EPA's response to the recommendation of the National Research Council (1994) that "EPA should assess risks to infants and children whenever it appears that their risks might be greater than those of adults." For several potential carcinogens, there is some evidence of higher cancer risks following early-life exposure. Accordingly, the Supplemental Guidance describes the approaches that EPA could use in assessing cancer risks following early-life exposures. The 1999 NATA does not include default adjustments for early life exposures recently recommended in the Supplemental Guidance. Incorporation of such adjustments, if needed, would lead to higher estimates of lifetime risk.

1.2.2. Chronic Exposure and Noncancer Health Effects

Noncancer effects resulting from chronic exposures include a wide range of effects in many organ systems, e.g., respiratory, cardiovascular, immune, kidney. Hazard identification procedures for chronic noncancer effects are described in EPA guidelines. The EPA has published guidelines for assessing several specific types of noncancer effects, including mutagenicity,[8] developmental toxicity,[9] neurotoxicity[10]; and reproductive toxicity.[11] For identification of hazards resulting from long-term (chronic) exposures, EPA reviews available data on different health endpoints and target organs and describes the range of effects observed and the related dose/exposure levels. EPA focuses particular attention to effects that occur at relatively low doses or that may have particular relevance to human populations. The inhalation reference concentration (RfC) and oral reference dose (RfD) are the Agency consensus quantitative toxicity values for use in chronic noncancer risk assessment. The RfC or RfD is defined as an estimate, with uncertainty spanning perhaps an order of magnitude, of an inhalation exposure/oral dose to the human population (including sensitive subgroups) that is likely to be without appreciable risks of deleterious effects during a lifetime. The RfC or RfD is derived using 1) a thorough review of the health effects database for an individual chemical and 2) the most sensitive and relevant endpoint and the principal study(ies) demonstrating that endpoint. RfCs for inhalation are derived according to the Agency's 1994 guidance.[12] A statement regarding the confidence in the RfC and/or RfD is developed to reflect the confidence in the principal study or studies on which the RfC or RfD are based and the confidence in the underlying database. Factors that affect the confidence in the principal study include how well the study was designed, conducted and reported. Factors that affect the confidence in the database include an assessment of the availability of information regarding identification of the critical effect, potentially susceptible populations and exposure scenarios relevant to assessment of risk. In 2002 an EPA RfC/RfD Technical Panel prepared several recommendations for preparation of noncancer reference values.[13]

1.2.3. Acute Exposure and Noncancer Health Effects

Noncancer health impacts resulting from acute (short-term) exposures have been assessed for many compounds in the occupational setting. EPA currently does not have acute exposures reference values in IRIS comparable to the RfC described above. EPA's Office of Research and Development proposed an Acute Reference Exposure (ARE) approach for evaluating short term exposure effects in 1998.[14] In 2002 EPA completed a review document which summarizes recommendations of the EPA RfC/RfD Technical Panel for preparation of noncancer reference values including acute exposure values.[15] In response to the EPA Science Advisory Board review of the Acute Reference Exposure methodology and recommendations from EPA's RfC/RfD Technical Panel, ORD is currently developing an advanced acute inhalation reference concentration (acute RfC) methodology. As part of this new methodology, acute inhalation assessments are being developed for a few selected compounds including acrolein and hydrogen sulfide.

1.3. Summary of Air Toxic Health Effects

From a public health perspective, it is important to assess the emission contributions to atmospheric levels of various air toxics (including diesel PM and exhaust organic gases) emitted by motor vehicle engines, including their physical properties, sources of potential exposure, and health hazards. In this section, we describe the cancer and noncancer health effects attributed to chronic exposure to various mobile source air toxics as well as any acute exposure health effects, where data are available. We focus here on the air toxics that are identified in the NATA as risk drivers (see Section 1.1) and that account for a significant share of mobile sources emissions. We also consider compounds for which we expect emission reductions from today's proposed rule. We are also including diesel particulate matter and diesel exhaust organic gases in this discussion. EPA has concluded that diesel exhaust ranks with the other substances that the national-scale assessment suggests pose the greatest relative risk.

1.3.1. Benzene

Benzene is an aromatic hydrocarbon that is present as a gas in both exhaust and evaporative emissions from mobile sources. Inhalation is the major source of human exposure to benzene in the occupational and non-occupational setting.

The EPA's IRIS database lists benzene as a known human carcinogen (causing leukemia) by all routes of exposure.[16] A number of adverse noncancer health effects including blood disorders and immunotoxicity, have also been associated with long-term occupational exposure to benzene.

Long-term occupational inhalation exposure to benzene has been shown to cause cancers of the hematopoetic (blood cell) system in adults. Among these are acute nonlymphocytic leukemia,[E] and chronic lymphocytic leukemia.[17,18] A doubling of risk for acute nonlymphocytic leukemia and myelodysplastic syndrome was found at average exposure levels under 10 ppm (32 mg/m^3).[19] EPA has not formally evaluated this study as part of the IRIS review process. Leukemias, lymphomas, and other tumor types have been observed in experimental animals exposed to benzene by inhalation or oral administration. Exposure to benzene and/or its metabolites has also been linked with

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[E] Leukemia is a blood disease in which the white blood cells are abnormal in type or number. Leukemia may be divided into nonlymphocytic (granulocytic) leukemias and lymphocytic leukemias. Nonlymphocytic leukemia generally involves the types of white blood cells (leukocytes) that are involved in engulfing, killing, and digesting bacteria and other parasites (phagocytosis) as well as releasing chemicals involved in allergic and immune responses. This type of leukemia may also involve erythroblastic cell types (immature red blood cells). Lymphocytic leukemia involves the lymphocyte type of white blood cell that is responsible for antibody and cell-mediated immune responses. Both nonlymphocytic and lymphocytic leukemia may, in turn, be separated into acute (rapid and fatal) and chronic (lingering, lasting) forms. For example; in acute myeloid leukemia there is diminished production of normal red blood cells (erythrocytes), granulocytes, and platelets (control clotting), which leads to death by anemia, infection, or hemorrhage. These events can be rapid. In chronic myeloid leukemia (CML) the leukemic cells retain the ability to differentiate (i.e., be responsive to stimulatory factors) and perform function; later there is a loss of the ability to respond.

chromosomal changes in humans and animals[20, 21] and increased proliferation of mouse bone marrow cells.[22, 23]

The latest assessment by EPA estimates the excess risk of developing leukemia from inhalation exposure to benzene at 2.2 x 10^{-6} to 7.8 x 10^{-6} per µg/m^3. In other words, there is an estimated risk of about two to eight excess leukemia cases in one million people exposed to 1 µg/m^3 of benzene over a lifetime.[24] This range of unit risks reflects the MLEs calculated from different exposure assumptions and dose-response models that are linear at low doses. At present, the true cancer risk from exposure to benzene cannot be ascertained, even though dose-response data are used in the quantitative cancer risk analysis, because of uncertainties in the low-dose exposure scenarios and lack of clear understanding of the mode of action. A range of estimates of risk is recommended, each having equal scientific plausibility. There are confidence intervals associated with the MLE range that reflect random variation of the observed data. For the upper end of the MLE range, the 5th and 95th percentile values are about a factor of 5 lower and higher than the best fit value. The upper end of the MLE range (7.8 x 10^{-6} per µg/m^3) was used in the 1999 NATA.

It should be noted that not enough information is known to determine the slope of the dose-response curve at environmental levels of exposure and to provide a sound scientific basis to choose any particular extrapolation/exposure model to estimate human cancer risk at low doses. EPA risk assessment guidelines suggest using an assumption of linearity of dose response when (1) there is an absence of sufficient information on modes of action or (2) the mode of action information indicates that the dose-response curve at low dose is or is expected to be linear.[25] Data that were considered by EPA in its carcinogenic update suggested that the dose-response relationship at doses below those examined in the studies reviewed in EPA's most recent benzene assessment may be supralinear. This relationship could support the inference that cancer risks are as high, or higher than the estimates provided in the existing EPA assessment.[26] However, since the mode of action for benzene carcinogenicity is unknown, the current cancer unit risk estimate assumes linearity of the low-dose response. Data discussed in the EPA IRIS assessment suggest that genetic abnormalities occur at low exposure in humans, and the formation of toxic metabolites plateaus above 25 ppm (80,000 µg/m^3).[27] More recent data on benzene adducts in humans, published after the most recent IRIS assessment, suggest that the enzymes involved in benzene metabolism start to saturate at exposure levels as low as 1 ppm.[28,29,30] These data highlight the importance of ambient exposure levels and their contribution to benzene-related adducts. Because there is a transition from linear to saturable metabolism below 1 ppm, the assumption of low-dose linearity extrapolated from much higher exposures could lead to substantial underestimation of leukemia risks. This is consistent with recent epidemiological data which also suggest a supralinear exposure-response relationship and which "[extend] evidence for hematopoietic cancer risks to levels substantially lower than had previously been established".[31,32,33] These data are from the largest cohort study done to date with individual worker exposure estimates. However, these data have not yet been formally evaluated by EPA as part of the IRIS review process, and it is not clear how they might influence low-dose risk estimates. A better understanding of the biological mechanism of benzene-induced leukemia is needed.

Children may represent a subpopulation at increased risk from benzene exposure, due to factors that could increase their susceptibility. Children may have a higher unit body weight exposure because of their heightened activity patterns which can increase their exposures, as well as different ventilation tidal volumes and frequencies, factors that influence uptake. This could entail a greater risk of leukemia and other toxic effects to children if they are exposed to benzene at similar levels as adults. There is limited information from two studies regarding an increased risk to children whose parents have been occupationally exposed to benzene.[34,35] Data from animal studies have shown benzene exposures result in damage to the hematopoietic (blood cell formation) system during development.[36, 37, 38] Also, key changes related to the development of childhood leukemia occur in the developing fetus.[39] Several studies have reported that genetic changes related to eventual leukemia development occur before birth. For example, there is one study of genetic changes in twins who developed T cell leukemia at 9 years of age.[40] An association between traffic volume, residential proximity to busy roads and occurrence of childhood leukemia has also been identified in some studies, although some studies show no association. These studies are discussed later in Chapter 3.

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.[41,42] People with long-term occupational exposure to benzene have experienced harmful effects on the blood-forming tissues, especially in the bone marrow. These effects can disrupt normal blood production and suppress the production of important blood components, such as red and white blood cells and blood platelets, leading to anemia (a reduction in the number of red blood cells), leukopenia (a reduction in the number of white blood cells), or thrombocytopenia (a reduction in the number of blood platelets, thus reducing the ability of blood to clot). Chronic inhalation exposure to benzene in humans and animals results in pancytopenia,[F] a condition characterized by decreased numbers of circulating erythrocytes (red blood cells), leukocytes (white blood cells), and thrombocytes (blood platelets).[43, 44] Individuals that develop pancytopenia and have continued exposure to benzene may develop aplastic anemia, whereas others exhibit both pancytopenia and bone marrow hyperplasia (excessive cell formation), a condition that may indicate a preleukemic state.[45, 46] The most sensitive noncancer effect observed in humans, based on current data, is the depression of the absolute lymphocyte count in blood.[47, 48]

EPA's inhalation reference concentration (RfC) for benzene is 30 µg/m^3. The overall confidence in this RfC is medium. The RfC is based on suppressed absolute lymphocyte counts seen in humans under occupational exposure conditions. Since

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[F] Pancytopenia is the reduction in the number of all three major types of blood cells (erythrocytes, or red blood cells, thrombocytes, or platelets, and leukocytes, or white blood cells). In adults, all three major types of blood cells are produced in the bone marrow of the skeletal system. The bone marrow contains immature cells, known as multipotent myeloid stem cells, that later differentiate into the various mature blood cells. Pancytopenia results from a reduction in the ability of the red bone marrow to produce adequate numbers of these mature blood cells.

development of this RfC, there have appeared reports in the medical literature of benzene's hematotoxic effects in humans that provide data suggesting a wide range of hematological endpoints that are triggered at occupational exposures of less than 5 ppm (about 16 mg/m^3)[49] and, more significantly, at air levels of 1 ppm (about 3 mg/m^3) or less among genetically susceptible populations.[50] These studies had large sample sizes and extensive individual exposure monitoring. One recent study found benzene metabolites in mouse liver and bone marrow at environmental doses, indicating that even concentrations in urban air may elicit a biochemical response in rodents that indicates toxicity.[51] EPA has not formally evaluated these recent studies as part of the IRIS review process to determine whether or not they will lead to a change in the current RfC. EPA does not currently have an acute reference concentration for benzene. The Agency for Toxic Substances and Disease Registry Minimal Risk Level for acute exposure to benzene is 160 µg/m^3 for 1-14 days exposure.

1.3.2. 1,3-Butadiene

1,3-butadiene is formed in engine exhaust by the incomplete combustion of fuel. It is not present in engine evaporative emissions because it is not generally present in an appreciable amount in vehicle fuels.

EPA has characterized 1,3-butadiene as a leukemogen, carcinogenic to humans by inhalation.[52, 53] The specific mechanisms of 1,3-butadiene-induced carcinogenesis are unknown however, it is virtually certain that the carcinogenic effects are mediated by genotoxic metabolites of 1,3-butadiene. Animal data suggest that females may be more sensitive than males for cancer effects; nevertheless, there are insufficient data from which to draw any conclusions on potentially sensitive subpopulations. The upper bound cancer unit risk estimate is 0.08 per ppm or $3x10^{-5}$ per µg/m^3 (based primarily on linear modeling and extrapolation of human data). In other words, it is estimated that approximately 30 persons in one million exposed to 1 µg/m^3 of 1,3-butadiene continuously for their lifetime would develop cancer as a result of this exposure. The human incremental lifetime unit cancer risk estimate is based on extrapolation from leukemias observed in an occupational epidemiologic study.[54, 55, 56] This estimate includes a two-fold adjustment to the epidemiologic-based unit cancer risk applied to reflect evidence from the rodent bioassays suggesting that the epidemiologic-based estimate (from males) may underestimate total cancer risk from 1,3-butadiene exposure in the general population, particularly for breast cancer in females.[57]

A recent study extended the investigation of 1,3-butadiene exposure and leukemia among synthetic rubber industry workers.[58] The results of this study strengthen the evidence for the relationship between 1,3-butadiene exposure and lymphohematopoietic cancer. This relationship was found to persist after controlling for exposure to other toxics in this work environment.

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.[59] Based on this critical effect and the benchmark concentration methodology, an RfC for chronic health effects was calculated at 0.9 ppb (approximately 2 µg/m^3). Confidence in the inhalation RfC is medium.

1.3.3. Formaldehyde

Formaldehyde is the most prevalent aldehyde in engine exhaust. It is formed as a result of incomplete fuel combustion in both gasoline and diesel engines, although formaldehyde accounts for a smaller quantity of total exhaust hydrocarbons from gasoline engines. Formaldehyde emissions can vary substantially by engine duty cycle, emission control system and composition of fuel. Formaldehyde is not a component of evaporative emissions but it can be formed photochemically in the atmosphere.

Since 1987, EPA has classified formaldehyde as a probable human carcinogen based on evidence in humans and in rats, mice, hamsters, and monkeys.[60] EPA's current IRIS summary provides an upper bound cancer unit risk estimate of 1.3x10^{-5} per µg/m^3.[G] In other words, there is an estimated risk of about thirteen excess leukemia cases in one million people exposed to 1 µg/m^3 of formaldehyde over a lifetime. 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.[61, 62] NCI is currently performing an update of these studies. 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.[63] Extended follow-up of a cohort of British chemical workers did not find evidence of an increase in nasopharyngeal or lymphohematopoeitic cancers, but a continuing statistically significant excess in lung cancers was reported.[64]

Based on the developments of the last decade, in 2004, the working group of the International Agency for Research on Cancer concluded that formaldehyde is carcinogenic to humans (Group 1 classification), on the basis of sufficient evidence in humans and sufficient evidence in experimental animals—a higher classification than previous IARC evaluations. In addition, the National Institute of Environmental Health Sciences recently nominated formaldehyde for reconsideration as a known human carcinogen under the National Toxicology Program. Since 1981 it has been listed as a "reasonably anticipated human carcinogen." Recently the German Federal Institute for Risk Assessment determined that formaldehyde is a known human carcinogen.[65]

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.[66,67,68] CIIT's risk assessment of formaldehyde incorporated mechanistic and dosimetric information on formaldehyde. The risk assessment analyzed carcinogenic risk from

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[G] U.S. EPA (1989). Integrated Risk Information System File for Formaldehyde. This material is available electronically at http://www.epa.gov/iris/subst/0419.htm.

inhaled formaldehyde using approaches that are consistent with EPA's draft guidelines for carcinogenic risk assessment. In 2001, Environment Canada relied on this cancer dose-response assessment in their assessment of formaldehyde.[69] In 2004, EPA also relied on this cancer unit risk estimate during the development of the plywood and composite wood products national emissions standards for hazardous air pollutants (NESHAPs).[70] In these rules, EPA concluded that the CIIT work represented the best available application of the available mechanistic and dosimetric science on the dose-response for portal of entry cancers due to formaldehyde exposures. 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.

Noncancer effects of formaldehyde have been observed in humans and several animal species and include irritation to eye, nose and throat tissues in conjunction with increased mucous secretions.[71]

1.3.4. Acetaldehyde

Acetaldehyde is formed as a result of incomplete fuel combustion in both gasoline and diesel engines, although acetaldehyde accounts for a smaller quantity of total exhaust hydrocarbons from gasoline engines. Acetaldehyde emissions can vary substantially by engine duty cycle, emission control system and composition of fuel. Acetaldehyde is not a component of evaporative emissions but it can be formed photochemically in the atmosphere.

Acetaldehyde is classified in EPA's IRIS database as a probable human carcinogen and is considered toxic by inhalation.[72] Based on nasal tumors in rodents, the upper confidence limit estimate of a lifetime extra cancer risk from continuous acetaldehyde exposure is about 2.2×10^{-6} per µg/m^3. In other words, it is estimated that about 2 persons in one million exposed to 1 µg/m^3 acetaldehyde continuously for their lifetime (70 years) would develop cancer as a result of their exposure although the risk could be as low as zero.

In short-term (4 week) rat studies, compound-related histopathological changes were observed only in the respiratory system at various concentration levels of exposure.[73, 74] Data from these studies showing degeneration of the olfactory epithelium were found to be sufficient for EPA to develop an RfC for acetaldehyde of 9 µg/m^3. Confidence in the principal study is medium and confidence in the database is low, due to the lack of chronic data establishing a no observed adverse effect level and due to the lack of reproductive and developmental toxicity data. Therefore, there is low confidence in the RfC.[75] The Agency is currently conducting a reassessment of risk from inhalation exposure to acetaldehyde.

The primary acute effect of exposure to acetaldehyde vapors is irritation of the eyes, skin, and respiratory tract.[76] Some asthmatics have been shown to be a sensitive subpopulation to decrements in functional expiratory volume (FEV1 test) and broncho-constriction upon acetaldehyde inhalation.[77]

1.3.5. Acrolein

Acrolein is found in vehicle exhaust and is formed as a result of incomplete combustion of both gasoline and diesel fuel. It is not a component of evaporative emissions but it can be formed photochemically from 1,3-butadiene in the atmosphere.

EPA determined in 2003 using the 1999 draft cancer guidelines 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.

Acrolein is an extremely volatile organic compound which possesses considerable water solubility.[78] As such, it readily absorbs into airway fluids in the respiratory tract when inhaled. The toxicological data base demonstrating the highly irritating nature of this vapor has been consistent, regardless of test species. Acrolein is intensely irritating to humans when inhaled, with acute exposure resulting in upper respiratory tract irritation, mucus hypersecretion and congestion.

Lesions to the lungs and upper respiratory tract of rats, rabbits, and hamsters exposed to acrolein formed the basis of the reference concentrations for inhalation (RfC) developed in 2003.[79] The Agency has developed an RfC for acrolein of 0.02 µg/m^3 and an RfD of 0.5 ug/kg-day.[80] The overall confidence in the RfC assessment is judged to be medium and the confidence in the RfD is medium to high.

The Agency is currently in the process of conducting an assessment of acute exposure effects for acrolein. The intense irritancy of this carbonyl has been demonstrated during controlled tests in human subjects who suffer intolerable eye and nasal mucosal sensory reactions within minutes of exposure.[81]

1.3.6. 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 and evaporative emissions from mobile sources.

In 2004, EPA released an external review draft of a reassessment of the inhalation carcinogenicity of naphthalene.[82] The draft reassessment (External Review Draft, IRIS Reassessment of the Inhalation Carcinogenicity of Naphthalene) completed external peer review in 2004 by Oak Ridge Institute for Science and Education.[83] Based on external comments, additional analyses are being considered. California EPA has released a new risk assessment for naphthalene with a cancer unit risk estimate of $3\text{x}10^{-5}$ per µg/m^3.[84] The California EPA value was used in the 1999 NATA and in the analyses done for this rule. In addition, IARC has reevaluated naphthalene and re-classified it as Group 2B:

possibly carcinogenic to humans.[85] Current risk estimates for naphthalene are based on extrapolations from rodent studies conducted at higher doses. At present, human data are inadequate for developing estimates.

The current EPA IRIS assessment includes noncancer data on hyperplasia and metaplasia in nasal tissue that form the basis of the inhalation RfC of 3 µg/m^3.[86] The principal study was given medium confidence because adequate numbers of animals were used, and the severity of nasal effects increased at the higher exposure concentration. However, the study produced high mortality and hematological evaluation was not conducted beyond 14 days. The database was given a low-to-medium confidence rating because there are no chronic or subchronic inhalation studies in other animal species, and there are no reproductive or developmental studies for inhalation exposure. In the absence of human or primate toxicity data, the assumption is made that nasal responses in mice to inhaled naphthalene are relevant to humans; however, it cannot be said with certainty that this RfC for naphthalene based on nasal effects will be protective for hemolytic anemia and cataracts, the more well-known human effects from naphthalene exposure. As a result, we have medium confidence in the RfC.

1.3.7. 2,2,4-Trimethylpentane

2,2,4-Trimethylpentane is a colorless liquid hydrocarbon also known as isooctane, isobutyltrimethylmethane, and TMP. Automotive exhaust and automotive evaporative emissions are important sources of 2,2,4-trimethylpentane in the atmosphere.

EPA is in the process of assembling a review draft of a reassessment of its 1991 2,2,4-TMP health effects assessment in EPA's IRIS database. The earlier document found little conclusive evidence of specific health effects associated with 2,2,4-TMP exposures in humans.[87] Overall, there was "inadequate information to assess carcinogenic potential," in accordance with EPA's *Guidelines for Carcinogen Risk Assessment* (U.S. EPA, 1986), for 2,2,4-trimethylpentane. No chronic bioassay studies were available that assessed the carcinogenic effects of 2,2,4-trimethylpentane in humans.

Oral studies existed linking 2,2,4-TMP with male rat kidney toxicity and an increase in alpha$_{2u}$-globulin protein and hyaline droplet accumulation in the proximal tubules of the kidneys.[88] These effects were not seen in the female rat test subjects. These renal effects, specific to the male rat, are not thought to be relevant to humans. Inhalation studies in animals had been performed but none were adequate to calculate an inhalation RfC for the compound.

1.3.8. Ethylbenzene

Ethylbenzene is present as in both gasoline and diesel exhaust and in evaporative emissions from gasoline-powered vehicles.[89] Limited information is available on the carcinogenic effects of ethylbenzene in humans and animals. Under the 1987 Cancer Guidelines, EPA has classified ethylbenzene as a Group D carcinogen, meaning it is not classifiable as to human carcinogenicity. This classification is the result of inadequate data from animal bioassays and human studies.[90]

Chronic (long-term) exposure to ethylbenzene by inhalation in humans may result in effects on the blood, kidney and liver. No information is available on the developmental or reproductive effects of ethylbenzene in humans, although animal studies have reported developmental effects via inhalation. The data from these studies were found to be sufficient for EPA to develop an RfC of $1x10^3$ ug/m^3 for ethylbenzene exposure. Confidence in the RfC is considered low because higher study exposure levels might have been more informative and no chronic studies or multi-generational developmental studies were available at the time. Animal studies have reported effects on the blood, liver, and kidneys from ingestion exposure to ethylbenzene. The data from these studies were found to be sufficient for EPA to develop an RfD for ethylbenzene exposure of 100 ug/kg-day. Confidence in this RfD is considered low because rats of only one sex were tested, no chronic studies were then available, and no other oral toxicity data were found. Ethylbenzene is currently undergoing an IRIS update for both cancer and noncancer effects, based on new data.

Acute (short-term) exposure to ethylbenzene in humans results in noncancer respiratory effects, such as throat irritation and chest constriction, irritation of the eyes, and neurological effects such as dizziness.[91]

1.3.9. n-Hexane

n-Hexane is a component of gasoline and is also found in exhaust and evaporative emissions from motor vehicles. Monitoring data indicate that n-hexane occurs widely in the atmosphere.[92]

Under the 2005 Guidelines for Carcinogen Risk Assessment, there is inadequate information to assess the carcinogenic potential of n-hexane.[93] Chronic exposure to n-hexane in air is associated with polyneuropathy in humans, with numbness in the extremities, muscular weakness, blurred vision, headache, and fatigue observed. Neurotoxic effects have also been exhibited in rats. Mild inflammatory and degenerative lesions in the nasal cavity have been observed in rodents chronically exposed by inhalation. Limited information is available on the reproductive or developmental effects of n-hexane; one study reported testicular damage in rats exposed to n-hexane through inhalation. Birth defects have not been observed in the offspring of rats chronically exposed via inhalation in several studies. The data from a study of peripheral neuropathy was used to develop an RfC of 700 ug/m^3 for n-hexane exposure.[94] This RfC has been given a confidence rating of medium due to medium confidence in the underlying study and medium confidence in the database. The database lacks chronic exposure information on the pure compound via any route of exposure, a multigenerational developmental and reproductive toxicity study and a developmental neurotoxicity study.

Acute inhalation exposure of humans to high levels of n-hexane causes mild central nervous system (CNS) depression and irritation of the skin. Nervous system effects include dizziness, giddiness, slight nausea, and headache in humans.[95]

1.3.10. Methyl Tertiary Butyl Ether (MTBE)

Methyl *tert*-butyl ether (MTBE) has been used in the United States since the late-1970's as an octane-enhancing agent in gasoline.

In 1994, EPA's Office of Research and Development concluded that, under the 1986 EPA cancer risk assessment guidelines, inhalation cancer test results support placing MTBE in Group C as a "possible human carcinogen."[96] An Interagency Assessment of Oxygenated Fuels similarly concluded that "While there are no studies on the carcinogenicity of MTBE in humans, there is sufficient evidence to indicate that MTBE is an animal carcinogen and to regard MTBE as having a human hazard potential. However, estimates of human risk from MTBE contain large uncertainties in both human exposure and cancer potency."[97] The Agency is currently conducting a reassessment of MTBE.

By the inhalation route, MTBE has been found to cause increases in liver and kidney weights and increased severity of spontaneous kidney lesions, as well as swelling around the eyes and increased prostration in laboratory rats[98]. These effects are cited as the basis for EPA's current inhalation reference concentration (RfC) of 3 mg/m^3 for MTBE. The RfC has a medium to high confidence rating.

1.3.11. Styrene

Styrene is found in the exhaust from both gasoline- and diesel-powered engines. Several epidemiologic studies suggest that there may be an association between styrene exposure and an increased risk of leukemia and lymphoma. However, the evidence is inconclusive due to confounding factors. Animal studies have produced both negative and positive results. EPA is currently assessing the potential of styrene to cause cancer.

Chronic exposure of humans to styrene results in effects on the central nervous system (CNS), such as headache, fatigue, weakness, depression, peripheral neuropathy, minor effects on some kidney enzyme functions and on the blood. Human studies are inconclusive on the reproductive and developmental effects of styrene. The data from human studies looking at central nervous system effects was found to be sufficient for EPA to develop an RfC of 1 mg/m^3 for styrene exposure. The RfC is assigned an overall confidence rating of medium. Data from animal oral exposure studies was found to be sufficient for EPA to also develop an RfD of 200 ug/kg-day for styrene oral exposure. The RfD is assigned an overall confidence rating of medium.

Acute exposure to styrene results in mucous membrane and eye irritation, and central nervous system effects in humans. [99, 100]

1.3.12. Toluene

Toluene is found in evaporative as well as exhaust emissions from motor vehicles.

Under the 2005 Guidelines for Carcinogen Risk Assessment, there is inadequate information to assess the carcinogenic potential of toluene because studies of humans chronically exposed to toluene are inconclusive, toluene was not carcinogenic in adequate inhalation cancer bioassays of rats and mice exposed for life, and increased incidences of mammary cancer and leukemia were reported in a lifetime rat oral bioassay.[101]

The central nervous system (CNS) is the primary target for toluene toxicity in both humans and animals for acute and chronic exposures. CNS dysfunction (which is often reversible) and narcosis have been frequently observed in humans acutely exposed to low or moderate levels of toluene by inhalation; symptoms include fatigue, sleepiness, headaches, and nausea. Central nervous system depression has been reported to occur in chronic abusers exposed to high levels of toluene. Symptoms include ataxia, tremors, cerebral atrophy, nystagmus (involuntary eye movements), and impaired speech, hearing, and vision. Chronic inhalation exposure of humans to toluene also causes irritation of the upper respiratory tract, eye irritation, dizziness, headaches, and difficulty with sleep.[102]

Human studies have also reported developmental effects, such as CNS dysfunction, attention deficits, and minor craniofacial and limb anomalies, in the children of women who abused toluene during pregnancy. A substantial database examining the effects of toluene in subchronic and chronic occupationally exposed humans exists. The weight of evidence from these studies indicates neurological effects (i.e., impaired color vision, impaired hearing, decreased performance in neurobehavioral analysis, changes in motor and sensory nerve conduction velocity, headache, dizziness) as the most sensitive endpoint. The data from these human studies was found to be sufficient for EPA to develop an RfC of 5 mg/m^3 for toluene exposure. The overall confidence in this RfC is high. Additional data from animal oral exposure studies was found to be sufficient for EPA to also develop an RfD of 80 ug/kg-day for toluene oral exposure.[103] The overall confidence in the RfD is medium.

1.3.13. Xylenes

Mixed xylenes are blended into gasoline and are present in diesel fuels. Xylenes are emitted in the exhaust emissions and evaporative emissions of both gasoline- and diesel-powered engines.

Inadequate information is available on the carcinogenic effects of mixed xylenes in humans, and animal studies have been inconclusive. Under the 1999 Draft Revised Guidelines for Carcinogen Risk Assessment, data are inadequate for an assessment of the carcinogenic potential of xylenes.[104]

Chronic inhalation exposure in humans to mixed xylenes results primarily in central nervous system effects, such as headache, nausea, fatigue and also included eye and nose irritation and sore throat.[105] Animal studies have reported developmental effects, such as an increased incidence of skeletal variations in fetuses, and fetal resorptions via inhalation. EPA developed an RfC of 100 ug/m^3 for xylenes based on impaired motor coordination in rats. The confidence rating assigned to the RfC for xylenes is medium. Data from animal oral exposure studies, looking at decreased body weight and increased mortality were found to be sufficient for EPA to develop an RfD of 200 ug/kg-day for oral xylene exposure. The RfD was assigned an overall confidence rating of medium.[106]

Acute inhalation exposure to mixed xylenes in humans results in irritation of the nose and throat, gastrointestinal effects such as nausea, vomiting, and gastric irritation, mild transient eye irritation, and neurological effects.[107]

1.3.14. Polycyclic Organic Matter (POM)

POM is a class of chemicals consisting of organic compounds having multiple benzene rings and boiling points in excess of 100 degrees Celsius. POM is a byproduct of the incomplete combustion of fossil fuels and, as such, is a component of diesel and gasoline engine emissions. At least eight of the compounds included in the class of compounds known as POM are classified by EPA as probable human carcinogens based on animal data. These include acenaphthene, benzo(a)anthracene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, chrysene, dibenz(a,h)anthracene, and indeno(1,2,3-cd)pyrene. One POM, naphthalene, is discussed separately in this section.

Recent studies have found that maternal exposures to polyaromatic hydrocarbons (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.[108] These studies are discussed later in Chapter 3.

1.3.15. Diesel Exhaust

In EPA's Diesel Health Assessment Document (HAD),[109] diesel exhaust was classified as likely to be carcinogenic to humans by inhalation at environmental exposures, in accordance with the revised draft 1996/1999 EPA cancer guidelines. A number of other agencies (National Institute for Occupational Safety and Health, the International Agency for Research on Cancer, the World Health Organization, California EPA, and the U.S. Department of Health and Human Services) have made similar classifications. EPA concluded in the Diesel HAD that it is not possible currently to calculate a cancer unit risk for diesel exhaust due to a variety of factors that limit the current studies, such as limited quantitative exposure histories in occupational groups investigated for lung cancer.

However, in the absence of a cancer unit risk, the EPA Diesel HAD sought to provide additional insight into the significance of the cancer hazard by estimating possible ranges of risk that might be present in the population. An exploratory analysis was used to characterize a possible risk range by comparing a typical environmental exposure level for highway diesel sources to a selected range of occupational exposure levels. The occupationally observed risks were then proportionally scaled according to the exposure ratios to obtain an estimate of the possible environmental risk. A number of calculations are needed to accomplish this, and these can be seen in the EPA Diesel HAD.

The outcome was that environmental risks from diesel exhaust exposure could range from a low of 10^{-4} to 10^{-5} to as high as 10^{-3}, reflecting the range of occupational exposures that could be associated with the relative and absolute risk levels observed in the occupational studies. Because of uncertainties, the analysis acknowledged that the risks could be lower than 10^{-4} or 10^{-5}, and a zero risk from diesel exhaust exposure was not ruled out.

Noncancer health effects of acute and chronic exposure to diesel exhaust emissions are also of concern to the Agency. EPA derived an RfC from consideration of four well-conducted chronic rat inhalation studies showing adverse pulmonary effects.[110, 111, 112, 113] The RfC is 5 µg/m^3 for diesel exhaust as measured by diesel PM. This RfC does not consider allergenic effects such as those associated with asthma or immunologic effects. There is growing evidence, discussed in the Diesel HAD, that diesel exhaust can exacerbate these effects, but the exposure-response data are presently lacking to derive an RfC. The EPA Diesel HAD states, “With DPM [diesel particulate matter] being a ubiquitous component of ambient PM, there is an uncertainty about the adequacy of the existing DE [diesel exhaust] noncancer database to identify all of the pertinent DE-caused noncancer health hazards” (p. 9-19).

The Diesel HAD also briefly summarizes health effects associated with ambient PM and discusses the EPA’s annual National Ambient Air Quality Standard (NAAQS) of 15 µg/m^3. There is a much more extensive body of human data showing a wide spectrum of adverse health effects associated with exposure to ambient PM, of which diesel exhaust is an important component. The $PM_{2.5}$ NAAQS is designed to provide protection from the noncancer and premature mortality effects of $PM_{2.5}$ as a whole, of which diesel PM is a constituent.

1.4. Emerging Issues

Beyond the specific areas of quantifiable risk discussed above in Chapter 1.1.2, EPA is interested in emerging mobile source toxics issues that might require action in the future. The emerging issues currently under investigation by EPA are gasoline PM and metals.

1.4.1. Gasoline PM

Gasoline exhaust is a complex mixture that has not been evaluated in EPA’s IRIS. Gasoline exhaust is a ubiquitous source of particulate matter, contributing to the health effects observed for ambient PM which is discussed extensively in the EPA Particulate Matter Criteria Document.[114] The PM Criteria Document notes that the PM components of gasoline and diesel engine exhaust are hypothesized, important contributors to the observed increases in lung cancer incidence and mortality associated with ambient $PM_{2.5}$.[115] Gasoline PM is also a component of near-roadway emissions that may be contributing to the health effects observed in people who live near roadways (see Chapter 3.1.3.1). There is also emerging evidence for the mutagenicity and cytotoxicity of gasoline exhaust and gasoline PM. Seagrave et al. investigated the combined particulate and semivolatile organic fractions of gasoline and diesel engine emissions in various animal and bioassay tests.[116] The authors suggest that emissions from gasoline engines (including both the semi-volatile organic compounds and the particulate matter) are mutagenic and can induce inflammation and have cytotoxic effects.

EPA is working to improve the understanding of PM emissions from gasoline engines, including the potential range of emissions and factors that influence emissions. EPA led a large cooperative test program that recently completed testing approximately 500 randomly procured vehicles in the Kansas City metropolitan area. The purpose of this study was to determine the distribution of gasoline PM emissions from the in-use light-duty fleet. Results from this study are expected to be available shortly. This work shows how PM emissions vary for light-duty gasoline vehicles (automobiles and light-duty trucks) for different model years. It also shows how colder temperatures increase gasoline PM emissions. The data from this program are being evaluated. Some source apportionment studies in various areas of the country, including Denver and California, show gasoline and diesel PM can result in larger contributions to ambient PM than predicted by EPA emission inventories.[117,118] These source apportionment studies were one impetus behind the Kansas City study.

Another issue related to gasoline PM is the effect of mobile source on ambient PM, especially secondary PM. Ambient PM is composed of primary PM emitted directly into the atmosphere and secondary PM is formed in the atmosphere from chemical reactions in the atmosphere. Sulfates and nitrates are major examples of inorganic secondary PM, both of which have been well studied and quantified. Carbonaceous PM, from both primary PM emissions and secondary PM formed in the atmosphere, is a major source of PM, especially in urban areas. Various studies show that carbonaceous PM specifically from mobile sources is a major PM constituent in many urban areas over many portions of the country (including urban areas in the Northeast, Southeast, Midwest, and California/Washington portions of the United States). This information is included in EPA reports and various source apportionment studies.[119,120,121,122,123,124,125]

Primary carbonaceous mobile source emissions can be evaluated from emission inventories. The ambient PM levels from these emissions and secondary PM formed in the atmosphere from mobile sources can then be estimated by air quality modeling studies using the CMAQ (Community Multi-scale Air Quality) model. In addition to primary carbonaceous (organic aerosol) emissions, some specific compounds contribute to atmospheric PM loadings via formation of secondary organic aerosols (SOA). These compounds include monoterpenes and possibly isoprene and sesquiterpenes, as well as anthropogenic aromatic hydrocarbons such as toluene (and probably higher molecular weight non-aromatic hydrocarbons).

Smog chamber studies show that benzene forms SOA possibly through reactions with NOx. Prior smog chamber work[126] suggested benzene might be relatively inert in forming SOA, although this early study may not be conclusive. However, the more recent work shows that benzene does form SOA in smog chambers. This new smog chamber work shows that benzene can be oxidized in the presence of NOx to form SOA with maximum mass of SOA being 8-25% of the mass of benzene.[127] 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.

Upon release into the atmosphere, these numerous compounds can react with free radicals in the atmosphere to form SOA. While SOA formation from many reactive hydrocarbons has been investigated in the laboratory, there is relatively little information available on the chemical composition of SOA compounds from specific hydrocarbon precursors. This lack of information is largely due to having few reliable methods for measuring the polar, high molecular weight compounds that are thought to make up much of ambient SOA. The absence of compositional data has largely prevented identifying 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.

Recently EPA has taken the first step in addressing these issues by developing a tracer-based method for detecting SOA precursors in ambient samples. The method consists of irradiating the SOA precursor of interest in a smog chamber in the presence of NOx, collecting the SOA produced on filters, and then analyzing the samples for highly polar compounds using advanced organic chemistry methods. Employing this method, candidate tracers have been identified for several hydrocarbon compounds which are emitted in significant quantities and known to produce SOA in the atmosphere. Some of these compounds forming SOA that have been investigated in the current study are toluene, a variety of monoterpenes, isoprene, and β-caryophyllene, the latter three of which are emitted by vegetation. [128, 129, 130, 131, 132,133] The tracers provide a means to identify the hydrocarbon SOA precursors present in ambient $PM_{2.5}$ samples and show promise for estimating their contributions to the organic carbon concentrations.

The results of a recent EPA field study, to be published in the peer-reviewed literature, suggest aromatic hydrocarbon emissions, including toluene and possibly xylenes, contribute to SOA in Research Triangle Park, North Carolina, with initial estimates as high as 0.7 $\mu g/m^3$ during smog events in July/August. The level of toluene-derived SOA is the lowest in the November-February time frame (about 0.2 $\mu g/m^3$) with intermediate levels in the other months. Currently, EPA is conducting similar analyses of ambient $PM_{2.5}$ samples in Cincinnati, OH, Northbrook, IL, Detroit, MI, Bondville, IL, and St. Louis, MO, the results of which will be available by the end of 2006. After acceptance of the EPA field study results in the peer-reviewed literature, they will be used to assess whether current treatment of aromatic SOA in the EPA CMAQ model need to be modified. Along with most of the other state-of-the-science air quality models, CMAQ predicts low levels of aromatic SOA.

One caveat regarding this work is that a large number of gaseous hydrocarbons emitted into the atmosphere having the potential to form SOA have not yet been studied in this way. It is possible that hydrocarbons which have not yet been studied produce some of SOA species which are being used as tracers for other gaseous hydrocarbons. This means that the present work could overestimate the amount of SOA in the atmosphere to the gaseous hydrocarbons studied to date.

The issue of SOA formation from aromatic precursors is an important one to which EPA and others are paying significant attention. Due to the large contribution of mobile source emissions to overall aromatic levels in the atmosphere, this issue is a crucial one for assessing what further reductions are possible in mobile source PM.

1.4.2. Metals

The emission of metals to the environment is receiving increasing attention. Metals comprise a complex class of elements, some of which are toxic at very low exposure levels. The chemical form in which a metal or metal compound is emitted often determines the potential toxicity and ultimate fate of the element in the environment. Research in recent years suggests that some metals (e.g., transition metals) play an important role in the toxicity of ambient PM, and inhalation as well as ingestion of metals is known to cause a diverse array of cancer and noncancer effects in mammals. Since metals do not degrade in the environment, concerns arise regarding their accumulation in plants, animals, soil and water. The emission of metals from mobile sources is an emerging area of interest since the emissions are in the breathing zone and are distributed in a concentrated fashion in the roadway environment.

Emission of metals from mobile sources occurs as the result of metallic impurities in lubricating oil and fuel, catalyst wear, engine wear, brake wear, and tire wear. Emission rates of most metals from mobile sources are quite low, presenting challenges for many common measurement methods. In recent years, improvements in analytical chemistry allow both the quantification of very low levels of metals in mobile source exhaust as well as some characterization of the form of the metals emitted.[134] Currently, there are many gaps in our understanding of the quantity, chemical form and size distribution of metals in exhaust or from tire and brake wear. Application of state-of-the-art measurement techniques to mobile source metal emissions is just beginning. For example, EPA is currently conducting an emissions characterization program to understand the emission rate and chemical form of mercury in motor vehicle exhaust and the total mercury concentration in gasoline, diesel fuel, lubricating oil, and brake wear emissions. This work will help us understand the potential sources of motor vehicle mercury emissions, and the contribution of motor vehicles relative to other sources of mercury emissions. This information is necessary for any future consideration of control options. Other metals are also being evaluated in various studies.

Metals can also be emitted from mobile sources as a result of their use as an additive to gasoline and/or diesel fuel. As discussed in Chapter III.G of the preamble, Clean Air Act section 211 provides EPA with the authority to require a fuel additive manufacturer to collect necessary data to enable EPA to make a determination about the potential for risk to public health.

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Chapter 2: Table of Contents

Chapter 2: Emission Inventories

This chapter describes the methods used to develop inventories for air quality modeling, estimation of emission benefits, and calculation of cost-effectiveness for this rule. The chapter also presents and discusses these inventories. MSAT inventories for air quality modeling were developed well in advance of final rule promulgation, because of the lead time required to conduct air quality, exposure, and risk analyses. Thus, these inventories do not include revised estimates of emissions using new fuel quality estimates developed for the Renewable Fuel Standard Program, as discussed below. Therefore, the chapter has separate sections discussing MSAT inventories used for modeling, and revised inventories used to estimate emission benefits of the rule and cost-effectiveness.

2.1 Criteria Pollutants

2.1.1 Methods

For the final rule, we have revised the emission inventories to reflect conditions anticipated under the Renewable Fuel Standard (RFS) program. The RFS program was mandated by the Energy Policy Act of 2005 in order to increase national consumption of renewable fuels. In September 2006, EPA issued a proposed rule to implement the RFS program for 2007 and beyond.[1] The RFS proposal analyzed several different scenarios of increased ethanol use and developed county-level fuel properties specific to each scenario.

In one particular RFS scenario, we estimated county-level fuel properties by allocating the Energy Information Agency’s forecast of 9.6 billion gallons of national ethanol consumption in 2012, attributing as much as possible for use as an oxygenate in reformulated gasoline. For purposes of this rule, we have selected this scenario as the most likely ethanol volume and distribution in 2012, and have therefore adopted those fuel properties as the new baseline fuel for MSAT inventories used to evaluate the cost-effectiveness of the standards being finalized in this rule. In the discussion that follows, the new MSAT baseline fuel is referred to as the “RFS fuel”. The RFS Draft Regulatory Impact Assessment (DRIA) contains a detailed discussion of the effects of ethanol fuel on gasoline properties and the methods by which we derived RFS county-level fuel properties.[2]

Though cost-effectiveness inventories in both the RFS proposal and the MSAT final rule reflect RFS fuels, there are slight differences in other methodologies used to estimate the emissions inventories. However, the differences are minor and have little impact on emission reductions used to evaluate cost-effectiveness.

2.1.1.1 Highway Vehicles

Highway vehicle hydrocarbon (HC) emission inventories were calculated by using vehicle emission rates produced from the emission model MOBILE6.2 multiplied by vehicle miles traveled (VMT) using the National Mobile Inventory Model (NMIM).[3] MOBILE6.2 uses emission factors obtained through the analysis of emissions data collected from vehicle emission research.[4] The emission factors reflect impacts of vehicle standards as well as current and planned inspection and maintenance programs. They also reflect impacts of changes in properties of gasoline and diesel fuels. Impacts of alternative fueled vehicles and engines (e.g. liquid propane, compressed natural gas, methanol) are negligible in NMIM. The VMT used by NMIM was estimated for base years using historical data from the Federal Highway Administration, allocated to counties using the methodology documented for the National Emissions Inventory, and projected to future years using the Energy Information Administration's National Energy Modeling System (NEMS) Transportation Model. NEMS projects VMT for personal travel based on demographic effects and economic influences such as estimated fuel costs and disposable income, and projects commercial truck travel based on economic factors such as industrial output and demand. This is the same approach used in the Clean Air Interstate Air Quality (CAIR) rule.[5] As mentioned above, county-level fuel properties contained in the public release version of NMIM were revised to RFS fuel.

Analysis of vehicle emission certification data submitted by vehicle manufacturers to EPA as part of requirements to comply with requirements for cold temperature carbon monoxide (CO) standards, as well as surveillance testing data from the California Air Resources Board, indicated that MOBILE6.2 was substantially underestimating start emissions at cold temperatures for Tier 1 and later vehicles. This data was supplemented with test data collected by EPA at Southwest Research Institute (SwRI)[6] and was then used to adjust the temperature and engine start emission factors in MOBILE6.2 to provide inputs to NMIM, which calculates county-level national inventories.[7]

EPA cold CO certification data was paired as 20 ºF versus 75 ºF tests per engine family to calculate the additional hydrocarbon (HC) emissions due to lower temperature. Available bag emission data indicated that at 20 ºF, as in the standard Federal Test Procedure (FTP) at 75 ºF, the majority of HC emissions occur during vehicle start and that lower vehicle soak and start temperatures result in higher HC emissions. Table 2.1.-1 indicates the trends found in the EPA Cold CO program certification data.

The state of California has a 50 ºF emission standard requirement and that data, also supplied by manufacturers, reflects the same trend over the smaller temperature difference (Table 2.1.-2).

The EPA testing at SwRI was performed on four Tier 2 vehicles to confirm the effects seen in the certification data and to extend the range of soak temperature to 0 ºF. A summary of the hydrocarbon data is found in Table 2.1.-3.

Table 2.1.-1. FTP HC Data From Federal Certified Vehicles (grams per mile)

		75º		20º	
Emission Standard	Sample Size	Mean	Std. Dev.	Mean	Std. Dev.
Tier 1	410	0.1190	0.0553	0.8630	0.7269
TLEV	64	0.0804	0.0286	0.6996	0.2778
LEV	695	0.0501	0.0209	0.6402	0.3723
ULEV	132	0.0335	0.0214	0.4675	0.2727
LEV2	119	0.0296	0.0123	0.5035	0.2549
2004 Tier 2	172	0.0406	0.0169	0.5641	0.3269
2005 Tier 2	190	0.0415	0.0203	0.5651	0.3247
2006 Tier 2	90	0.0408	0.0239	0.5502	0.3107

Table 2.1.-2. FTP HC Emissions Data from California Certified Vehicles (grams per mile)

		75º		50º		
Emission Standard	Sample Size	Mean	Std. Dev.	Mean	Std. Dev.	Ratio of Averages
LEV	53	0.0397	0.0259	0.0988	0.0631	2.49
ULEV	14	0.0162	0.0043	0.0403	0.0176	2.48
LEV2	21	0.0346	0.0097	0.0843	0.0310	2.44

Table 2.1.-3. SwRI FTP (Bag 1 Only) Emissions from Four Tier 2 Vehicles			
Temperature in ºF	75	20	0
Number of Observations	4	8	4
Average THC (gm/mile)	0.115	1.658	3.752
Standard deviation	0.072	0.780	2.117
Ratio to 75 ºF	1	14.446	32.699

MOBILE6.2 currently has engine start emission factors based on 75º emission test data on 1981 and newer vehicles. These engine start emissions are the difference, in grams, between the emissions from phase 1 of the FTP after a 12-hour engine soak and the emissions of the same driving fully warm and without the engine start. Temperature effects on HC emissions are estimated using a multiplier that depends on ambient temperature. This process is described in the MOBILE6.2 documentation.[8] The current engine start adjustments in MOBILE6.2 are not as large for Tier 1 and later vehicles as what is indicated in the certification and SwRI test data. A method of correcting the emission factors was developed using the test data. Those methods are covered in detail in EPA technical report no. EPA420-D-06-001, "Cold Temperature Effects on Vehicle HC Emissions."

Based on our analysis from Tier 1 and newer vehicles, it was decided that additive values would be applied to 75 ºF start emission factors based on temperature and vehicle technology (i.e., Tier 1, NLEV, Tier 2, etc). Additive values can more closely approximate the additional hydrocarbon emissions caused strictly by the start and warm-up of the engine and/or the exhaust aftertreatment at the different temperatures than multiplicative values. These values were obtained from subtracting the FTP emissions at 0, 20, and 50 ºF from the FTP emissions at 75 ºF using the certification and SwRI test data. For emissions at temperature points where data was not available (i.e., 50 ºF for Tier 2 vehicles), linear interpolation between the 0º, 20º and 75 ºF test data was used. All of the difference in emissions is attributed to the increase in engine start emissions. The values used for inputs for start adjustments are found in Table 2.1.-4.

It is not clear what impact this phenomenon has on HC emissions in malfunctioning or deteriorated vehicles. Emissions could go up proportionally to properly operating vehicles or could go up at a lower rate. Properly operating vehicles are very clean due to their emissions technology. Vehicle starts represent a period of operation where the vehicle's emissions equipment is not fully operational and the oxidation of fuel to carbon dioxide and water is not optimal. This situation is similar to the conditions found in a deteriorated or improperly maintained vehicle except that the condition is temporary in a normal vehicle. While MOBILE currently uses a multiplier to account for temperature effects, doing so in the case of Tier 2 high emitting vehicles results in extremely high and unrealistic emission rates. Therefore we have used the MOBILE6.2 estimate of FTP emissions at 20 ºF for model year 2005 high-emitting vehicles in calendar year 2005 to develop the additive factor for all Tier 2 high-emitting vehicles. Those values are found in Table 2.1.-5. We are not changing high-emitting vehicle emission factors for Tier 1 and older vehicles.

Table 2.1.-4. Increase in Engine Start Hydrocarbon Emissions Over the 75 ºF Baseline at Low Temperatures (grams per engine start after a 12 hour soak)

		ºF		
Index	**Description**	**0**	**20**	**50**
1	Tier 0 (not used)	25.96	12.98	3.09
2	Intermediate Tier 1	25.96	12.98	3.09
3	Tier 1	25.96	12.98	3.09
4	Tier 2 (not used)	18.26	9.13	3.27
5	Intermediate Transitional Low Emission Vehicle	21.60	10.80	2.09
6	Transitional Low Emission Vehicle	21.60	10.80	2.09
7	Intermediate Low Emission Vehicle	20.59	10.29	1.30
8	Low Emission Vehicle (LEV)	20.59	10.29	1.30
9	Transitional Ultra Low Emission Vehicle	15.14	7.57	0.87
10	Ultra Low Emission Vehicle (ULEV)	15.14	7.57	0.87
11	Zero Emission Vehicle (ZEV) (not used)	0.00	0.00	0.00
Index	**Tier 2 (All Cars & Trucks) By Model Year**	**0**	**20**	**50**
1	2004	18.26	9.13	3.27
2	2005	18.27	9.13	3.27
3	2006	17.77	8.88	3.27
4	2007	17.77	8.88	3.27
5	2008	17.77	8.88	3.27
6	2009	17.77	8.88	3.27
7	2010	17.77	8.88	3.27
8	2011	17.77	8.88	3.27
9	2012	17.77	8.88	3.27
10	2013	17.77	8.88	3.27
11	2014	17.77	8.88	3.27
12	2015	17.77	8.88	3.27

Table 2.1.-5. Tier 2 High Emitter HC Adjustment Based on 2005 Model Year MOBILE6.2 Results in Calendar Year 2005

Temperature ºF	0	20	50	75
Engine start grams without adjustment	63.335	41.360	21.821	12.813
Additional grams	50.522	28.547	9.008	N/A

The above tables and the new emission standard were used to determine the effects of the cold temperature emission standard on start emission factors. The predicted reductions were applied to Tier 2 vehicles over the phase-in period of the standards. Those values are found in Table 2.1.-6. No reductions beyond those found for normally-emitting Tier 2 vehicles are applied for Tier 2 high-emitting vehicles.

With the appropriate HC start emission temperature adjustment factors, we can provide the necessary emission factors required as inputs to NMIM to project pre-control and control inventories for this rule. With the exception of using RFS fuel, no modification to any other components of NMIM is needed to calculate these inventories. The inventories are presented in Chapter 2.1.2.

Table 2.1.-6. Adjustments to Engine Start Hydrocarbon Emissions
Over the 75 ºF Baseline at Low Temperatures
For MSAT Rule
(grams per engine start after a 12 hour soak)

		ºF			**Phase In Fraction**
Index	**Tier 2 Cars & Light Trucks <6,000 lbs GVWR By Model Year**	**0**	**20**	**50**	
1	2004	18.26	9.13	3.27	0
2	2005	18.27	9.13	3.27	0
3	2006	17.77	8.88	3.27	0
4	2007	17.77	8.88	3.27	0
5	2008	17.77	8.88	3.27	0
6	2009	17.77	8.88	3.27	0
7	2010	6.66	3.3	1.215	0.25
8	2011	6.66	3.3	1.215	0.50
9	2012	6.66	3.3	1.215	0.75
10	2013	6.66	3.3	1.215	1.00
11	2014	6.66	3.3	1.215	1.00
12	2015	6.66	3.3	1.215	1.00
		ºF			**Phase In Fraction**
Index	**Tier 2 Light Trucks >6,000 lbs GVWR By Model Year**	**0**	**20**	**50**	
1	2004	18.26	9.13	3.27	0
2	2005	18.27	9.13	3.27	0
3	2006	17.77	8.88	3.27	0
4	2007	17.77	8.88	3.27	0
5	2008	17.77	8.88	3.27	0
6	2009	17.77	8.88	3.27	0
7	2010	17.77	8.88	3.27	0
8	2011	17.77	8.88	3.27	0
9	2012	11.0	5.5	2.025	0.25
10	2013	11.0	5.5	2.025	0.50
11	2014	11.0	5.5	2.025	0.75
12	2015	11.0	5.5	2.025	1.00

2.1.1.2 Portable Fuel Containers

In 1999, California's Air Resources Board (ARB) proposed a methodology to estimate annual VOC emissions from portable fuel containers (PFCs) within California. Their approach relied on survey data to first estimate the number of PFCs, and then to combine those estimates with results from testing PFCs to develop a statewide annual inventory.

EPA has modified California's approach. We first used our NONROAD2005 emissions model to estimate (for each month of the year and for each state) the quantity of gasoline dispensed from PFCs that was used to fuel nonroad equipment. Then using some of the California survey data on the amount of gasoline stored in each PFC, EPA estimated the number of PFCs in use (each season) with gasoline in each state. These estimated counts of PFCs were similar (but not identical) to the California estimates. EPA also adjusted the California emission estimates to account for daily temperature variations and seasonal RVP variations. (The estimated RVPs for future years include the effects of the Renewable Fuels Standard.) EPA then combined its state-by-state estimates of PFC usage with its adjusted emission rates to obtain seasonal VOC inventory estimates for each state.[9] This analysis does not consider usage of PFCs with diesel or kerosene fuels, as these fuels contribute minimally to evaporation emissions due to the very low volatilities of these fuels.

For each of the 50 states plus the District of Columbia, this EPA approach produced the estimates for calendar year 1990 given in Table 2.1.-7. Assuming no changes (i.e., no controls), each of these estimates will increase by approximately 1.21 percent annually due to the increase in gasoline consumption predicted by the NONROAD model.

Twelve states plus the District of Columbia (California, Connecticut, Delaware, Maine, Maryland, New Hampshire, New Jersey, New York, Ohio, Pennsylvania, Texas, Virginia, and Washington DC) already have or will implement controls on the design of PFCs that will reduce HC emissions. Additionally, three other states (Massachusetts, Rhode Island, and Vermont) are also planning to adopt the California PFC program. Inventories include the impacts of these programs, as described in a technical support document (EPA, 2006, Report No. EPA420-R-07-001).

Additionally, California has begun to adopt more stringent emission standards that will require each PFC to emit (permeation plus evaporation) no more than 0.3 grams of VOC per day for each gallon of capacity. This requirement will be effective July 1, 2007. Assuming that PFCs have a typical life of about five years on average, the "new" versions of the PFCs should replace virtually all of the earlier versions by 2013. As these state programs result in replacing the existing PFCs with lower-emitting PFCs, the estimated national inventory of VOCs associated with PFCs will drop by about 20 percent.

To estimate the VOC emissions from PFCs upon implementation of the final rule, we made the following three changes to our inventory estimates:

1. Since the final rule makes it unlikely for a newly designed PFC to be left in the "open" position, we altered the distribution of the cans (from the California survey) to 100 percent "closed." This change reduced the VOC emissions from both evaporation as well as spillage during transport. (Note, the 15 states plus the District of Columbia that are adopting the California PFC rules already had this change applied. So, this affected the VOC emissions from only PFCs in the other 35 states.)

2. This final rule also produces changes to the design of the individual PFCs that are expected to reduce the spillage by 50 percent when these PFCs are used to refuel individual pieces of equipment. Again, this emission reduction was already included in the base case for those states that are adopting the California rules. Therefore, only the PFCs in the remaining 35 states contributed to our estimated reductions of spillage.

3. Finally, the final rule includes a maximum emission rate of 0.3 grams per gallon per day for the new PFCs. We used this emission standard to estimate the total permeation plus evaporative emissions from each newly designed PFC. Only California has adopted this requirement. Thus, the effect of this final national requirement applies to the remaining 49 states.

The change in VOC emissions was then calculated by subtracting the emissions (on a state-by-state basis) estimated using these preceding three changes from our base estimates. The national estimate was simply the sum of the 50 individual state (plus DC) estimates. The national pre- and post-control inventories are presented in Chapter 2.1.2 below.

2.1.2 Emission Reductions of Criteria Pollutants Resulting From Controls

2.1.2.1 Light-Duty Gasoline Vehicles

We are finalizing as proposed a 20° F FTP emission standard for non-methane hydrocarbon (NMHC) emissions from spark ignition vehicles of 0.3 grams per mile for light-duty vehicles and trucks that weigh 6000 pounds or less and a 0.5 gram per mile standard for vehicles that weigh more than 6000 pounds (including medium-duty passenger vehicles; i.e., “MDPVs”). The standard will be applied to a manufacturer on a sales-weighted fleet-wide basis. Furthermore, the standards will be phased in over a period of time following the schedule found in Table 2.1.-8.

The resulting reductions were modeled based upon the above standard and the phase-in period. This was done as outlined in Section 2.1.1.1 with an external data file provided as input to MOBILE6.2 that altered MOBILE6.2 start emission factors for Tier

2 vehicles only. MOBILE6.2 was then used with NMIM (using fuel properties which reflect RFS, as described in Section 2.1.1) to generate county and nationwide inventories for the control case. When the standard is fully phased in we expect a 60% reduction in start emissions in gasoline-fueled vehicles that have a gross vehicle weight rating (GVWR) of less than or equal to 6000 lbs and a 30% reduction for gasoline-fueled vehicles that have a GVWR greater than 6000 lbs. The impact on future nationwide VOC inventories is found in Table 2.1.-9. Table 2.1.-10 shows the impacts on a state-by-state basis in year 2030.

Table 2.1-7. PFC Emissions (Tons VOC per Year) by Source Type (for 1990)

	Refilling PFC at Pump			Refueling Equipment			
State	**Vapor Displ**	**Spillage**	**Spillage During Transport**	**Vapor Displ**	**Spillage**	**Permeation Plus Evaporation**	**Totals by State**
AK	224.8	15.0	447.1	224.8	1,010.8	4,286.7	6,209.2
AL	24.8	1.9	60.1	24.8	103.2	776.6	991.3
AR	279.1	22.9	647.9	279.1	1,630.1	3,936.1	6,795.1
AZ	105.7	8.5	262.7	105.7	533.4	2,813.4	3,829.4
CA	1,532.1	133.9	3,760.8	1,532.1	9,284.9	19,682.1	35,925.8
CO	202.7	18.9	536.5	202.7	1,319.4	2,137.2	4,417.5
CT	123.2	12.0	342.7	123.2	837.2	1,422.5	2,860.8
DC	36.6	3.1	89.1	36.6	217.9	514.9	898.2
DE	7.6	0.7	25.0	7.6	56.6	235.1	332.7
FL	933.1	72.5	2,055.5	933.1	5,050.7	14,664.5	23,709.5
GA	390.9	32.4	930.8	390.9	2,234.7	5,918.5	9,898.3
HI	58.1	4.0	112.9	58.1	285.3	1,208.2	1,726.6
IA	50.6	4.9	146.3	50.6	316.0	780.1	1,348.5
ID	405.1	36.3	1,058.5	405.1	2,458.1	5,764.9	10,127.9
IL	241.4	19.8	578.2	241.4	1,353.8	3,914.8	6,349.3
IN	99.6	8.3	248.5	99.6	541.9	1,886.4	2,884.3
KS	93.5	8.5	247.9	93.5	567.2	1,457.6	2,468.2
KY	129.1	11.1	340.2	129.1	727.8	2,914.7	4,252.1
LA	168.9	12.1	370.7	168.9	771.4	5,178.9	6,670.9
MA	40.7	4.3	130.7	40.7	297.7	620.4	1,134.5
MD	226.0	21.1	597.8	226.0	1,520.6	2,528.1	5,119.6
ME	199.0	19.1	556.1	199.0	1,322.3	2,561.3	4,856.7
MI	316.9	29.6	886.3	316.9	1,966.1	5,253.7	8,769.4
MN	181.4	15.5	463.1	181.4	992.3	3,281.1	5,114.9
MO	97.0	7.4	230.6	97.0	476.0	2,997.4	3,905.5
MS	212.6	19.0	560.9	212.6	1,271.6	3,427.2	5,704.1
MT	26.4	2.6	81.9	26.4	160.5	506.1	803.9
NC	55.0	5.2	154.0	55.0	336.4	911.4	1,516.8
ND	123.4	10.6	295.8	123.4	759.6	1,362.6	2,675.3
NE	44.1	4.5	131.0	44.1	299.6	572.4	1,095.5
NH	332.9	30.0	857.4	332.9	2,041.2	4,049.9	7,644.2
NJ	58.0	5.2	155.6	58.0	358.7	1,050.8	1,686.2
NM	517.1	47.5	1,414.3	517.1	3,095.2	8,473.6	14,064.8
NV	407.9	31.5	911.8	407.9	2,179.0	6,950.0	10,888.3
NY	17.2	1.8	54.1	17.2	103.9	302.1	496.2
OH	507.3	41.1	1,188.5	507.3	2,843.0	7,500.9	12,588.0
OK	139.6	12.1	352.5	139.6	824.4	2,322.6	3,790.6
OR	133.8	12.8	373.6	133.8	864.5	1,889.7	3,408.1
PA	419.5	38.5	1,132.0	419.5	2,644.5	6,498.5	11,152.6
RI	28.3	2.7	80.8	28.3	188.9	422.5	751.5
SC	207.8	15.1	438.3	207.8	1,066.9	3,981.0	5,916.9
SD	20.9	2.0	62.1	20.9	124.8	398.1	628.9
TN	237.0	18.6	553.4	237.0	1,245.3	4,944.1	7,235.5
TX	875.0	67.6	1,954.5	875.0	4,645.6	15,730.9	24,148.7
UT	70.8	6.7	201.4	70.8	418.4	1,208.1	1,976.3
VA	18.7	1.9	57.6	18.7	127.6	296.3	520.9
VT	309.8	27.6	786.6	309.8	1,986.7	3,853.6	7,274.1
WA	225.6	20.5	595.1	225.6	1,399.7	3,174.0	5,640.6
WI	65.4	5.4	170.6	65.4	345.8	1,700.5	2,353.1
WV	166.3	16.4	488.5	166.3	1,089.3	2,512.5	4,439.2
WY	14.8	1.5	48.1	14.8	92.7	265.7	437.7
50-State	11,403.3	972.1	28,226.3	11,403.3	66,389.1	181,040.0	299,434.1

Table 2.1.-8. Phase-in Schedule for 20°F Standard by Model Year

Vehicle GVWR (Category)	2010	2011	2012	2013	2014	2015
≤ 6000 lbs (LDV/LLDT)	25%	50%	75%	100%		
> 6000lbs HLDT (and MDPV)			25%	50%	75%	100%

Table 2.1.-9. Impact on Nationwide VOC Emissions from Light Duty Vehicles and Trucks of a 20 ºF FTP Emission Standard for Non-Methane Hydrocarbons.

Year	Tons Without Standard	Tons With Standard	Reduction
1999	4,899,891	N. A.	N.A.
2010	2,990,760	2,839,012	151,748
2015	2,614,987	2,293,703	321,284
2020	2,538,664	2,009,301	529,363
2030	2,878,836	1,996,074	882,762

Table 2.1.-10. Impacts on State Light Duty Vehicle and Truck VOC Emissions of 20 ºF FTP Emission Standard for Non-Methane Hydrocarbons in 2030.

State	Reference Case Tons	Control Case Tons	Reduction in Tons [(a)]	Percent Reduction
AL	52,985	41,636	11,349	21
AK	11,605	6,299	5,306	46
AZ	50,655	39,988	10,667	21
AR	30,893	23,185	7,708	25
CA	259,253	185,702	73,551	28
CO	61,855	40,187	21,667	35
CT	28,766	17,706	11,059	38
DE	7,213	4,639	2,574	36
DC	3,229	2,146	1,082	34
FL	123,002	110,498	12,504	10
GA	100,284	75,270	25,014	25
HI	7,835	7,626	209	3
ID	21,439	13,588	7,851	37
IL	107,467	67,221	40,245	37
IN	85,144	57,529	27,615	32
IA	38,982	25,254	13,729	35
KS	31,740	22,190	9,550	30
KY	48,011	32,867	15,144	32
LA	36,806	30,134	6,672	18
ME	16,942	10,247	6,695	40
MD	45,754	29,230	16,525	36
MA	44,407	25,717	18,690	42
MI	133,830	86,171	47,659	36
MN	86,476	51,148	35,328	41
MS	25,290	19,642	5,648	22
MO	71,439	49,467	21,972	31
MT	16,326	10,015	6,311	39
NE	22,897	15,077	7,819	34
NV	28,102	20,771	7,330	26
NH	15,434	9,413	6,022	39
NJ	54,869	35,834	19,035	35
NM	31,625	22,152	9,473	30
NY	112,589	67,387	45,202	40
NC	94,614	69,429	25,185	27
ND	11,222	6,752	4,470	40
OH	115,095	73,824	41,271	36
OK	46,290	34,712	11,578	25
OR	66,957	46,226	20,731	31
PA	105,046	67,864	37,183	35
RI	9,036	5,641	3,395	38
SC	47,950	36,058	11,892	25
SD	11,920	7,443	4,476	38
TN	70,526	51,999	18,528	26
TX	159,952	126,799	33,154	21
UT	36,024	24,050	11,974	33
VT	9,873	5,906	3,967	40
VI	80,579	53,729	26,850	33
WA	108,386	74,481	33,905	31
WV	16,993	10,833	6,160	36
WI	64,663	37,816	26,847	42
WY	10,566	6,574	3,992	38

(a) Values calculated prior to rounding reference and control values.

Test data show that the controls on cold temperature hydrocarbon emissions will have the ancillary benefit of reducing PM emissions as well. Emissions generated during cold temperature starts tend to be elevated due to a combination of a cold catalyst and excess fuel in the combustion chamber. These factors increase emissions of benzene and other hydrocarbons, and at the same time allow for unburned or pyrolized fuel to be emitted.

A number of source apportionment studies have indicated previously that emissions from vehicles starting at cold temperatures contribute disproportionately to ambient $PM_{2.5}$. For instance, the Northern Front Range Air Quality study conducted in the Denver, CO area during the winter of 1997 estimated that, on average, 12% of ambient $PM_{2.5}$ could be attributed to cold start light-duty gasoline vehicle emissions.[10]

At this point, the PM emission factors in MOBILE6.2 for PM from light-duty gasoline vehicles are not sensitive to temperatures. However, as outlined above, the emission factors for hydrocarbons and gaseous toxics are temperature-dependent.

In order to estimate the expected emission reductions in PM as a result of the cold temperature standards, we evaluated the relationship between PM and NMHC in Tier 2 vehicles operating at different temperatures. All emissions benefits of the cold temperature standard are expected to affect only the cold temperature starting emissions. As such, all analyses were restricted to Bag 1. However, similar results were obtained when using full weighted FTP results.

First, data from the only extant testing program of Tier 2 vehicles at multiple temperatures was obtained from Southwest Research Institute.[11] Figure 2.1.-1 shows the PM emission factors as a function of temperature. Like NMHC, PM emission factors increase exponentially with lower temperatures through the entire range of testing.

Figure 2.1.-1. FTP Bag 1 PM Emissions vs. Temperature, Tier 2 Vehicles

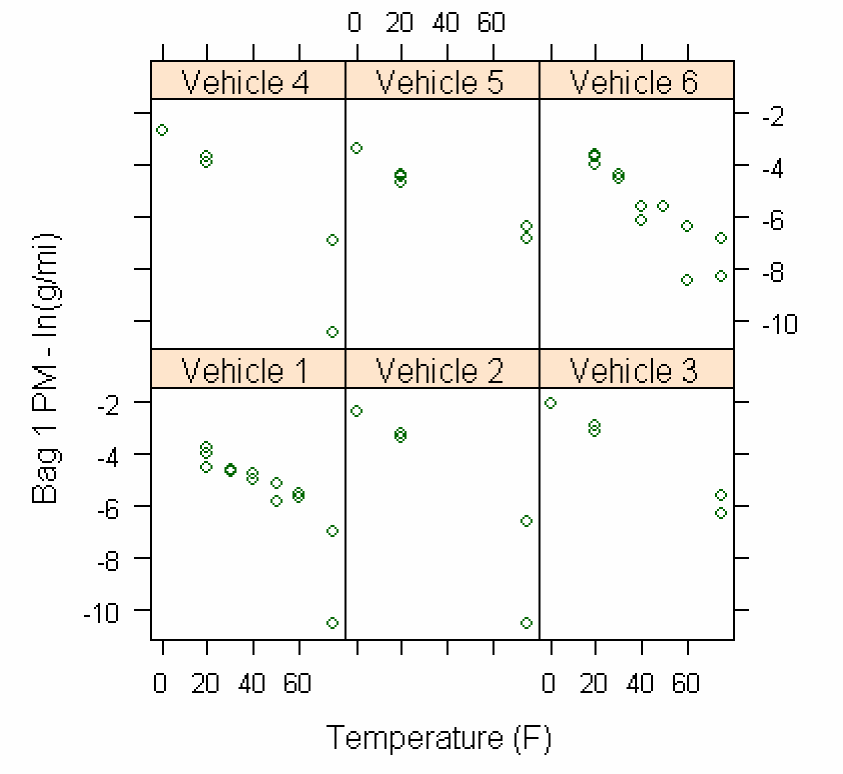
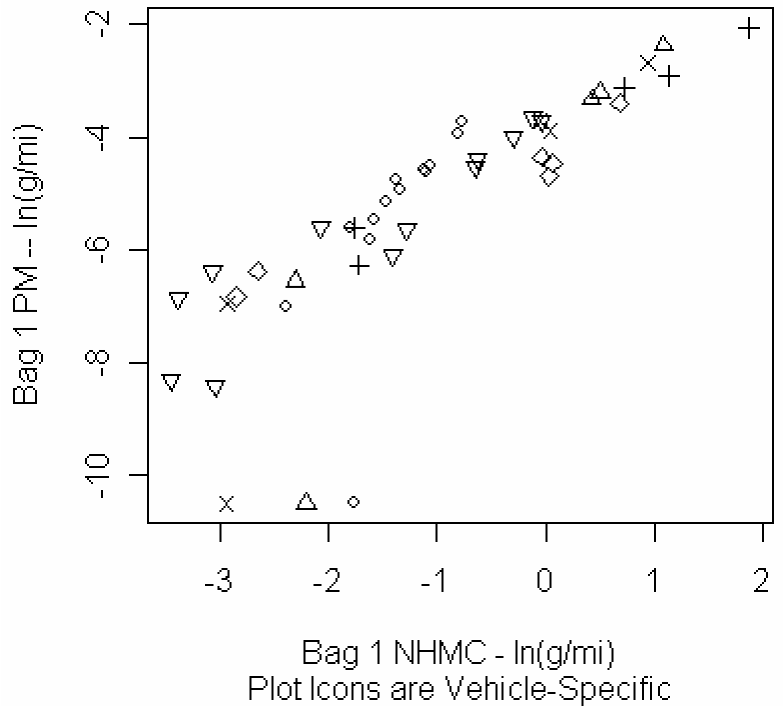


Figure 2.1.-2 illustrates the relationship between FTP Bag 1 NMHC and PM emission factors in this test program. Lower temperature tests are found to the upper right corner, corresponding to elevated emissions of both NMHC and PM. The symbol used for each data point represents the different vehicles in the test program. As shown, there is a clear, linear association. Thus, we concluded that estimated reductions in PM as a result of the hydrocarbon emission controls in this rule could be estimated by applying a PM to NMHC ratio to the estimated reduction in NMHC.

Figure 2.1.-2. FTP Bag 1 PM and FTP Bag 1 NMHC for Various Tier 2 Vehicles



In order to determine an appropriate PM/NMHC ratio for calculating PM reductions from NMHC reductions during cold start conditions, we employed mixed models with random vehicle terms.[12] We fit several models to the data, treating the PM/NMHC ratio as a dependent variable. In summary, the model fit to the data was:

$$\mathbf{Y} = \mu + \tau + \mathbf{b} + \mathbf{e}$$

Here, **Y** is a matrix of dependent variables (emission factors);
μ is the intercept term or "grand mean";
b is the change in emission factor associated with discrete testing temperatures;
τ is the vehicle effect, normally distributed around zero;
e is the random error term (normally distributed).

Tests in which temperature was treated as a continuous variable were also employed. Overall, the **b** term was found to be significant only at 75° testing, and this may have been due to random measurement errors in the PM/NMHC ratio as a result of very low emissions at 75°. The **b** term became insignificant when it was allowed to vary randomly by vehicle. In addition, because the standards apply only to cold starting conditions, the effect on the ratio at 75° is not relevant to changes in overall emissions. Therefore, we used the mean PM/NMHC ratio of 0.022 to calculate the expected ancillary reductions in PM. The 95% confidence interval for the mean was 0.020 – 0.024.

Using this number, the expected reductions in PM from this rule are estimated to be 7,068 tons in 2015, 11,646 tons in 2020 and 19,421 tons in 2030. These calculations provide initial evidence that the potential public health impacts of this final rule are substantial.

In subsequent test programs demonstrating the feasibility of the NMHC standards in this final rule, the test vehicles exhibited substantial reductions in PM emissions as well. The test results from the two feasibility vehicles fall within the range of those derived from the SwRI test program. These PM emission reductions at 20º F were of similar magnitude as those predicted by the above calculation. Furthermore, examining the feasibility demonstration results, the PM/NMHC ratio of the emission reductions were both close to the value of 0.022 used in the above calculation, spanning either side of the original number (0.010-0.025).[A] In the first feasibility test program, the vehicle reflected a unique control technology that requires careful coordination among the engine air-fuel ratio and secondary air injection timing and air volume to provide the maximum emission benefits. That feasibility program was a "proof of concept" study that did not have the ability to fully explore ideal control coordination and sizing of the emission control system. In the second feasibility study, the vehicle only received recalibration to achieve emission reductions, which is likely to be more representative of the emission control technologies that will be employed for the majority of vehicles. Despite different technologies being used in the feasibility tests, the six current unmodified production vehicles tested in the SwRI test program are considered to be more representative of emission control technologies found throughout the fleet.

Several factors are not accounted for in the emission reduction estimation procedures, which adds uncertainty to the level of emission reductions reported here. First, if manufacturers employ control technologies that differ substantially from those in the two feasibility test programs, actual emission reductions could differ from the estimates here. Second, actual PM reductions may be affected by the extent to which different vehicle or engine technologies penetrate into the vehicle market (such as hybrid electric drivetrains and direct injection gasoline engines).

2.1.2.2 Portable Fuel Containers

The PFC controls in this final rule will also reduce emissions of hydrocarbons. As noted in Section 2.1.1.2, fifteen states plus the District of Columbia have adopted controls on PFCs independent of the controls being finalized in this rule. In Figure 2.1.-3, we have graphed the estimated annual national VOC emissions (in tons) associated with PFCs for the following three scenarios:

-- a base scenario in which no PFC controls are used illustrated with the dotted (black) line,

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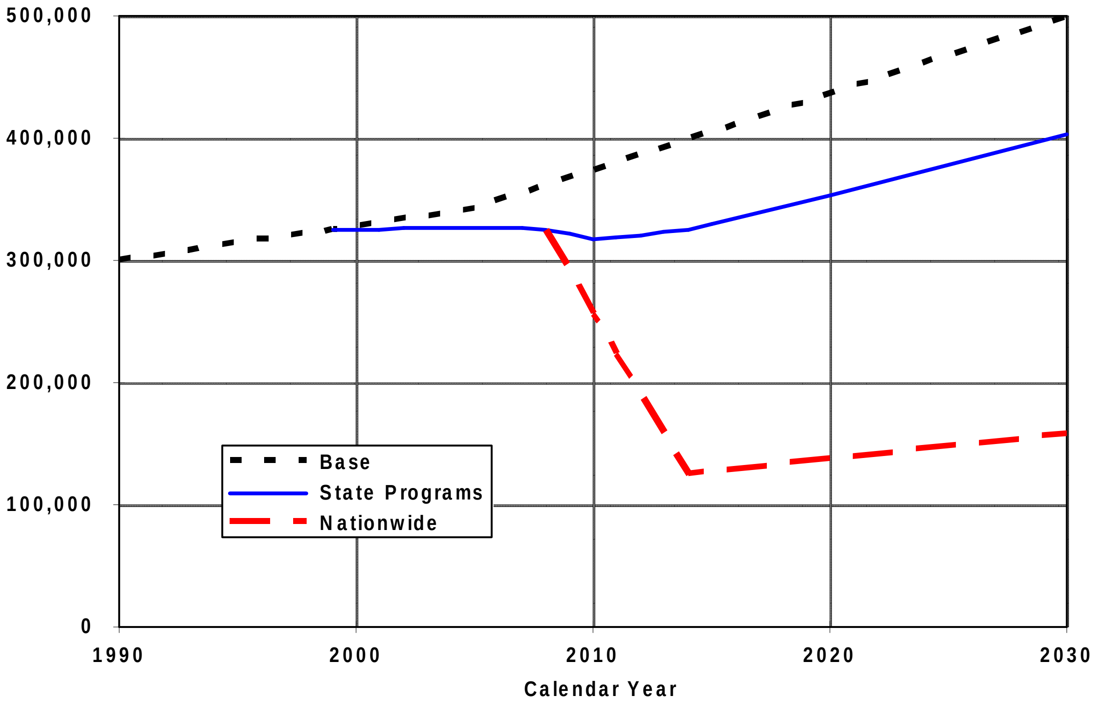
[A] This range derives from the feasibility tests with the lowest measured NMHC emissions.

-- a scenario in which only those 15 states plus DC have implemented PFC controls illustrated with the solid (blue) line, and

-- a scenario in which the PFC controls are implemented nationwide illustrated with the dashed (red) line

Figure 2.1-3. Comparison of PFC Control Scenarios
Annual Nationwide VOC Emissions (Tons) from PFCs by Calendar Year



As noted in Section 2.1.1.2, the estimates of the VOC inventory in the basic scenario are increasing (annually) at a rate of about 1.21 percent. The scenario containing just the state programs has the estimated VOC inventory increasing at an annual rate of about 1.33 percent once all of the programs are phased in. Similarly, the scenario in which nationwide requirements (of this RIA) are phased in exhibit an annual increase in the VOC inventory of about 1.44 percent after phase-in.

Table 2.1.-11 compares the estimated national (annual) inventory of PFC-related VOC with the control program to a reference case scenario that includes only State level controls.

Table 2.1.-11. Nationwide Annual PFC VOC Emissions (tons)

Calendar Year	With NO EPA PFC Controls	With EPA PFC Controls	Reduction
1999	325,030	NA	NA
2007	327,320	NA	NA
2010	316,756	256,175	60,580
2015	329,504	127,157	202,347
2020	353,470	137,175	216,294
2030	402,916	157,661	245,255

2.1.3 Strengths and Limitations of Criteria Pollutant Inventories

As previously discussed, the MSAT final rule inventories were estimated using fuel properties developed for the RFS proposed rule. Because the RFS and MSAT inventories were developed in relatively close proximity, we highlight in this section some minor differences in methodologies, as well as uncertainties related to the RFS fuel. Though these methodologies contribute to different baseline RFS and MSAT inventories, they have little impact on our estimates of emission reduction benefits associated with this MSAT final rule.

Future Volume of Renewable Fuel – Under the RFS mandate, a minimum volume of ethanol must be blended in gasoline. However, the Energy Information Agency (EIA) has forecasted that market forces alone will push ethanol use well beyond the minimum volume required by the RFS mandate[13]. The volume of renewable fuel forecasted by EIA, and not the RFS program mandate, was used as the baseline for developing RFS fuel properties used in MSAT inventories. Though there are uncertainties related to the future volume of renewable fuel use (and regional allocation), the effects on the emission reduction benefits achieved by the MSAT final rule are likely minimal. Furthermore, as presented in the RFS Draft RIA (DRIA)[2], inventories for criteria pollutants never differ by more than a few percent between the RFS mandate volume scenario (7.2 billion gallons of national ethanol use) and the EIA-predicted scenario (9.6 billion gallons of national ethanol use).

Ethanol Effects on Gasoline Properties – The MSAT rule inventories are based on fuel properties estimated under the RFS program. In the RFS draft regulatory impact analysis, we based our assessment of the effects of ethanol on gasoline fuel properties on annual fuel survey data provided by the Alliance of Automobile Manufacturers. We limited the analysis to cities for which data from both ethanol-blend and non-ethanol gasoline samples were available. These criteria reduced the data to samples from four cities, limiting the national geographic representation of the fuel effects. In addition, there was no distinction to indicate whether the fuel came from multiple refineries within any given city, which eliminates refinery-specific effects. However, we checked the results against the AAM data from all U.S. cities, comparing all conventional gasoline non-ethanol blends to all conventional gasoline ethanol blends. The results were very similar to those from the four cities.

Seasonal and Permeation Effects– For MSAT inventories, we interpolated summer and winter fuel properties to all 12 months and ran each month in NMIM individually. Due to time constraints during development of RFS proposal inventories, we ran NMIM for only January and July, using fuel survey data collected in summer and winter, and assumed that emissions for those two months could be extrapolated to represent the entire year. We estimated RFS annual emissions inventories by summing the two monthly inventories and multiplying by six. For RFS, we also added the effect of ethanol on permeation from onroad non-exhaust emissions. Again, these different methodologies have minimal effect on the emissions benefits associated with this final rule.

Light-Duty Gasoline Vehicles – Emission factors for hydrocarbons in the MOBILE model are based on tens of thousands of tests under a wide variety of conditions, and account for leaking fuel systems, aggressive driving, air conditioner use and a variety of other parameters. These data are supported by over 50 technical reports, and many of them received extensive scientific peer review. The strengths and limitations of the MOBILE model have been evaluated by the Coordinating Research Council and the National Research Council.[14,15]

There are significant uncertainties in emission inventories resulting from the use of national default data rather than local inputs, as well as “top-down” allocation schemes in estimating toxic emissions. Examples include use of national default vehicle registration distributions, default average speed distributions, and use of county level population data to allocate State or urban level VMT. Furthermore, emission rates were modeled for only a subset of the total number of counties. Therefore, we do not fully capture all local conditions, introducing additional uncertainty into the inventories.

Also, it should be noted that there are greater uncertainties in projection year estimates. Estimates of emissions from advanced technology vehicles and engines that will comply with planned future emission standards include assumptions regarding levels of emission deterioration and performance under various conditions. Also, vehicle miles traveled are estimated using economic projections with similar inherent limitations.

The revised estimates of cold start VOC emissions are based on a robust dataset at temperatures of 20ºF and above. At lower temperatures, however, data are more limited and the magnitude of cold temperature effects is not as certain. Similarly, the estimate of PM reductions from NMHC cold temperature controls are based on limited data, although PM shows a very strong correlation with NMHC. Future control strategies may also employ mechanisms that result in different PM/NMHC ratios than found in existing vehicles.

Finally, the MSAT inventories used the fuel effects contained in MOBILE6.2. In the RFS proposal, we accounted for uncertainties in MOBILE6.2 fuel effects by adjusting the model output for exhaust VOC and NOx emissions by applying EPA Predictive Model fuel effects instead. The MSAT inventories do not use the Predictive Model effects since the use of the Predictive Model would have little impact on estimates of emission benefits of this rule.

Portable Fuel Containers – To estimate PFC inventories we were able to build on survey and test data collected by the California Air Resources Board. We also developed inventories using a "bottom-up" approach which provides flexibility and permits very detailed fine-tuning of the various scenarios. However, the inventory involved many assumptions, including refueling activity and temperature effects. Spillage occurring when non-road equipment is refueled is a significant source of VOC emissions. We are assuming (from EPA's NONROAD model) that spillage is a constant 17 grams for each refueling event. We are also assuming that each refueling event occurs when the fuel tank on that piece of equipment is empty. However, if the user "tops off" the fuel tank prior to each use, then we are underestimating the total VOC emissions.

Another assumption relates to whether inactive PFCs are stored with fuel. For example, we assumed that a residence that uses a PFC to only fuel a lawn mower (perhaps six months of the year) will have that PFC empty the remainder of the year (i.e., no permeation or evaporative emissions). However, if that PFC were to contain a small amount of gasoline for those non-mowing months, then we are underestimating the total inventory.

Uncertainty in the characterization of the population of PFCs (i.e., commercial versus residential usage, open versus closed, metal versus plastic) is the major source of uncertainty in our estimates of the inventory of VOCs from PFCs. Our characterization of the population of PFCs is based on surveys performed by the Air Resources Board (ARB) of California. We used the same distribution of open versus closed PFCs determined by ARB. Since the PFC population in the rest of the country might not be exactly like California's, we performed a sensitivity analysis to determine the effects of varying that distribution. We found that even relatively large changes in that distribution produced changes in estimated total VOC of less than 13 percent.[16] Other source of uncertainty include estimates of the frequency of refilling of containers, estimates of effects of ambient temperature on vapor displacement and spillage, estimates of effects of RVP on vapor displacement, impacts of temperature of the fuel itself on emissions, and estimates of the amount of spillage during refilling.

2.2 Air Toxics

2.2.1 Emission Inventories Used in Air Quality Modeling

The data and methods employed to develop the county-level air toxics inventories used for air quality, exposure and risk modeling to support this final rule are discussed in detail in the EPA Technical Report, "National Scale Modeling of Air Toxics for the Final Mobile Source Air Toxics Rule; Technical Support Document," Report Number EPA-454/R-07-002. All underlying data and summary statistics are included in the docket for this rule. Major revisions have been made to the inventories used for air quality, exposure, and risk modeling since proposal. These revisions include:

- Revisions to cold temperature start emissions for gaseous air toxics in Tier 1 and later highway gasoline vehicles
- Estimation of air toxic emissions for nonroad equipment using NMIM2005 rather than NMIM2004
- Inclusion of air toxic emissions from portable fuel containers
- Revision of the benzene and naphthalene inventories for gasoline distribution based on recent analysis of benzene in gasoline vapor emitted during the distribution process

While cold temperature emissions and portable fuel container emissions were included in analyses of emission benefits and cost-effectiveness for the proposal, the proposal did not use NMIM2005 for nonroad equipment or include changes to the gasoline distribution emissions estimates based on recent analyses. While the air quality modeling inventories for the final rule included the above improvements, it did not include impacts of the renewable fuel standard, as the inventories were developed well in advance of the proposal for that standard. Furthermore, the modeling accounted only for the 0.62 percent standard, but not the 1.3 vol% maximum average. Thus, the emission reductions from highway vehicles and other sources attributable to the fuel benzene standard are underestimated in many areas of the country, particularly in areas where fuel benzene levels were highest without control, such as the Northwest. It should be noted that the inventories used in the proposal were presented in a peer reviewed journal article.[17]

The following sections summarize the methods used to develop the air quality modeling inventories, including details of the major revisions listed above, and also present inventory results. While air quality, exposure, and risk modeling was done for years 1999, 2015, 2020, and 2030 (with modeling for 1999 done as the National Scale Air Toxics Assessment), reference case inventories were also developed for 2010 in order to better assess emission trends over time. Control case modeling which included cumulative impacts of the controls being finalized in this rule was done for 2015, 2020 and 2030. For the reference case, we modeled all air toxic compounds listed in section 112 of the Clean Air Act for which we had adequate data to estimate emissions. Table 2.2.-1 lists the pollutants included in these inventories which were used in subsequent modeling of air quality, exposure, and risk. For the control case, we modeled a smaller subset of pollutants as discussed below. Emission inventories included stationary sources, highway vehicles, and nonroad equipment.

2.2.1.1 Methods Used to Develop Air Toxics Inventories for Air Quality Modeling

2.2.1.1.1 Highway Vehicles

Highway gasoline vehicle inventories for all emission types except refueling were developed using a modified version of NMIM2005.[18, 19, 20] NMIM develops inventories using EPA's MOBILE6.2 emission factor model for highway vehicles, EPA's

NONROAD emissions inventory model for nonroad equipment, and model inputs stored in data files. Model inputs include data such as temperatures, fuel properties, vehicle registration distributions, inspection and maintenance programs, vehicle miles traveled, and toxics inputs in the form of toxic to volatile organic compound (VOC) ratios, toxic to particulate matter (PM) ratios, or toxic emission factors. The toxics inputs were developed from a variety of emissions testing programs conducted by EPA, States, and industry over many years (see Section 2.2.1.1.6 for more information). Details on data sources can be found in the documentation for the National Emissions Inventory. Refueling emission estimates for 2015 and later years were carried over from the inventories used for air quality modeling in the proposal. For 1999 and 2010, benzene refueling emission estimates were not available, so benzene refueling emissions were backcast from 2015, using ratios of VOC refueling emissions in 1999 or 2010 to 2015 VOC. The approach used to do this is discussed in detail in the technical support document.

NMIM was modified to include the hydrocarbon start emission adjustment factors discussed in Section 2.1.1.1. Since the algorithms used to calculate toxic to hydrocarbon emission ratios in MOBILE6.2 do not vary with temperature, reductions in hydrocarbon emissions result in proportional reductions in air toxic emissions.

The assumption in MOBILE6.2 that reductions in air toxic emissions are proportional to hydrocarbon emission reductions was based on testing done at temperatures ranging from -20 to 75 ºF in EPA's Office of Research and Development in the late 1980's.[21, 22] These studies found that, overall, the composition of hydrocarbon emissions did not vary appreciably with temperature, although fractions of formaldehyde increased somewhat with lower temperature in port fuel injected vehicles. The validity of the assumption was re-evaluated for later model vehicles.

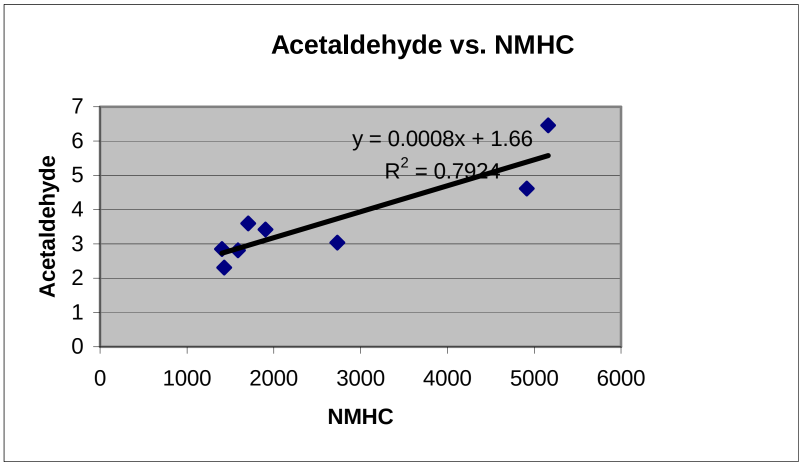
EPA's Office of Research and Development recently tested several late model vehicles at the same temperature ranges cited above.[23,24,25] These results can be used to reevaluate the validity of the assumption discussed above. The results of the test program are unpublished, but are included in the docket for the rule. Vehicles included in the test program were a 1993 Chevrolet Cavalier, a 1987 and 1993 Ford Taurus, a 1996 Chrysler Concord, a 2001 Ford Focus, a 1993 Buick Regal, and a 2001 Dodge Intrepid. This test program found increasing emissions of individual air toxics at lower temperatures. Benzene and 1,3-butadiene emissions increased proportionally with hydrocarbon emissions, with a very strong correlation. However, correlations were not as strong with aldehydes. Results from the 1993 Cavalier and 1993 Taurus found a statistically significant correlation for acetaldehyde but not for formaldehyde, whereas analysis of data from the other vehicles found a correlation for formaldehyde but not acetaldehyde.

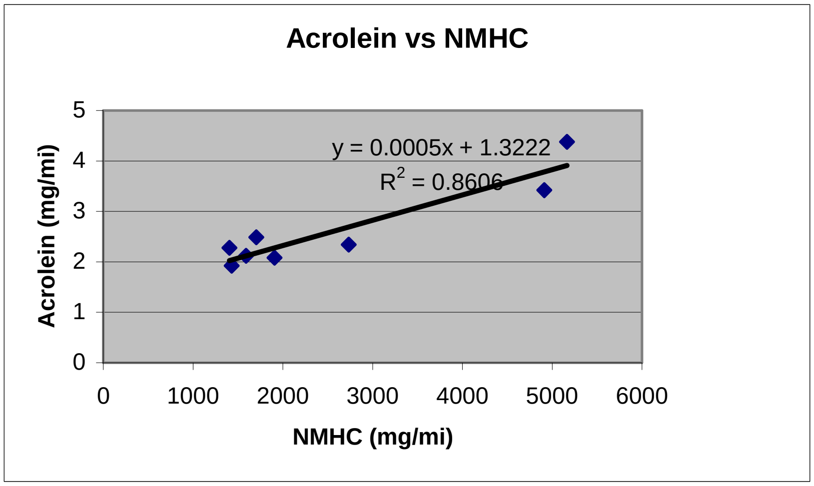
A major vehicle manufacturer also recently tested two Tier 2 compliant vehicles at 75 and 20 ºF. Although the data are confidential, they show emission of air toxics increase at the same rate as hydrocarbons, with a very high correlation.

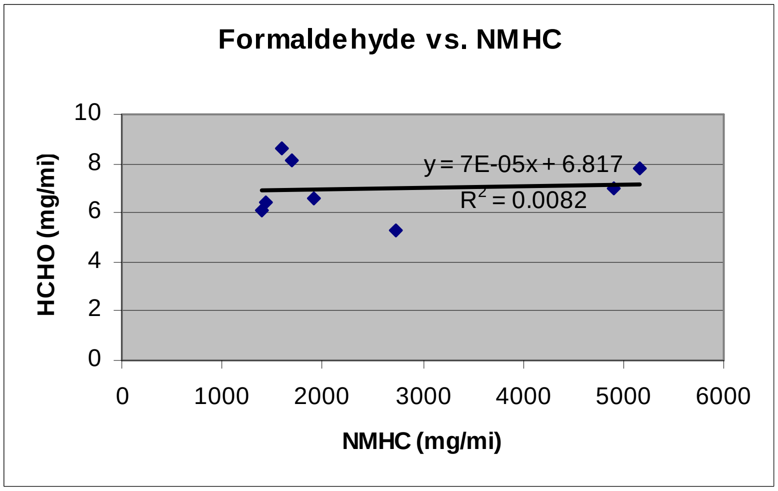
A third source of data is testing done by Southwest Research Institute for EPA on four model year 2005 vehicles – a Ford F-150, a Mazda 3, a Honda Odyssey and a Chevrolet Equinox.[26] The four vehicles were tested at 0, 20 and 75 ºF. Benzene and 1,3-butadiene correlated very strongly with hydrocarbon emissions, with r-square values above 0.9. Benzene accounted for about 3.6 percent of exhaust non-methane hydrocarbon emissions at all temperatures, while 1,3-butadiene accounted for about 0.3%. However, formaldehyde and acetaldehyde fractions appeared to decrease with decreasing temperature. When data for the largest vehicle, the Ford F-150, were removed, there seemed to be a stronger correlation between aldehyde emissions and non-methane hydrocarbons. This could be because this larger engine is running richer during cold starts than the other vehicles, and not enough oxygen is available for aldehyde formation.

Recent EPA testing of a Chevrolet Trailblazer, with its engine recalibrated to meet the cold temperature standard, showed reductions in acetaldehyde and acrolein proportional to the reduction in VOC. Formaldehyde was also reduced, but was not reduced as much as acetaldehyde and acrolein. Other air toxic compounds, including benzene, were not included in this testing. Figure 2.2.-1 depicts the relationship between carbonyl compounds and NMHC.

Figure 2.2.-1. Regressions of Carbonyl Emissions Versus NMHC for Chevrolet Trailblazer Recalibrated to Meet Cold Temperature Standard.







Given available data, we have concluded it is reasonable to retain the assumption that ratios of toxic emissions to hydrocarbon emission do not vary with temperature. However, as more data become available, this assumption should be reevaluated, particularly for aldehydes.

Within the MOBILE6.2 model, six MSATs (benzene, formaldehyde, acetaldehyde, 1,3 butadiene, acrolein, and methyl tertiary butyl ether [MTBE]) can be calculated directly by including detailed fuel parameters. These parameters are stored in the NMIM database. The fuel parameters are: sulfur content, olefins content, aromatics content, benzene content, E200 value, E300 value, oxygenate content by type, and oxygenate sales fraction by type.[B] Since these fuel parameters are area-specific, EPA developed county-level inputs for each of these parameters. Fuel parameters were collected for winter and summer seasons using a number of different data sources. These sources include the Alliance of Automobile Manufacturers, Northrop Grumman Mission Systems (formerly TRW Petroleum Technologies), and EPA reformulated gasoline

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[B] E200 and E300, represent the percentage of vapor that gasoline produces at 200 and 300 ºF, respectively.

surveys. Documentation for the National Emissions Inventory (NEI)[27] describes the development of the fuel parameter database used with MOBILE6.2 in detail. The fuel parameter data through 1999 are posted at the following website:

ftp://ftp.epa.gov/EmisInventory/finalnei99ver3/haps/datafiles/onroad/auxiliary/

Although fuel parameter data were prepared for only two seasons (summer and winter), NMIM uses monthly rather than seasonal fuel parameters, and parameters for spring and fall months are estimated by interpolating from summer and winter data. In addition, documentation of the fuel parameters used in NMIM was compiled in 2003 (Eastern Research Group, 2003), and subsequently, a number of changes were made, based on comments from States. These changes are documented in the change log for NMIM, dated May 14, 2004. This change log is included in the docket for this rule, along with the original documentation. In general, multiplicative adjustment factors were used to calculate future year gasoline parameters (i.e., future year parameter = base year parameter x adjustment factor). However, additive adjustment factors were used to calculate future year parameters for E200, E300, and oxygenate market shares (i.e., future year parameter = base year parameter + adjustment factor). These adjustment factors were developed using results of several refinery modeling analyses conducted to assess impacts of fuel control programs on fuel properties.[28, 29, 30] The database used for this assessment assumes no Federal ban on MTBE, but does include State bans. Also, it did not account for recent increases in the use of ethanol oxygenated gasoline, the renewable fuels mandate in the recent Energy Policy Act, or the 1.3 vol% maximum average fuel benzene level.

MOBILE6.2 also has a command (ADDITIONAL HAPS) which allows the user to enter emission factors or air toxic ratios for additional air toxic pollutants. Emission factors for the other HAPs in Table 2.2.-1 were calculated by MOBILE6.2 through the use of external data stored in the NMIM database, specifying emission factors for these pollutants in one of three ways: as fractions of volatile organic compounds (VOC), fractions of PM, or by supplying the basic emission factors. The ratios used with this command must be expressed as milligrams of HAP per gram of VOC or PM. Gaseous hydrocarbons were estimated as fractions of VOC. Polycyclic aromatics hydrocarbons (PAHs) were calculated as fractions of PM, although the data used to calculate mass ratios included both gas and particle phase PAH emissions. Metals were estimated using basic emission factors. Evaporative emissions (e.g., toluene, xylenes) can only be estimated as fractions of VOC. Because toxic to VOC ratios for several gaseous HAPs vary between baseline (i.e., non-oxygenated) gasoline and gasoline oxygenated with MTBE or ethanol, separate ADDITIONAL HAPS input data were developed for: 1) baseline gasoline; 2) gasoline oxygenated with 2% MTBE by weight (e.g., Federal reformulated gasoline); 3) gasoline oxygenated with 2.7% MTBE by weight (e.g., winter oxygenated gasoline); and 4) gasoline oxygenated with 3.5% ethanol by weight (gasohol).

Table 2.2.-1. Air Toxics Included in Emission Inventories and Used for Air Quality, Exposure, and Risk Modeling.

1,3-Butadiene	Ethyl Benzene
2,2,4-Trimethylpentane	Fluoranthene
Acenaphthene	Fluorene
Acenaphthylene	Formaldehyde
Acetaldehyde	n-Hexane
Acrolein	Indeno(1,2,3,c,d)-pyrene
Anthracene	Manganese
Benzene	Methyl tert-butyl ether (MTBE)
Benz(a)anthracene	Naphthalene
Benzo(a)pyrene	Nickel
Benzo(b)fluoranthene	Phenanthrene
Benzo(g,h,i)perylene	Propionaldehyde
Benzo(k)fluoranthene	Pyrene
Chromium	Styrene
Chrysene	Toluene
Dibenzo(a,h)anthracene	Xylenes

Vehicle miles traveled used in this assessment were those developed for the Clean Air Interstate Air Quality Rule (CAIR).[31]

For years 2015, 2020, and 2030, inventories were developed that reflected the cumulative impacts of the controls being finalized in this rule. These control case inventories included all the pollutants in Table 2.2-1.

To develop these inventories, NMIM was rerun with revised gasoline fuel parameter inputs for fuel benzene and aromatics levels, as well as estimated emission reductions from new start emission standards for hydrocarbons. The fuel parameter inputs were revised based on refinery modeling done for the proposed rule, rather than the final rule refinery modeling discussed in Chapter 6 of the this document. As part of the refinery modeling, average fuel properties under a 0.62% fuel benzene standard, with no maximum average level, were estimated for each Petroleum Administration for Defense District (PADD). Average fuel benzene levels for conventional gasoline and reformulated gasoline in each PADD before and after implementation of the standards were used to develop multiplicative factors which were applied to the reference case fuel benzene levels for each county in the NMIM database. These multiplicative factors are summarized in Table 2.2.-2. Although California is part of PADD5, it was treated separately, since California has its own reformulated gasoline program. Table 2.2.-3 compares average fuel benzene levels for each PADD used in the air quality modeling inventories, compared to levels predicted by refinery modeling for the final rule, which assumes a 1.3 vol% maximum average. If the refinery modeling data had been available to be used in the air quality modeling inventories, benzene emission reductions from the fuel standard would have been significantly greater in PADDs 2 and 5, but slightly lower in PADDs 1 and 3.

The refinery modeling also indicated that the reduction in fuel benzene levels would result in small proportional decreases in aromatics levels as well.[32] Thus aromatics levels were adjusted using the additive factors calculated as follows:

$$\text{Additive Factor} = 0.77\,(\text{BZ(control)} - \text{BZ(ref)}) \qquad (1)$$

Where BZ = benzene

An Excel workbook, designated “fuel changes.xls”, summarizes the control and reference case fuel benzene and aromatics levels used for 2015, 2020, and 2030. This file is included in the docket for the rule. We also checked the control case fuel benzene levels to make sure the nationwide average level was close to the standard. We did this by weighting county fuel benzene level by VMT as a surrogate for fuel sales. The resulting nationwide average level was a little under 0.63%, very close to the standard. The refinery modeling methodology is discussed in Chapter 9 of the Regulatory Impact Analysis. Since the reduction in fuel benzene changes well below one percent of the gasoline, the level of uncertainty in the impacts on other fuel parameters and emissions is quite small.

Once fuel parameters were developed for the control case, NMIM was rerun with data files that included new start emission standards for hydrocarbons. Output included exhaust emissions, non-refueling evaporative emissions, and refueling evaporative emissions.

It should be noted that the inventory used for air quality modeling included an error in contractor-supplied input files for 13 Northeastern states. This error had a small impact on reference case inventories, but the impact on estimates of emission reductions with controls was insignificant. In addition, the control case inventory for 2015 assumes that the fuel program is fully phased in, which is a simplification of the actual phase-in. For more information about fuel program phase-in, refer to Chapter 6 of the Regulatory Impact Analysis.

Table 2.2.-2. Average Fuel Benzene Level (Volume Percent) by PADD with Implementation of Fuel Benzene Standard (CG – Conventional Gasoline; RFG – Reformulated Gasoline)

		PADD 1	PADD 2	PADD 3	PADD 4	PADD 5	Calif.
Reference Case	CG	0.91 %	1.26%	0.95%	1.47%	1.42%	0.62%
	RFG	0.59%	0.80%	0.57%	1.05%	0.65%	0.62%
Control Case	CG	0.55%	0.68%	0.54%	0.93%	0.85%	0.61%
	RFG	0.54%	0.71%	0.55%	0.62%	0.60%	0.61%
Multiplicative Factor	CG	0.60	0.54	0.57	0.63	0.60	0.98
	RFG	0.92	0.89	0.96	0.59	0.92	0.98

Table 2.2-3. Comparison of Average Fuel Benzene Level (Volume Percent) by PADD In Inventories Versus Final Rule Refinery Modeling..

		PADD 1	PADD 2	PADD 3	PADD 4	PADD 5	Calif.
Average Fuel Benzene Level Assumed in Inventories (0.62% standard)	CG	0.55 %	0.68%	0.54%	0.93%	0.85%	0.61%
	RFG	0.54%	0.71%	0.55%	0.62%	0.60%	0.61%
Average Fuel Benzene Level, Final Rule Refinery Modeling, with 0.62% Standard and 1.3 vol% Maximum Average	CG	0.61%	0.62%	0.63%	0.85%	0.65%	0.61%
	RFG	0.54%	0.60%	0.55%	0.62%	0.60%	0.61%

For highway diesel vehicles, we used a different approach than we used for gasoline vehicles. NMIM2004 outputs for 1999, 2007, 2010, 2015 and 2020 were used to develop ratios of future year to 1999 air toxic inventories. These were then applied to 1999 NEI inventory estimates by SCC, county and HAP:

$$PF_{20XX} = \frac{E_{NMIM,20XX}}{E_{NMIM,1999}} \qquad (2)$$

where PF_{20XX} is the projection factor for 2007, 2010, 2015, 2020, or 2030, E_{20XX} is the emissions for the corresponding year and E_{1999} is the 1999 emissions. Highway diesel vehicle air toxic emission estimates remained unchanged from the proposal.

2.2.1.1.2 Nonroad Equipment in the Nonroad Model

Nonroad equipment in the NONROAD model includes such sources as recreational, construction, industrial, lawn and garden, farm, light commercial, logging, airport service, railway maintenance, recreational marine vessels. For final rule modeling, we used 1999 and future year inventories developed using NMIM2005, which includes NONROAD2005. NONROAD2005 includes a number of improvements over NONROAD 2004, which was used in the proposed rule. These improvements include new evaporative categories for tank permeation, hose permeation, hot soak, and running loss emissions, a revised methodology for calculating diurnal emissions, and improvements to allocation of emissions from recreational marine and construction equipment.

As with highway vehicles, exhaust gaseous hydrocarbons were estimated as fractions of VOC, PAHs were calculated as fractions of PM, and metals were estimated using basic emission factors. Evaporative emissions were estimated as fractions of VOC.

Changes in fuel benzene and aromatics levels are expected to result in similar emission changes for nonroad gasoline equipment as for gasoline highway vehicles. However, NMIM does not have the capability to model impacts of these fuel changes on nonroad equipment emissions. Thus, we assumed that changes in county-level exhaust and evaporative emissions of nonroad gasoline equipment were proportional to changes in highway light-duty gasoline vehicle emissions.

$$PF\ nonroad\ exhaust_{20XX} = \frac{E_{LDGVexhaust\ NMIM\ Control\ 20XX}}{E_{LDGVExhaust\ NMIM\ Reference\ 20XX}} \qquad (3)$$

$$PF\ nonroad\ evap_{20XX} = \frac{E_{LDGVevap\ NMIMControl20XX}}{E_{LDGVEvap\ NMIMReference20XX}} \qquad (4)$$

The nonroad refueling associated with PFCs was subtracted from the nonroad inventory prior to air quality modeling, and the inventory summaries presented in Section 2.2.1.2.1 include this subtraction.

2.2.1.1.3 Commercial Marine Vessels, Locomotives and Aircraft

These source sectors will not be impacted by the fuel benzene standards being finalized in this rule. Final rule inventories are unchanged from those used to model the proposal.

Emissions for these source sectors in 1999 were obtained from the 1999 National Emissions Inventory, Final Version 3. Gaseous air toxic and PAH emissions for turbine engine aircraft were estimated by applying toxic to VOC ratios obtained from detailed characterization of turbine engine emissions. Since no emissions data were available for piston engine aircraft, a speciation profile from a non-catalyst light-duty gasoline vehicle was used as a surrogate. Metal emissions were not estimated for aircraft. No speciated emissions data were available for commercial marine vessels. For diesel marine vessels, profiles from heavy-duty diesel highway vehicles were used; for steamships, a profile for stationary and industrial boilers was used. Locomotive air toxic emissions were estimated using speciation data from a year 2000 study done by the California Air Resources Board.[33] More detailed information on methods used to develop air toxic inventories for these sectors can be found in the documentation for the 1999 NEI.[34] This documentation also describes methods used to develop inventories for 1990 and 1996.

The following approaches were used to project emissions for these source categories:

Locomotives and commercial marine vessels – For gaseous HAPs, inventories were developed by applying ratios of future year to 1999 national level 50 state VOC inventory estimates (from the recent Clean Air Nonroad Diesel rule) by SCC code. For polycyclic aromatic hydrocarbons, PM ratios were used. Metal inventory estimates were projected to future years based on activity. Locomotive activity was projected using fuel consumption data from the Energy Information Administration, as discussed in the Regulatory Impact Analysis for Clean Air Nonroad Diesel Rule. For commercial marine vessels, projected equipment populations from 1998 Power Systems Research (PSR) data were used to develop factors. The future year inventories do not account for potential reductions of additional locomotive or commercial marine vessel emission controls currently under consideration.

Aircraft – To project emissions from aircraft and from aviation gas distribution emissions, we developed and applied growth factors (in EMS-HAP) to 1999 emissions based on landing and take off data. The Federal Aviation Administration’s Terminal Area Forecast System provided landing and take off data for future years up to 2020, associated with commercial aircraft, general aviation, air taxi and military aircraft.[35] These four categories map directly to the inventory categories for aircraft emissions. The landing and take off data were summed across airports to create growth factors at the national level. The general aviation growth factors were used for aviation gas distribution emissions. After 2020, activity was assumed to increase at the same rate as the increase from 2015 to 2020.

2.2.1.1.4. Portable Fuel Containers

Any MSATs contained in the liquid gasoline will be present as a component of the VOCs. Specifically, the VOC emissions (estimated in Sections 2.1.1.2 and 2.1.3) will contain the following eight MSATs:

- benzene,
- MTBE,
- n-hexane,
- toluene,
- xylenes,
- ethylbenzene,
- naphthalene, and
- 2,2,4-trimethylpentane.

While MSAT inventories for portable fuel containers (PFCs) were developed at the State level (benzene) or national level (other MSATs above) to estimate emission benefits and cost-effectiveness of the proposed rule, county-level inventories for portable fuel containers were not developed for use in air quality modeling for the proposal. In this section, we describe the methodology used to develop such inventories for 1999, 2010, 2015, 2020, and 2030, for the final rule.

As discussed in Section 2.1.1., VOC inventories were developed at the State level for the following years – 1990, 2005, 2010, 2015, 2020, and 2030. Thus an inventory had to be developed for 1999. This was done by linear interpolation of the 1990 and 2005 inventories. Permeation and evaporative emissions had to be separated as well, since they were combined in the State-level VOC inventories. Based on analyses done by the California Air Resources Board, 33.87 percent of combined permeation plus evaporative emissions was assumed to be permeation (see Section 2.1.1.2). This percentage was applied to all the State inventory estimates.

Statewide total annual VOC inventories were allocated to counties using county level fuel consumption ratios for calendar year 2002, obtained from the public release version of NONROAD2005:

$$PFC\ VOC\ Emissions_{Emission\ Type\ X,\ SCC\ YYY,\ County\ Z} = PFC\ VOC\ Emissions_{Emission\ Type\ X,\ SCC\ YYY,\ StateZ} \times \frac{County\ Fuel\ Consumption_{Nonroad\ 2005}}{State\ Fuel\ Consumption_{Nonroad\ 2005}} \quad (5)$$

For all compounds except benzene and naphthalene, the fraction of total PFC emissions that is composed of each of those HAPs was assumed to be directly proportional to the ratio of each of those HAPs at the county level in total evaporative emissions from light-duty gasoline vehicles (Equation 8).

$$PFC\ MSAT\ evap_{20XX} = \frac{MSAT\ Emissions_{\ LDGVevap_{20XX}}}{VOC\ Emissions_{\ LDGVEvap_{20XX}}} \quad x\ PFC VOC\ Emissions \quad (6)$$

These ratios were obtained from the database of toxic to VOC ratios in the NMIM model, discussed in previous sections. NMIM has ratios that vary by fuel type (conventional or baseline gasoline, ethanol oxygenated gasoline, and MTBE oxygenated gasoline).

Another approach was used to estimate emissions of benzene with and without PFC control, and also with and without the fuel benzene standard. First, we divided county-level benzene refueling emissions by county-level VOC refueling emissions estimated by NMIM, for both reference and control case scenarios. The resultant ratios were multiplied by VOC emissions from evaporation, vapor displacement, and spillage. These ratios were then adjusted based on a recent analysis of average nationwide percentage of benzene in gasoline vapor from gasoline distribution with an RVP of 10 psi at 60 degrees Fahrenheit.[36] That analysis shows that the percentage of benzene in gasoline vapor from gasoline distribution is 0.27%, in contrast to 0.74% benzene on average nationwide in vehicle refueling emissions from highway vehicles. The reason for this difference is that the refueling algorithm in MOBILE6.2 is based on a temperature of 90 degrees, whereas temperatures for gasoline marketing emissions will typically be lower. Thus a ratio of 0.36 was applied to the gasoline vehicle refueling ratios. For all emission types except permeation, the equation used was:

$$\begin{aligned}&PFC\ \ Benzene\ \ Emissions_{Emission\ Type\ X\ ,\ SCC\ YYY,\ County\ Z} = \\ &PFC\ \ VOC\ \ Emissions_{Emission\ Type\ X\ ,\ SCC\ YYY,\ County\ Z} \times \qquad (7)\\ &\left(\frac{\mathrm{Re}\ fueling\ \ Benzene_{LDGV\ ,\ County\ Z}}{\mathrm{Re}\ fueling\ \ VOC_{LDGV\ ,\ County\ Z}}\right) \times 0.36\end{aligned}$$

A separate ratio was used for permeation emissions since recent research suggests that the ratio of benzene from permeation is higher than for evaporation, vapor displacement or spillage. A recent study[37] suggests that the ratio of benzene from permeation to total VOC from permeation is about 1.7727 times higher than the ratio associated with evaporation. Thus, we multiplied the benzene refueling ratios for each state by 1.7727 to obtain the benzene to VOC ratios for permeation:

$$\begin{aligned}&PFC\ \ Benzene\ \ Emissions_{\ Emission\ \ Type\ \ X\ ,\ SCC\ \ YYY\ ,\ County\ \ Z} = \\ &PFC\ \ VOC\ \ Emissions_{\ Emission\ \ Type\ \ X\ ,\ SCC\ \ YYY\ ,\ County\ \ Z} \times \qquad (8)\\ &\left(\frac{\mathrm{Re}\ fueling\ \ Benzene_{\ LDGV\ \ ,\ County\ \ Z}}{\mathrm{Re}\ fueling\ \ VOC_{\ LDGV\ \ ,\ County\ \ Z}}\right) \times 0.36 \times 1.77\end{aligned}$$

A similar adjustment was applied to naphthalene emissions with and without fuel benzene control, based on a recent analysis of average nationwide percentage of naphthalene in gasoline vapor from gasoline distribution with an RVP of 10 psi at 60 degrees Fahrenheit.[38, 39] The percentage is 0.00027, in contrast to 0.05% naphthalene on average nationwide in vehicle refueling emissions from highway vehicles. Thus a ratio of 0.0054 was applied to the gasoline vehicle refueling ratios:

$$
\begin{aligned}
&PFC\ Naphthalene\ Emissions_{Emission\ Type\ X,\ SCC\ YYY,\ County\ Z} = \\
&PFC\ VOC\ Emissions_{Emission\ Type\ X,\ SCC\ YYY,\ County\ Z} \times \\
&\left(\frac{\mathrm{Re}\ fueling\ Naphthalene_{LDGV,\ County\ Z}}{\mathrm{Re}\ fueling\ VOC_{LDGV,\ County\ Z}} \right) \times 0.0054
\end{aligned}
\qquad (9)
$$

2.2.1.1.5. Gasoline Distribution

EPA's estimates of gasoline distribution emissions reflect improvements in its methodology developed for the 2002 National Emissions Inventory (NEI). The key changes are:

1) Vehicle refueling emissions are estimated as part of the highway vehicle inventory using NMIM2004, as discussed previously, and included in the highway vehicle inventory. Details of how the modeling was done can be found in the documentation for the mobile source 2002 NEI.[40] The previous methodology is described in the nonpoint 1999 NEI documentation.[41] In this older method, national VOC emissions were calculated using fuel sales data and estimates of emissions per fuel volume in areas with and without Stage 2 vapor recovery systems. Air toxic emissions were estimated from VOC by applying speciation profiles for different fuel types, such as baseline gasoline, MTBE oxygenated gasoline, and ethanol oxygenated gasoline. Total emissions for each combination of vapor recovery system and fuel type were allocated to individual counties using vehicle miles traveled.

2) For all other source categories in the gasoline distribution sector, EPA is using an improved set of methods. These improvements include: (a) for source categories where activity-based emission factors were available (all except bulk terminals and pipelines), EPA established methods that maintain mass balance for storage and transfer activities, such that there is agreement with the activity estimates used for each of the different distribution sectors; (b) EPA developed criteria pollutant and air toxic emission estimates using the same activity data and a consistent set of speciation profiles; and (c) EPA accounted for local differences in fuel properties for downstream emissions (e.g. bulk plants, transit, unloading, storage, Stage 1 evaporative losses). More details on these improvements can be found in a technical memorandum on the website for the 2002 NEI.[42]

The results of these changes were a significant increase in the air toxic inventory estimates for vehicle refueling and a small increase nationwide for other sources of gasoline distribution emissions. County-level estimates for some gasoline distribution sources changed considerably since local differences in fuel properties were accounted for. Table 2.2.-4 compares benzene estimates in the 1999 NEI, final version 3, and the final 2002 NEI.

Table 2.2.-4. Vehicle Refueling and Gasoline Distribution Benzene Emissions (Tons), 1999 and 2002 NEI.

	1999 NEI	2002 NEI	% Difference
Vehicle Refueling	1558	2129	+36
Gasoline Distribution	4978	5119	+3

In order to develop better estimates of the emission benefits of the fuel benzene control being finalized in this rule, EPA developed updated air toxic inventories for vehicle refueling and gasoline distribution to reflect the changes made in the 2002 NEI. In addition, the same adjustment factors for benzene and naphthalene described above for PFC emissions were also applied to gasoline distribution emissions.

Inventories were developed as follows:

1) Vehicle refueling emissions were estimated using NMIM2004. Refueling emissions were estimated for reference case inventories in 1999, 2010, 2015, 2020 and 2030. Control case inventories were estimated for 2015, 2020 and 2030.

2) For other gasoline distribution emissions, for each air toxic pollutant, EPA estimated a national-scale adjustment factor as follows:

   Adjustment factor = 2002 NEI national emissions/2002 national emissions estimated from interpolation of the 1999 NEI and a 2007 projection for the proposed rule.

3) EPA developed new county-level reference case inventories for these pollutants by applying these adjustment factors to county-level gasoline distribution emissions for 1999 and future years. The gasoline distribution projections were based on projection information (growth factors, closures, reductions, etc.) from the 1999 NEI.[43] Revised inventories were developed for years 1999, 2015, and 2020. 2030 was assumed to be the same as 2020.

4) Additional nationwide adjustments of 0.36 and 0.0054, respectively, were applied to emissions of benzene and naphthalene. The basis for these adjustments is discussed in the Section 2.2.1.1.4.

5) EPA developed new control case inventories for gasoline distribution, for benzene, for years 2015, 2020, and 2030. These revised county-level inventories were estimated by applying the following ratios:

   emissions proposed rule control scenario/emissions proposed rule reference case

   These ratios reflect reductions estimated based on the assumption that reductions are proportional to reductions in vehicle refueling emissions.

2.2.1.1.6. Other Stationary Sources

Stationary source estimates for 1999, for all source categories except gasoline distribution, were obtained from the National Emissions Inventory.[44, 45]

For nearly all stationary sources (point and non-point source inventories), we used the Emissions Modeling System for Hazardous Air Pollutants (EMS-HAP), Version 3.0 to apply growth and control factors to the 1999 NEI, source type by source type.[46] EMS-HAP has the capability of projecting emissions to 2020. After 2020, stationary source emissions were assumed to remain constant.

The general methodology for projecting stationary source emissions using EMS-HAP is as follows:

Future Year Emissions = Base Year Emissions * Growth Factor * (100% - % Reduction)/100 (10)

The actual equations used by EMS-HAP also allow the application of a “new source” reduction to a fraction of the emissions to allow for a different level of emission reduction to be applied to a portion of the emissions. In addition, if the source is already controlled, and the value of the overall control efficiency is provided in the emission inventory, EMS-HAP adjusts the percent reduction (% Reduction) based on the overall control efficiency value provided in the inventory. The actual projection equations are provided in Chapter 6 (PtGrowCntl) of the EMS-HAP User’s Guide (U. S. EPA, 2004b, pp. 6-15 – 6-17).

Stationary source growth -- EMS-HAP allows growth factors to be applied to the inventory on either a national, state or county level basis, based on one of the following inventory codes that describe the source: (1) MACT, which identifies an emission source as a belonging to a particular regulatory category or subcategory; (2) Standard Industrial Classification (SIC), which classifies establishments by their primary type of activity, as defined by the U.S. Census Bureau; (3) Source Category Code (SCC), which defines the source using EPA’s coding system for the NEI. The MACT and SCC code definitions are contained in the code tables supplied with the NEI. Note that even though the code is called “MACT”, it is also used for other regulations besides MACT such as section 129 rules. The hierarchy built into EMS-HAP is to use a MACT-based growth factor first, followed by an SIC-based and lastly, an SCC-based growth factor. The most detailed geographic level is used first (e.g., a state-specific growth factor replaces a national growth factor). EMS-HAP does not have the capability to apply growth factors to specific point source facilities, nor can they be applied differently for the different pollutants for a particular source category.

For stationary sources, growth factors were developed using three primary sources of information:

- Regional Economic Models, Inc. (REMI) Policy Insight® model, version 5.5;[47, 48]
- Regional and National fuel-use forecast data from the Energy Information Administration, U.S. Department of Energy, Annual Energy Outlook (AEO)[49]

- Rule development leads or economists who had obtained economic information in the process of rule development.

The first two sources of information were also used in projecting criteria pollutant emissions for EPA's 2005 Clean Air Interstate Rule.[50]

More details on how these sources were used can be found in the EPA technical report, "National Scale Modeling of Mobile Source Air Toxic Emissions, Air Quality, Exposure and Risk for the Mobile Source Air Toxics Rule," cited previously.

Stationary source reductions -- Emission reductions were applied to the grown emissions to account for regulatory efforts which are expected to reduce HAPs from 1999 levels. The percent reductions we determined were primarily based on estimates of national average reductions for specific HAPs or for groups of HAPs from a source category or subcategory as a result of regulatory efforts. These efforts are primarily the MACT and section 129 standards, mandated in Title III of the 1990 Clean Air Act Amendments. We determined percent reductions, and whether they apply to major only or both major and area sources, for the various rules from rule preambles, fact sheets and through the project leads (questionnaire and phone calls). A major source is defined as any stationary source or group of stationary sources located within a contiguous area and under common control that has the potential to emit considering controls, in the aggregate, 10 tons per year or more of any hazardous air pollutant or 25 tons per year or more of any combination of hazardous air pollutants. For some rules, percent reductions were provided for specific HAPs or groups of HAPs (e.g., all metals, or all volatiles) rather than a single number for all HAPs in the categories. After 2010, stationary source emissions are based only on economic growth. They do not account for reductions from ongoing toxics programs such as the urban air toxics program, residual risk standards and area source program, which are expected to further reduce toxics.

2.2.1.1.7 Precursor Emissions

In addition to the air toxics in Table 2.2.-1, emissions of a number of other compounds were estimated because they are precursor emissions which are atmospherically transformed into air toxics. These pollutants are listed in Table 2.2.-5, along with air toxic pollutants included in the inventory which can be transformed into other air toxics. Precursor emissions in 1999 were estimated by applying speciation profiles from SPECIATE to VOC estimates from version 2 of the 1999 NEI.[51] Stationary source precursor emissions were assumed to remain at 1999 levels in future year modeling since the impact of growth and control is unknown. However, mobile source precursor emissions are expected to increase along with VOCs. To account for this in modeling done to support the final rule, we estimated secondary concentrations from mobile sources in future years by assuming they increased proportionally with primary concentrations. For the proposed rule, we had projected precursor emissions for 1999 to future years using ratios of VOCs for future years versus 1999, then used these projected emissions to model secondary concentrations. A comparison of the two approaches, using modeling data from the proposal, yielded very similar results. A more detailed discussion of the comparison can be found in EPA Technical Report Number EPA-454/R-07-002

2.2.1.1.8 Strengths and Limitations

Highway Vehicles – Limitations in the VOC and PM emission estimates which are the basis for calculating air toxic emissions are discussed in Section 2.1.3. MOBILE6.2 toxic to VOC ratios for key toxics from gasoline vehicles, such as benzene, 1,3-butadiene, formaldehyde and acetaldehyde, are based on almost 900 vehicle tests on a wide variety of fuels. These data account for impacts of emissions control technology, normal vs. high emitters, and impacts of a variety of fuel properties, including benzene. level, aromatics levels, olefin level, sulfur level, RVP, E200, E300, and oxygenate content.

However, there are a number of significant uncertainties in our highway vehicle air toxic inventories for air quality modeling. Among the uncertainties are:

- The Agency has limited emissions data for advanced technology highway vehicles, including hybrid and alternative technology vehicles. The toxic to VOC ratios in MOBILE6.2 are all based on Tier 0 and earlier vehicles. EPA has recently evaluated data on more recent technology vehicles and what might be the potential impacts of these data on inventories. The result of this analysis is discussed in Section 2.3.1.
- MOBILE6.2 uses the same toxic to VOC ratios for cold starts and hot running operation even though these ratios for benzene and 1,3-butadiene are higher during cold starts than hot running. We have a limited understanding of the impact of off-cycle operation on highway vehicle air toxic emissions.
- Data are limited for certain sources and pollutants not significant to this rule. For heavy-duty highway vehicles (both gasoline and diesel engines) the toxic to VOC ratios used in MOBILE6.2 to develop inventory estimates are based on very limited data. Moreover, we lack data on how diesel fuel properties impact air toxic emissions, and we have very little data on mobile source metal emissions.

There are also significant uncertainties resulting from the use of national default data rather than local inputs, as well as “top-down” allocation schemes in estimating toxic emissions. Examples include use of national default vehicle registration distributions, default average speed distributions, and use of county level population data to allocate State or urban level VMT. A recent paper evaluated the impacts of these default inputs and allocation schemes on local level inventories.[52]

Finally, as discussed in Section 2.1.3, there are greater uncertainties in projection year estimates.

Table 2.2.-5. Precursor Pollutants.

Pollutant	Precursor for	Pollutant	Precursor for
Acetaldehyde	Formaldehyde (reactive and inert)	Isoprene	Formaldehyde (reactive and inert)
1,3-Butadiene	Formaldehyde (reactive and inert), Acrolein (reactive and inert)	MTBE	Formaldehyde (reactive and inert)
1-Butene	Formaldehyde (reactive and inert), Propionaldehyde (reactive and inert)	Methanol	Formaldehyde (reactive and inert)
1-2,3-Dimethyl butene	Formaldehyde (reactive and inert)	1-Nonene	Formaldehyde (reactive and inert)
1-2-Ethyl butene	Formaldehyde (reactive and inert)	2-Nonene	Acetaldehyde (reactive and inert)
1-2-Methyl butene	Formaldehyde (reactive and inert)	1-Octene	Formaldehyde (reactive and inert)
1-3-Methyl butene	Formaldehyde (reactive and inert)	2-Octene	Acetaldehyde (reactive and inert)
2-Butene	Acetaldehyde (reactive and inert)	1-Pentene	Formaldehyde (reactive and inert)
2-2-Methyl butene	Acetaldehyde (reactive and inert)	1-2,4,4-Trimethyl pentene	Formaldehyde (reactive and inert)
1-Decene	Formaldehyde (reactive and inert)	1-2-Methyl pentene	Formaldehyde (reactive and inert)
Ethanol	Acetaldehyde (reactive and inert)	1-3-Methyl pentene	Formaldehyde (reactive and inert)
Ethene	Formaldehyde (reactive and inert)	1-4-Methyl pentene	Formaldehyde (reactive and inert)
1-Heptene	Formaldehyde (reactive and inert)	2-Pentene	Acetaldehyde (reactive and inert), Propionaldehyde (reactive and inert)
2-Heptene	Acetaldehyde (reactive and inert)	2-3-Methyl pentene	Acetaldehyde (reactive and inert)
1-Hexene	Formaldehyde (reactive and inert)	2-4-Methyl pentene	Acetaldehyde (reactive and inert)
2-Hexene	Acetaldehyde (reactive and inert)	Propene	Acetaldehyde (reactive), Acetaldehyde (inert), Formaldehyde (reactive and inert)
3-Hexene	Propionaldehyde (reactive and inert)	2-Methylpropene	Formaldehyde (reactive and inert)

Nonroad Equipment – The toxic to VOC ratios in NMIM for lawn and garden equipment, which makes the single largest contribution of any nonroad sector to the air toxics inventory, is supported by a large amount of test data. The VOC estimates for uncontrolled engines in the NONROAD model are based on a large amount of in-use test data and peer reviewed methodologies. Estimates for controlled engines are based on certification test data and emission standards. However, for a number of source categories—in particular heavy-duty diesel engines and aircraft engines--the toxic to VOC ratios used to develop inventory estimates are based on very limited data. In addition, the Agency has limited emissions data for nonroad equipment with emission controls. The Agency has been doing test data to address some of the limitations. This work is discussed in Sections 2.3.3 and 2.3.4. There are also significant uncertainties associated with allocating nonroad equipment emissions from the national to the local level. As with highway sources, future year inventories are more uncertain. Finally, the relationship between fuel parameters and emission rates for gasoline nonroad equipment is much more poorly understood than the relationship for highway gasoline vehicles. In our modeling, we assumed that the impacts of fuel control on emissions from nonroad equipment would be proportional to the impact on highway vehicle emissions, as discussed above.

Portable Fuel Containers -- Since no direct measurements of air toxic emissions from evaporation of gasoline in portable fuel containers were available, they were estimated based on toxic to VOC ratios obtained from evaporative emissions measurements taken from light-duty gasoline vehicles. However, since evaporation of fuel occurs at higher temperatures in vehicles than in PFCs, speciation profiles are different. An effort to account for these differences was made for benzene and naphthalene based on recent analyses done for the gasoline distribution sector.

Stationary Sources -- For the 1999 NEI, there are a number of known or suspected issues for stationary source emissions listed on the emission inventory website (U. S. EPA, 2004a). The issues listed are generally limited to specific geographic areas and are not expected to influence national-level results. Of these, it is expected that issues related to acrolein are most likely to affect the results for assessment of noncancer effects. Another uncertainty concerning the base year inventory is the proper identification of sources using the inventory codes. These codes are utilized for applying growth and reduction factors.

There are several uncertainties associated with the growth and reduction information. The growth information is uncertain for a number of reasons. For most sources, activity growth is used as a surrogate for emissions growth, which may not be appropriate for some industry sectors. In addition the growth information available is from economic models, is typically specific to broad industry categories, and is not resolved geographically for all categories. The stationary source reductions are uncertain because they are generally based on national-average reductions (although we have used facility-specific reductions where available). We do not expect this uncertainty to have an impact on national-level results.

As previously mentioned, after 2010, stationary source emissions are based only on economic growth. They do not account for reductions from ongoing toxics programs such as the urban air toxics program, residual risk standards and area source program, which are expected to further reduce toxics. Furthermore, the 2030 stationary source inventory estimates are equal to the 2020 estimates, because of additional uncertainties in the available growth data past 2020 and the lack of knowledge of the effect of stationary source control programs that far into the future.

2.2.1.2 Trends in Air Toxic Emissions

2.2.1.2.1 Emission Trends Without Controls

In 1999, based on the National Emissions Inventory (NEI), mobile sources accounted for 44% of total emissions of 188 hazardous air pollutants (see Figure 2.2.-2). Diesel particulate matter is not included in this list of 188 pollutants. Sixty-five percent of the mobile source tons in this inventory were attributable to highway mobile sources, and the remainder to nonroad sources. Furthermore, over 90% of mobile source air toxic emissions are attributable to gasoline vehicles and equipment

Overall, emissions from all air toxics are projected to decrease from 5,030,000 tons in 1999 to 4,010,000 tons in 2020, as a result of existing and planned emission controls on major, area, and mobile sources. In the absence of Clean Air Act emission controls currently in place, EPA estimates air toxic emissions would total 11,590,000 tons in 2020 (Figure 2.2-2). It should be noted that these estimates do not account for higher estimates of cold temperature hydrocarbon emissions in vehicles, PFC emissions, or categories of nonroad gasoline evaporative emissions included in NONROAD2005 and discussed in Section 2.2.1.1.2.

If higher estimates of cold temperature hydrocarbon emissions and vehicles and evaporative emissions from nonroad gasoline equipment are accounted for, air toxic emissions emitted from mobile sources will be reduced 46% between 1999 and 2020 without the controls in this proposal, from 2.38 million to 1.29 million tons (Figure 2.2-3). This reduction will occur despite a projected 57% increase in vehicle miles traveled, and a 47% projected increase in nonroad activity (See Figures 2.2.-4 and 2.2.-5). It should be noted, however, that EPA anticipates mobile source air toxic emissions will begin to increase after 2020, from about 1.29 million tons in 2020 to 1.42 million tons in 2030. Benzene emissions from all sources decrease from about 366,000 tons in 1999 to 279,000 tons in 2020, and as is the case with total air toxic emissions, begin to increase between 2020 and 2030 (Figure 2.2.-5).

Figure 2.2.-2. Contribution of Source Categories to Air Toxic Emissions, 1990 to 2020 (not Including Diesel Particulate Matter). Dashed Line Represents Projected Emissions without Clean Air Act Controls. Does not Account for Higher Estimates of Cold Temperature Hydrocarbon Emissions in Vehicles, PFC Emissions, or Categories of Nonroad Gasoline Evaporative Emissions Included in NONROAD2005.

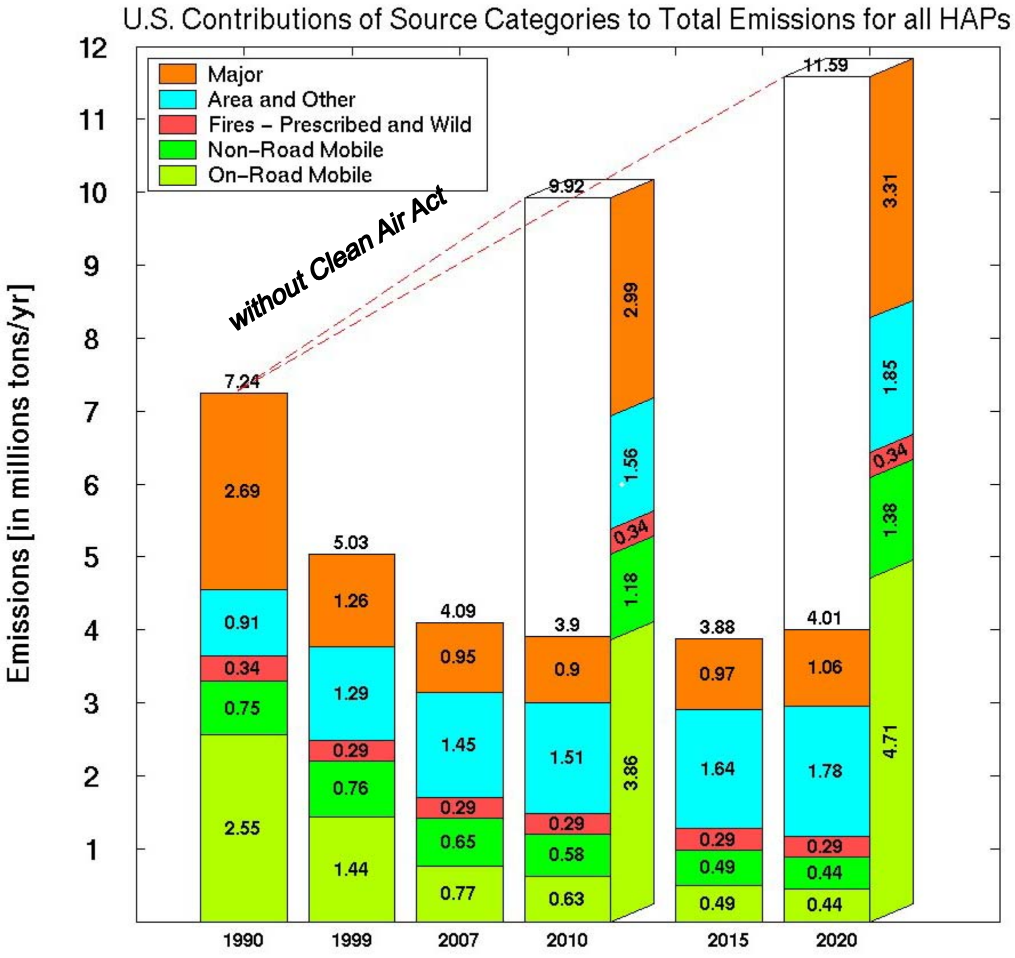


Figure 2.2.-3. Contribution of Source Categories to Mobile Source Air Toxic Emissions, 1999 to 2030 (Not Including Diesel Particulate Matter). Includes Higher Estimates of Cold Temperature Hydrocarbon Emissions and Vehicles, Evaporative Emisions from Nonroad Gasoline Equipment, and PFC Emissions as Part of Area Source Inventory.

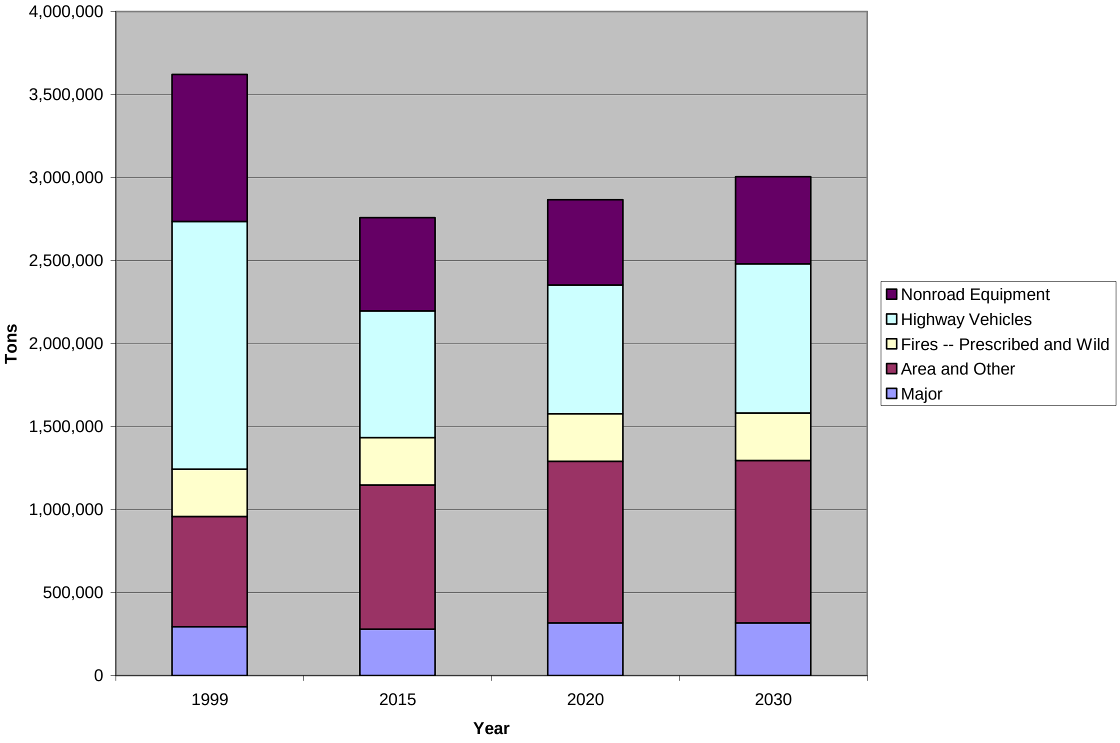


Figure 2.2.-4. Trend in Highway Vehicle Air Toxic Emissions Versus VMT, 1999 to 2030.

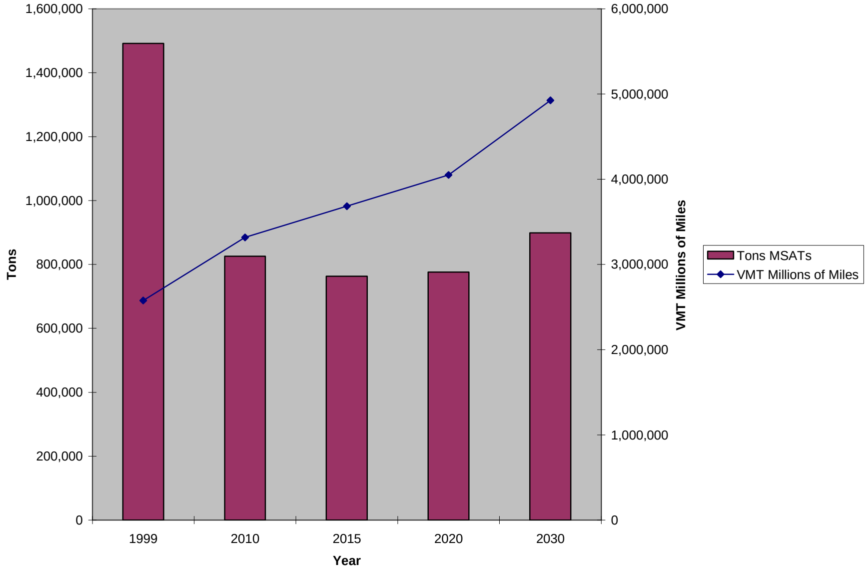


Figure 2.2.-5. Trend in Emissions of Nonroad Equipment Air Toxic Emissions (Excluding Commercial Marine Vessels, Locomotives and Aircraft) versus Activity, 1999 to 2030.

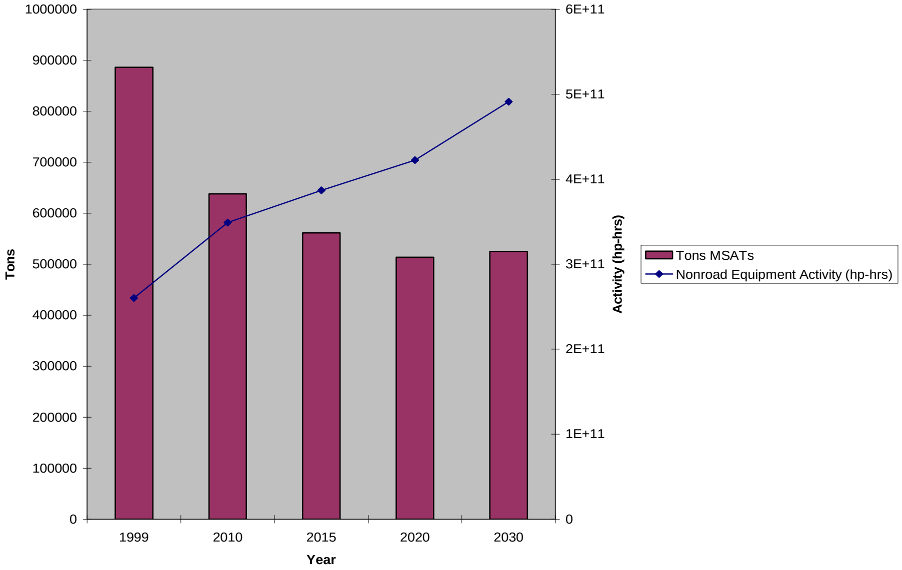
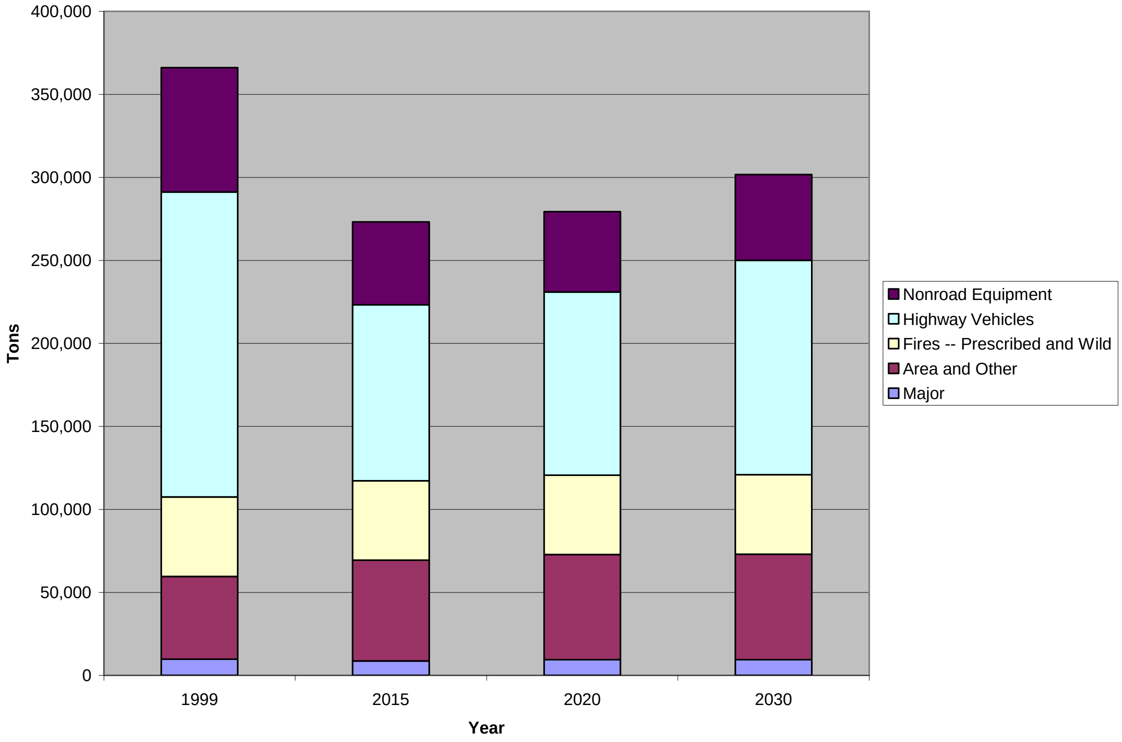


Figure 2.2.-6. Trend in Benzene Emissions, 1999 to 2030.



Highway Vehicle Trends – Table 2.2.-6 summarizes nationwide emissions of individual air toxics from highway vehicles from 1999 to 2030. Fifteen POM compounds listed in Table 2.2.-1 (except for naphthalene) are grouped together as POM. For mobile sources, forty percent of the chromium from highway vehicles and eighteen percent of the chromium from nonroad sources was assumed to be the highly toxic hexavalent form. The estimate for highway vehicles is based on data from utility boilers,[53] and the estimate for nonroad equipment is based on combustion data from stationary combustion turbines that burn diesel fuel.[54]

Table 2.2.-6. Nationwide Emissions (Tons) of Individual Air Toxic Pollutants from Highway Vehicles.

Pollutant	1999	2010	2015	2020	2030
1,3-Butadiene	23,876	11,473	10,763	11,355	13,378
2,2,4-Trimethylpentane	182,120	101,880	94,469	96,315	111,783
Acetaldehyde	29,821	17,169	16,149	16,893	19,879
Acrolein	3,845	1,824	1,650	1,704	1,981
Benzene	183,661	110,526	105,956	110,317	129,290
Chromium III	8	10	11	12	15
Chromium VI	5	7	8	8	10
Ethyl Benzene	73,439	40,732	37,528	38,080	44,055
Formaldehyde	80,458	38,885	35,857	37,153	43,404
Hexane	66,267	39,801	33,481	30,727	33,468
MTBE	57,801	29,886	23,089	18,372	17,957
Manganese	5	6	6	7	9
Naphthalene	4,056	2,261	2,022	1,986	2,259
Nickel	10	13	14	16	19
POM	497	255	234	239	278
Propionaldehyde	4,288	2,327	2,154	2,222	2,574
Styrene	14,284	7,652	7,368	7,814	9,253
Toluene	489,873	268,871	250,646	257,367	299,677
Xylenes	277,285	152,046	141,710	145,473	169,369

Table 2.2.-7 summarizes total tons of air toxic emissions from highway vehicles by vehicle class in 1999, 2007, 2010, 2015, 2020, and 2030. Table 2.2.-8 provides the percentage of total highway vehicle emissions associated with each vehicle class. In 1999, 55% of air toxic emissions from highway vehicles were emitted by light-duty gasoline vehicles (LDGVs) and 37% by light-duty trucks (LDGTs). EPA projects that in 2020, only 34% of highway vehicle HAP emissions will be from LDGVs and 60% will be from LDGTs. More detailed summaries of emissions by individual pollutant, by State, and for urban versus rural area can be found in Excel workbooks included in the docket for this rule.

Table 2.2.-7. Tons of Air Toxic Emissions from Highway Vehicle Classes, 1999 to 2030 (Not Including Diesel Particulate Matter).

	Emissions (tons/yr)				
Vehicle Type	**1999**	**2010**	**2015**	**2020**	**2030**
HDDV	36,958	22,622	19,605	19,469	22,172
HDGV	66,672	21,323	14,812	11,638	10,188
LDDT	1,215	589	528	470	389
LDDV	688	41	23	16	16
LDGT1	353,671	279,674	287,644	319,974	375,603
LDGT2	188,134	144,254	141,165	144,247	159,682
LDGV	836,995	349,220	290,746	270,956	319,395
MC	7,267	7,899	8,595	9,291	11,213
Total Highway	**1,491,600**	**825,624**	**763,117**	**776,062**	**898,659**

HDDV: Heavy Duty Diesel Vehicles
HDGV: Heavy Duty Gasoline Vehicles
LDDT: Light Duty Diesel Trucks
LDDV: Light Duty Diesel Vehicles
LDGT1: Light Duty Gasoline Trucks 1
LDGT2: Light Duty Gasoline Trucks 2
LDGV: Light Duty Gasoline Vehicles
MC: Motorcycles

Table 2.2.-8. Percent Contribution of Vehicle Classes to Highway Vehicle Air Toxic Emissions, 1999 to 2030 (Not Including Diesel Particulate Matter).

Vehicle	**1999**	**2010**	**2015**	**2020**	**2030**
LDGV	56%	42%	38%	35%	35%
LDGT1 and 2	36%	51%	56%	60%	60%
HDGV	5%	3%	2%	1%	1%
HDDV	2%	3%	2%	2%	2%
Other (motorcycles and light-duty diesel vehicles and trucks)	1%	1%	2%	2%	2%

Tables 2.2.-9 through 2.2.-14 summarize total tons of emissions nationwide for benzene, 1,3-butadiene, formaldehyde, acetaldehyde, naphthalene, and acrolein from highway vehicles. About 90% of benzene emissions from gasoline vehicles were in exhaust, with the remainder in evaporative and refueling emissions. Benzene emissions from diesel vehicles were all exhaust. There are no evaporative emissions of 1,3-butadiene, formaldehyde, acetaldehyde, and acrolein.

Table 2.2.-9. Tons of Benzene Emissions from Highway Vehicle Classes, 1999 to 2030.

Vehicle Type	Emissions (tons/yr)				
	1999	2010	2015	2020	2030
HDDV	2,564	1,574	1,366	1,358	1,547
HDGV	6,665	2,383	1,715	1,399	1,213
LDDT	200	97	87	78	64
LDDV	112	7	4	3	3
LDGT1	46,358	39,456	41,796	47,352	56,290
LDGT2	21,392	19,742	20,074	21,083	23,737
LDGV	105,724	46,598	40,186	38,257	45,489
MC	646	669	728	787	947
Total Highway	**183,661**	**110,526**	**105,956**	**110,317**	**129,290**

Table 2.2.-10. Tons of 1,3-Butadiene Emissions from Highway Vehicle Classes, 1999 to 2030.

Vehicle Type	Emissions (tons/yr)				
	1999	2010	2015	2020	2030
HDDV	1,489	915	794	789	899
HDGV	1,177	197	99	78	63
LDDT	90	44	39	35	29
LDDV	50	3	2	1	1
LDGT1	5,307	3,820	3,929	4,520	5,411
LDGT2	3,526	1,991	1,913	2,064	2,344
LDGV	12,034	4,280	3,743	3,605	4,312
MC	202	224	243	263	318
Total Highway	**23,876**	**11,473**	**10,763**	**11,355**	**13,378**

Table 2.2.-11. Tons of Formaldehyde Emissions from Highway Vehicle Classes, 1999 to 2030.

	Emissions (tons/yr)				
Vehicle Type	**1999**	**2010**	**2015**	**2020**	**2030**
HDDV	19,094	11,724	10,176	10,114	11,522
HDGV	6,142	1,213	688	556	460
LDDT	386	188	168	150	124
LDDV	217	13	7	5	5
LDGT1	15,666	9,702	10,030	11,487	13,790
LDGT2	9,916	4,851	4,656	4,961	5,652
LDGV	28,522	10,627	9,515	9,213	11,044
MC	516	567	617	667	806
Total Highway	**80,458**	**38,885**	**35,857**	**37,153**	**43,404**

Table 2.2.-12. Tons of Acetaldehyde Emissions from Highway Vehicle Classes, 1999 to 2030.

	Emissions (tons/yr)				
Vehicle Type	**1999**	**2010**	**2015**	**2020**	**2030**
HDDV	7,032	4,318	3,748	3,725	4,243
HDGV	1,411	390	248	204	173
LDDT	123	60	54	48	40
LDDV	69	4	2	2	2
LDGT1	6,050	4,808	5,068	5,836	7,039
LDGT2	3,429	2,367	2,329	2,502	2,880
LDGV	11,555	5,043	4,504	4,364	5,246
MC	152	180	196	213	258
Total Highway	**29,821**	**17,169**	**16,149**	**16,893**	**19,879**

Table 2.2.-13. Tons of Acrolein Emissions from Highway Vehicle Classes, 1999 to 2030.

	Emissions (tons/yr)				
Vehicle Type	**1999**	**2010**	**2015**	**2020**	**2030**
HDDV	855	525	455	453	516
HDGV	689	76	24	17	12
LDDT	35	17	15	14	11
LDDV	20	1	1	0	0
LDGT1	623	457	472	538	644
LDGT2	326	231	226	240	271
LDGV	1,286	503	442	425	508
MC	13	14	15	16	20
Total Highway	**3,845**	**1,824**	**1,650**	**1,704**	**1,981**

Table 2.2.-14. Tons of Naphthalene Emissions from Highway Vehicle Classes, 1999 to 2030.

	Emissions (tons/yr)				
Vehicle Type	**1999**	**2010**	**2015**	**2020**	**2030**
HDDV	167	65	32	19	16
HDGV	773	400	248	195	176
LDDT	7	2	1	1	1
LDDV	7	0	0	0	0
LDGT1	760	640	697	769	900
LDGT2	489	267	273	281	315
LDGV	1,830	861	743	693	817
MC	23	25	27	29	35
Total Highway	**4,056**	**2,261**	**2,022**	**1,986**	**2,259**

Nonroad Equipment Trends -- Table 2.2.-15 summarizes nationwide emissions of individual air toxics from nonroad equipment, from 1999 to 2030. The lead emissions in the table are from piston engine aircraft, which use leaded gasoline. Table 2.2.-16 summarizes total tons of air toxic emissions from categories of nonroad equipment by equipment type in 1999, 2010, 2015, 2020, and 2030. Table 2.2.-17 provides the percentage of total nonroad equipment emissions associated with each equipment type. Air toxic emissions from nonroad equipment are dominated by lawn and garden equipment, recreational equipment, and pleasure craft, which collectively account for about 80% of nonroad HAP emissions in all years. More detailed summaries of emissions by individual pollutant, by State, and for urban versus rural area can be found in Excel workbooks included in the docket for this rule.

Table 2.2.-15. Nationwide Emissions of Individual Air Toxics from Nonroad Equipment, from 1999 to 2030.

Pollutant	Annual Total Nonroad Emissions (Tons)				
	1999	2010	2015	2020	2030
1,3-Butadiene	10,333	7,136	6,586	6,518	7,004
2,2,4-Trimethylpentane	109,793	83,546	71,362	62,991	62,250
Acetaldehyde	21,952	16,208	14,459	13,663	14,153
Acrolein	2,754	2,264	2,179	2,168	2,340
Benzene	74,902	54,763	49,985	48,453	51,647
Chromium III	15	15	16	16	16
Chromium VI	3	4	4	4	4
Ethyl Benzene	46,072	33,435	29,489	27,057	28,033
Formaldehyde	52,083	38,213	34,406	32,678	33,994
Hexane	36,925	29,758	27,430	26,083	27,439
Manganese	2	2	2	2	2
MTBE	78,585	28,464	27,238	27,245	29,865
Naphthalene	1,212	1,182	1,228	1,291	1,440
Nickel	31	34	36	37	41
POM	347	305	287	275	287
Propionaldehyde	4,968	3,462	3,036	2,824	2,865
Styrene	3,055	2,297	2,003	1,807	1,835
Toluene	234,558	189,605	164,871	146,220	145,330
Xylenes	208,728	147,242	126,825	114,252	116,764

Table 2.2.-16. Tons of Air Toxic Emissions from Nonroad Equipment Types, 1999 to 2030 (Not Including Diesel Particulate Matter).

Equipment Type	Annual Total Nonroad Emissions (Tons)				
	1999	2010	2015	2020	2030
Agriculture	21,397	12,512	9,686	7,875	6,567
Aircraft	14,276	14,965	16,081	17,256	19,603
Airport Support	325	198	157	141	152
Commercial	59,302	33,977	35,994	39,207	46,503
Commercial Marine Vessel	8,736	9,742	10,213	10,973	13,354
Construction	42,496	22,280	18,688	16,439	15,207
Industrial	11,422	4,247	2,793	2,239	2,093
Lawn/Garden	261,635	129,932	130,157	139,762	160,669
Logging	3,578	2,094	2,228	2,452	2,960
Pleasure Craft	332,631	202,760	163,953	148,746	147,720
Railroad	4,412	3,972	3,886	3,752	3,533
Recreational	125,933	201,118	167,488	124,640	106,845
Underground Mining	177	138	114	101	102
Total Nonroad	886,318	637,934	561,439	513,583	525,309

Table 2.2.-17. Contribution of Equipment Types to Nonroad Air Toxic Emissions, 1999 to 2030 (not Including Diesel Particulate Matter).

Equipment Type	1999	2010	2015	2020	2030
Lawn and Garden	30%	20%	23%	27%	31%
Pleasure Craft	38%	32%	29%	29%	28%
Recreational	14%	32%	30%	24%	20%
All Others	18%	16%	18%	19%	21%

Over 90% of nonroad toxic emissions are from 2-stroke and 4-stroke gasoline engines, with the remainder from diesel engines and turbine engine aircraft. Similarly, over 90% of benzene emissions from nonroad equipment are from gasoline engines, and these emissions would be reduced by a fuel benzene standard.

Tables 2.2.-18 through 2.2.-23 summarize total tons of emissions nationwide for benzene, 1,3-butadiene, formaldehyde, acetaldehyde, naphthalene, and acrolein from nonroad equipment types.

Table 2.2.-18. Tons of Benzene Emissions from Nonroad Equipment Types, 1999 to 2030.

	Annual Total Nonroad Emissions (Tons)				
Equipment Type	**1999**	**2010**	**2015**	**2020**	**2030**
Agriculture	2,105	1,283	1,020	855	736
Aircraft	1,102	1,163	1,247	1,335	1,511
Airport Support	33	19	15	14	15
Commercial	7,931	5,140	5,478	6,010	7,178
Commercial Marine Vessel	644	719	753	809	982
Construction	3,945	2,111	1,786	1,595	1,494
Industrial	1,498	524	335	263	233
Lawn/Garden	25,753	15,996	15,540	16,644	19,133
Logging	202	131	130	140	168
Pleasure Craft	24,963	16,698	14,101	13,145	13,264
Railroad	162	143	139	134	126
Recreational	6,548	10,825	9,430	7,502	6,798
Underground Mining	15	12	10	9	9
Total Nonroad	74,902	54,763	49,985	48,453	51,647

Table 2.2.-19. Tons of 1,3-Butadiene Emissions from Nonroad Equipment Types, 1999 to 2030.

	Annual Total Nonroad Emissions (Tons)				
Equipment Type	**1999**	**2010**	**2015**	**2020**	**2030**
Agriculture	236	145	116	98	85
Aircraft	824	859	924	993	1,131
Airport Support	4	2	22	2	
Commercial	1,324	774	820	901	1,080
Commercial Marine Vessel	6	6	67	6	
Construction	455	231	198	180	171
Industrial	242	76	47	37	31
Lawn/Garden	4,034	2,240	2,085	2,225	2,558
Logging	35	21	21	23	28
Pleasure Craft	2,069	1,291	1,034	928	909
Railroad	114	104	102	99	94
Recreational	990	1,385	1,230	1,025	907
Underground Mining	1	1	11	1	
Total Nonroad	10,333	7,136	6,586	6,518	7,004

Table 2.2.-20. Tons of Formaldehyde Emissions from Nonroad Equipment Types, 1999 to 2030.

Equipment Type	Annual Total Nonroad Emissions (Tons)				
	1999	2010	2015	2020	2030
Agriculture	8,890	5,051	3,759	2,915	2,296
Aircraft	6,549	6,809	7,333	7,885	8,990
Airport Support	123	83	66	58	63
Commercial	3,516	2,331	2,122	2,019	2,080
Commercial Marine Vessel	4,715	5,252	5,499	5,899	7,152
Construction	12,103	7,352	5,662	4,541	3,858
Industrial	2,487	1,212	837	697	718
Lawn/Garden	7,050	3,902	3,633	3,816	4,328
Logging	334	153	117	109	116
Pleasure Craft	2,345	1,548	1,274	1,160	1,147
Railroad	1,895	1,721	1,683	1,624	1,527
Recreational	1,990	2,731	2,365	1,904	1,669
Underground Mining	87	68	56	50	50
Total Nonroad	52,083	38,213	34,406	32,678	33,994

Table 2.2.-21. Tons of Acetaldehyde Emissions from Nonroad Equipment Types, 1999 to 2030.

Equipment Type	Annual Total Nonroad Emissions (Tons)				
	1999	2010	2015	2020	2030
Agriculture	3,986	2,265	1,685	1,306	1,028
Aircraft	2,019	2,098	2,259	2,430	2,770
Airport Support	55	37	30	26	28
Commercial	1,390	999	902	850	866
Commercial Marine Vessel	2,364	2,639	2,768	2,974	3,619
Construction	5,433	3,308	2,550	2,046	1,739
Industrial	1,087	539	372	310	320
Lawn/Garden	2,381	1,522	1,410	1,476	1,670
Logging	133	59	41	37	37
Pleasure Craft	1,615	1,098	920	844	834
Railroad	850	772	755	728	685
Recreational	599	843	743	613	533
Underground Mining	39	30	25	22	23
Total Nonroad	21,952	16,208	14,459	13,663	14,153

Table 2.2.-22. Tons of Acrolein Emissions from Nonroad Equipment Types, 1999 to 2030.

Equipment Type	Annual Total Nonroad Emissions (Tons)				
	1999	2010	2015	2020	2030
Agriculture	232	132	99	77	61
Aircraft	968	1,005	1,083	1,165	1,329
Airport Support	3	2	2	2	2
Commercial	143	89	85	86	94
Commercial Marine Vessel	98	112	118	129	161
Construction	326	195	151	123	105
Industrial	72	33	23	19	19
Lawn/Garden	398	206	195	207	236
Logging	11	5	5	5	5
Pleasure Craft	218	134	106	95	93
Railroad	130	119	117	113	107
Recreational	151	231	194	148	128
Underground Mining	2	2	1	1	1
Total Nonroad	2,754	2,264	2,179	2,168	2,340

Table 2.2.-23. Tons of Naphthalene Emissions from Nonroad Equipment Types, 1999 to 2030.

Equipment Type	Annual Total Nonroad Emissions (Tons)				
	1999	2010	2015	2020	2030
Agriculture	42	26	21	17	12
Aircraft	456	496	530	566	638
Airport Support	1	1	0	0	0
Commercial	104	103	113	125	149
Commercial Marine Vessel	65	68	72	79	102
Construction	56	37	30	22	17
Industrial	26	13	9	6	4
Lawn/Garden	305	245	246	264	303
Logging	2	2	2	1	2
Pleasure Craft	34	36	37	39	42
Railroad	61	44	42	40	35
Recreational	59	112	127	132	136
Underground Mining	0	0	0	0	0
Total Nonroad	1,212	1,182	1,228	1,291	1,440

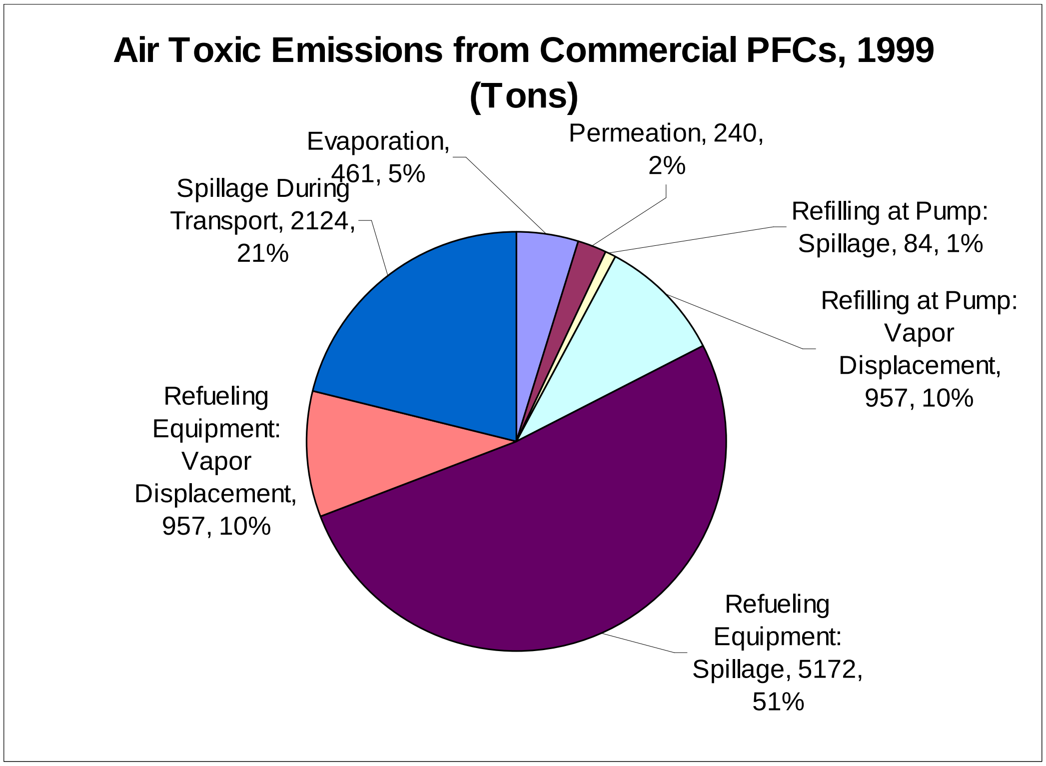
Portable Fuel Containers – Table 2.2.-24 summarizes nationwide emissions of individual air toxics from gasoline in portable fuel containers (PFCs), from 1999 to 2030.

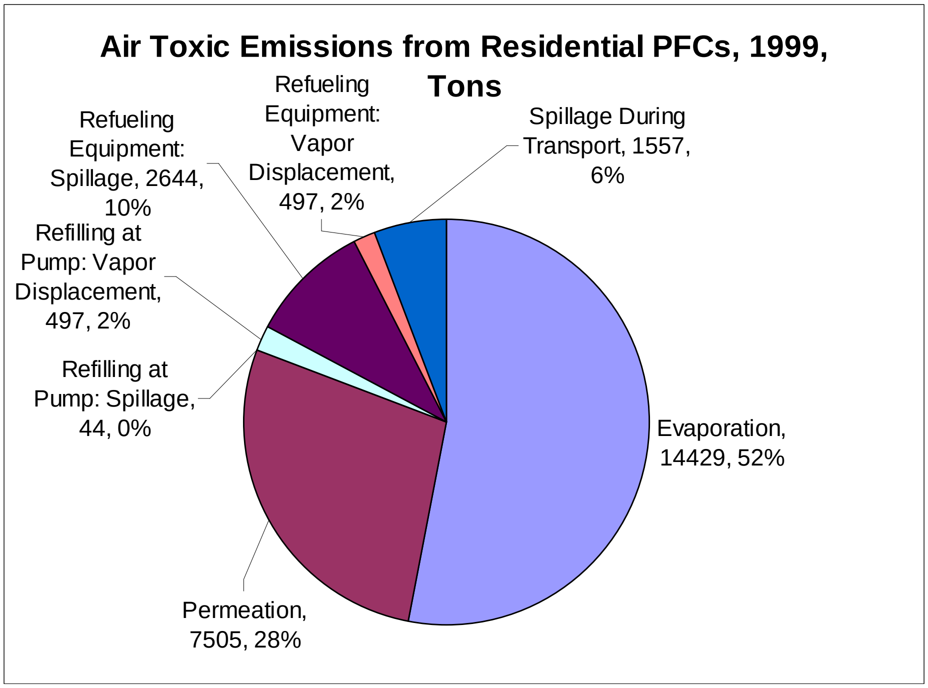
Table 2.2.-24. Tons of Air Toxic Emissions from Portable Fuel Containers, 1999 to 2030.

Pollutant	1999	2010	2015	2020	2030
2,2,4-Trimethylpentane	4,870	4,461	4,741	5,088	5,805
Benzene	853	833	889	953	1,086
Ethyl Benzene	2,135	1,900	2,027	2,175	2,480
Hexane	5,417	5,176	5,532	5,935	6,766
MTBE	6,969	4,763	4,987	5,007	5,503
Naphthalene	1	1	1	1	1
Toluene	10,733	9,668	10,329	11,082	12,636
Xylenes	6,189	5,432	5,800	6,223	7,096
Total	37,166	32,232	34,306	36,464	41,374

About 75% of all HAP emissions and benzene emissions from PFCs are associated with residential use, and the rest are from commercial use. As can be seen in Figure 2.2.-7, most commercial PFC air toxic emissions are associated with equipment refueling, and most residential emissions are associated with evaporation and permeation.

Figure 2.2.-7. Distribution of air toxic emissions (tons) among emission types for commercial versus residential PFCs, 1999.





Diesel Particulate Matter – The inventory estimates presented above for mobile source air toxics do not include diesel particulate matter. Table 2.2.-25 summarizes the trend in diesel particulate matter between 1999 and 2030, by source category. These inventory estimates were obtained from EPA's recently proposed national ambient air quality standard for particulate matter.[55] Diesel particulate matter emissions will be reduced by 75% between 2001 and 2030. As controls on highway diesel engines and nonroad diesel engines phase in, diesel-powered locomotives and commercial marine vessels increase from 13% of the inventory in 2001 to 55% in 2030.

Table 2.2.-25. Percent Contribution of Mobile Source Categories to Diesel Particulate Matter (PM_{10}) Emissions, 2001 to 2030 in Tons Per Year (Percent of Total).

Source	2001	2015	2020	2030
Highway Vehicles	125,162 (36.7%)	37,463 (24.8%)	26,471 (24.4%)	18,135 (21.6%)
Commercial Marine Vessels	20,541 (6%)	17,085 (11.3%)	16,984 (15.7%)	21,388 (25.5%)
Locomotives	25,173 (7.4%)	17,521 (11.6%)	16,535 (15.3%)	25,086 (29.9%)
Other Nonroad Equipment	170,357 (49.9%)	78,930 (52.3%)	48,284 (44.6%)	19,285 (23.0%)

2.2.1.2.2 Impact on Inventory of Controls

The controls being finalized in this rule would reduce air toxic emissions from highway gasoline vehicles, nonroad gasoline equipment, gasoline distribution and portable fuel containers. The total air toxic emissions reduced in the 2030 inventories used for air quality modeling for these sectors are 335,000 tons, and the total benzene emissions reduced are 65,000 tons. It should be emphasized that the air quality, exposure and risk modeling inventory does not account for recent increases in the use of ethanol oxygenated gasoline or implementation of the renewable fuels standard. For inventories which include these emissions, see Section 2.2.2.2.

Table 2.2.-26 summarizes the nationwide impact of the controls on emissions of key air toxics from highway vehicles in 2015, 2020, and 2030. The reductions in highway vehicle air toxic emissions by 2030 are dramatic, about 35%. Benzene reductions are over 40%. Nonroad equipment emissions are impacted by fuel benzene control, which result in reductions of about 14% for that pollutant (Table 2.2.-27). Emissions from PFCs will be impacted by both controls on the containers themselves as well as the fuel benzene standard (Table 2.2-28), with reductions in total air toxic emissions of over 60% in 2030, and reductions in benzene of about 80%. In addition, fuel benzene controls would reduce emissions within the gasoline distribution sector. Table 2.2.-29 presents estimated reductions for this source in 2015 and 2020, which total over 30%, due to the fuel benzene standard. Figures 2.2.-8 and 2.2.-9 depict the trend in total MSAT and benzene emissions for all sources with the controls being finalized in this rule. More detailed summaries of emissions by individual pollutant, by State, and for urban versus rural areas can be found in Excel workbooks included in the docket for this rule.

Table 2.2.-26. Nationwide Impact of Controls on Emissions of Gaseous Air Toxics from Highway Vehicles in 2015, 2020, and 2030.

	Annual Emissions (tons) by Vehicle Type								
Pollutant	**2015 Reference Case**	**2015 Control Case**	**2015 Reduction**	**2020 Reference Case**	**2020 Control Case**	**2020 Reduction**	**2030 Reference Case**	**2030 Control Case**	**2030 Reduction**
1,3-Butadiene	10,763	9,160	1,602	11,355	8,655	2,700	13,378	8,707	4,670
2,2,4-Trimethylpentane	94,469	80,630	13,840	96,315	73,103	23,212	110,895	72,262	38,634
Acetaldehyde	16,149	13,970	2,180	16,893	13,222	3,671	19,879	13,677	6,202
Acrolein	1,650	1,458	192	1,704	1,382	322	1,981	1,434	548
Benzene	105,956	79,034	26,922	110,317	73,141	37,176	129,290	72,673	56,617
Ethyl Benzene	37,528	32,189	5,339	38,080	29,117	8,962	43,676	28,770	14,906
Formaldehyde	35,857	31,475	4,382	37,153	29,877	7,276	43,404	31,196	12,207
Hexane	33,481	30,802	2,679	30,727	26,241	4,486	32,435	25,832	6,602
MTBE	23,089	22,363	725	18,372	17,226	1,146	17,109	16,080	1,029
Propionaldehyde	2,154	1,925	230	2,222	1,837	385	2,574	1,919	655
Styrene	7,368	6,134	1,234	7,814	5,743	2,071	9,253	5,720	3,533
Toluene	250,646	212,901	37,745	257,367	194,002	63,365	297,748	191,607	106,141
Xylenes	141,710	120,444	21,266	145,473	109,772	35,701	168,285	108,480	59,805
Total	**760,821**	**642,486**	**118,336**	**773,793**	**583,319**	**190,474**	**889,908**	**578,358**	**311,549**

Table 2.2.-27. Nationwide Impact of Controls on Emissions of Key Air Toxics from all Nonroad Equipment in 2015, 2020, and 2030.

	Annual Emissions (tons)								
Pollutant	**2015 Reference Case**	**2015 Control Case**	**2015 Reduction**	**2020 Reference Case**	**2020 Control Case**	**2020 Reduction**	**2030 Reference Case**	**2030 Control Case**	**2030 Reduction**
1,3-Butadiene	6586	6599	-13	6518	6530	-12	7004	7017	-13
Acetaldehyde	14459	14468	-9	13663	13671	-8	14153	14162	-9
Acrolein	2179	2179	0	2168	2168	0	2340	2340	0
Benzene	49985	43220	6265	48453	41736	6717	51647	44427	7220
Formaldehyde	34406	34433	-27	32678	32703	-25	33994	34020	-26
5 MSAT Total	**107615**	**101418**	**6197**	**103480**	**97339**	**6141**	**109138**	**102528**	**6610**

Table 2.2.-28. Nationwide Impact of Controls on Emissions of Air Toxics from Portable Fuel Containers in 2010, 2015, 2020, and 2030.

			Annual Emissions (tons)					
Pollutant	2010 Reference Case	2010 Control Case	2015 Reference Case	2015 Control Case	2020 Reference Case	2020 Control Case	2030 Reference Case	2030 Control Case
2,2,4-Trimethylpentane	4,461	4,003	4,741	1,864	5,088	2,012	5,805	2,315
Benzene	833	752	889	179	953	193	1,086	222
Ethyl Benzene	1,900	1,700	2,027	756	2,175	816	2,480	939
Hexane	5,176	4,622	5,532	1,932	5,935	2,085	6,766	2,399
MTBE	4,763	4,295	4,987	2,360	5,007	2,382	5,503	2,638
Naphthalene	1	1	1	0	1	0	1	0
Toluene	9,668	8,646	10,329	3,752	11,082	4,050	12,636	4,658
Xylenes	5,432	4,862	5,800	2,157	6,223	2,328	7,096	2,678
Total	32,232	28,880	34,306	13,000	36,464	13,867	41,374	15,849

Table 2.2.-29. Nationwide Impact of Controls Emissions of Benzene from Gasoline Distribution in 2015 and 2020 (2030 Assumed to be the Same as 2020).

Annual Emissions (tons)					
2015 Reference Case	2015 Control Case	2015 Reduction	2020 Reference Case	2020 Control Case	2020 Reduction
2,160	1,460	700	2,234	1,516	719

Figure 2.2.-8. Contribution of Source Categories to Mobile Source Air Toxic Emissions, 1999 to 2030, with Final Rule Standards in Place (Not Including Diesel Particulate Matter).

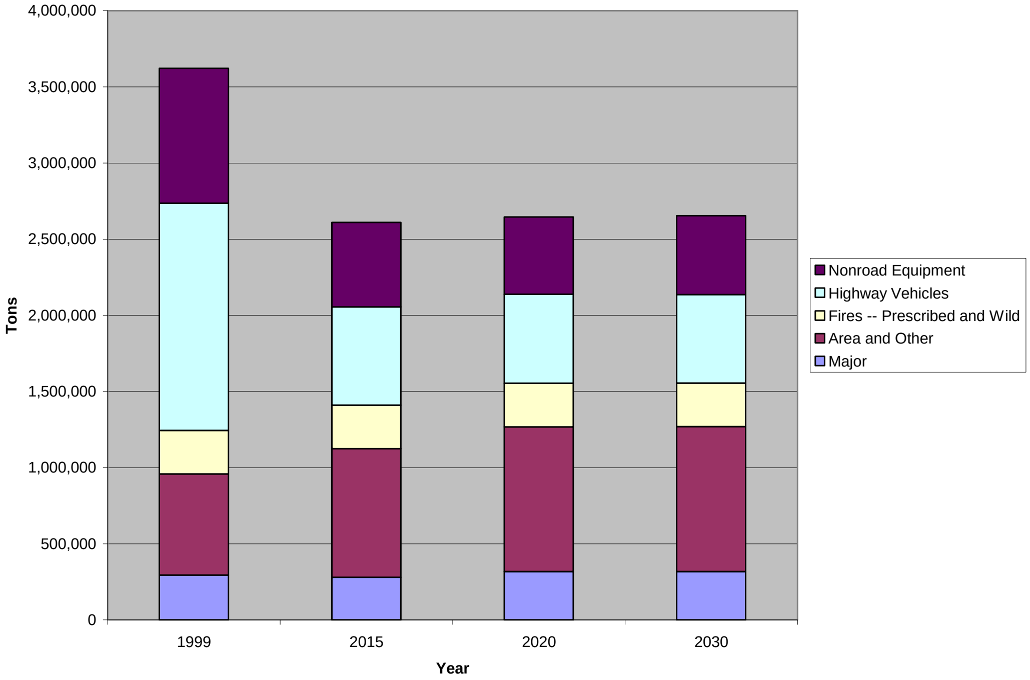
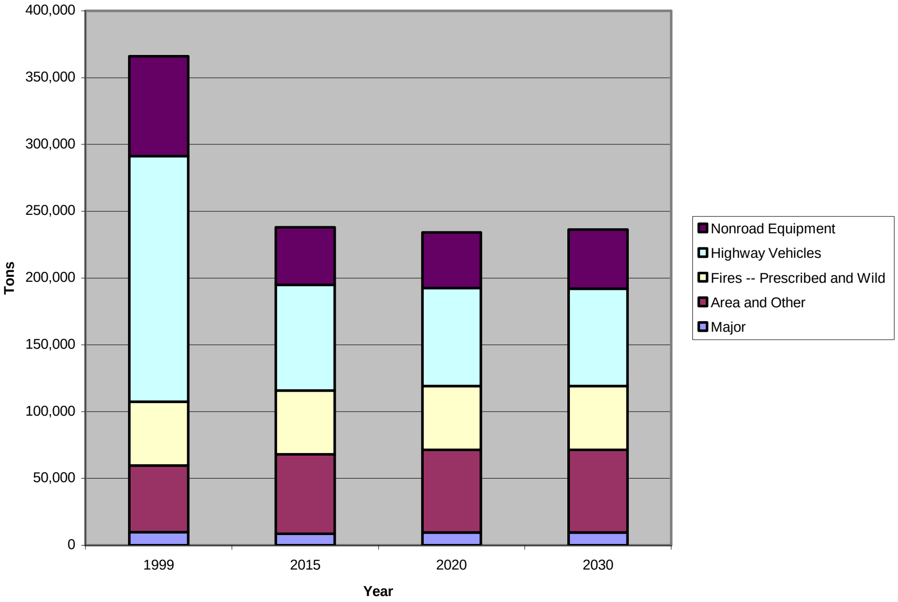


Figure 2.2.-9. Contribution of Source Categories to Mobile Source Benzene Emissions, 1999 to 2030, with Final Rule Standards in Place.



2.2.2 Emission Reductions from Controls

Section 2.2.2 describes revisions made to emission inventories after we developed MSAT inventories for air quality modeling ("air quality inventories"). The primary revision is accounting for the impacts of implementing the federal Renewable Fuel Standard (RFS). The revised inventories were used to estimate emission benefits of the rule and the cost-effectiveness of the control strategies. We refer to the revised inventories as "cost-effectiveness inventories" in this section to distinguish them from the air quality inventories discussed in Section 2.2.1.

2.2.2.1 Methodology Changes from Air Quality Inventories

2.2.2.1.1 Highway Vehicles

The fundamental difference between the air quality and cost-effectiveness inventories is the use of fuel parameters that reflect implementation of the Renewable Fuel Standard (RFS fuel), as described in Section 2.1.1. We also corrected a minor error which addresses how MOBILE6.2 calculates benzene evaporative emissions with ethanol oxygenated fuel. In addition, for the control case, aromatics levels were adjusted using a different algorithm to calculate additive adjustment factors:

$$\text{Additive Factor} = 1.0\,(\text{BZ(control)} - \text{BZ(ref)}) \qquad (11)$$

Where BZ = benzene

We assume that with increased ethanol use, when fuel benzene is reduced there will be no increase in other aromatic levels to help compensate for octane loss. An Excel workbook with all the fuel parameters used, "MSAT Fuels Cost Effectiveness.xls," is included in the docket for this rule. Also, we estimated vehicle refueling emissions using NMIM 2005, instead of projecting them from the 1999 NEI, as discussed in Section 2.2.1. Finally, it should be noted that inventories do not account increased permeation due to ethanol use, nor do they account for the 1.3 vol% maximum average fuel benzene level.

2.2.2.1.2 Nonroad Equipment

Unlike the air quality inventories, the cost-effectiveness inventories for nonroad equipment used the RFS fuel as described in Section 2.1. As with the air quality inventories, we assumed that changes in county-level exhaust and evaporative emissions of nonroad gasoline equipment were proportional to changes in highway light-duty gasoline vehicle emissions. It should be noted that our inventories did not account for increased hose and tank permeation associated with increased ethanol use. As a result, our estimates of emission reductions from fuel benzene control may be slightly underestimated.

2.2.2.1.3 Portable Fuel Containers

The RFS fuel was used to develop cost-effectiveness inventories for PFCs, as described in Section 2.1. Air toxic inventories for PFCs for the reference and control cases were developed by speciating VOC, following the same approach used for the air quality modeling inventories (See Section 2.2.1.1.4). However, since the air quality modeling inventories did not account for RFS fuel, we used revised highway gasoline vehicle inventories for benzene and VOC from refueling that did account for RFS fuel to develop benzene to VOC ratios, and total evaporative emission ratios for other air toxics.

2.2.2.1.4 Gasoline Distribution

Gasoline distribution inventories were also revised to account for the RFS fuel. The reference case (RC) inventory was estimated for each source category (SCC code) at the county level as follows:

$$\begin{aligned}&Gas\,Distr.\,Benzene\,Emissions\,RC_{SCC\ YYY,\ County\ Z,\ RFS\ 9.6\,Max} = \\ &Gas\,Distr.\,Benzene\,RC\ Emissions_{SCC\ YYY,\ County\ Z,\ Final\ Rule\ AQ\ Inventory} \times \left(\frac{Nonrefueling\ evap\ Benzene\ RC_{LDGV,\ County\ Z,\ RFS\ 9.6Max}}{Nonrefueling\ evap\ Benzene\ RC_{LDGV,\ County\ Z,\ AQ\ Inventory}} \right) \qquad 12)\end{aligned}$$

Where,
Final Rule AQ Inventory = the inventory for SCC code YYY in county Z from the air quality inventory, as discussed in Section 2.2.1
RFS Max 9.6 = the inventory for SCC code YYY in county Z assuming 9.6 billion gallons of national ethanol consumption nationwide, attributing as much as possible for use as an oxygenate in reformulated gasoline.

The air quality inventory was adjusted using ratios of non-refueling evaporative emissions, because the methodology for estimating refueling emissions differed for the air quality inventory versus the final rule inventory, as discussed above.

The control case (CC) inventory was estimated using the following equation:

$$\begin{aligned}&Gas\,Distr.\,Benzene\ Emissions\ CC_{SCC\ YYY,\ County\ Z,\ RFS\ 9.6\,Max} = \\ &Gas\,Distr.\,Benzene\ RC\ Emissions_{SCC\ YYY,\ County\ Z,\ RFS9.6Max} \times \left(\frac{\mathrm{Re}\ fueling\ Benzene\ CC_{LDGV,\ County\ Z,\ RFS\ 9.6Max}}{\mathrm{Re}\ fueling\ Benzene\ RC_{LDGV,\ County\ Z,\ RFS\ 9.6\ Max}} \right) \qquad (13)\end{aligned}$$

2.2.2.2 Estimated Reductions for Air Toxic Pollutants of Greatest Concern

The following sections present control case inventories and reductions for each individual control, and then cumulative reductions for all controls combined.

2.2.2.2.1 Fuel Benzene Standard

Highway Gasoline Vehicles – The fuel benzene standard will reduce emissions from light-duty gasoline vehicles and trucks, motorcycles, and heavy-duty gasoline trucks. Tables 2.2.-30, 2.2.-31, and 2.2.-32 present nationwide benzene emissions for these vehicle classes with and without the fuel standard in 2015, 2020, and 2030. Total benzene emissions from these vehicle classes were 178,000 tons in 1999. Since impacts of fuel benzene control on emissions of other MSATs are negligible (see Section 2.2.1.2), they are not presented here, although they are available in the docket for the rule.

Table 2.2.-30. Impact of Fuel Benzene Control on Benzene Emissions from Highway Vehicles, by Class, 2015.

Vehicle Class	Reference Case Tons	Control Case Tons	Reduction
LDGV	37,881	33,766	4,115
LDGT1	39,657	35,279	4,378
LDGT2	17,696	15,658	2,037
MC	773	663	110
HDGV	1,782	1,509	273
TOTAL	97,789	86875	10914

Table 2.2.-31. Impact of Fuel Benzene Control on Benzene Emissions from Highway Vehicles, by Class, 2020.

Vehicle Class	Reference Case Tons	Control Case Tons	Reduction
LDGV	35,987	32,213	3,774
LDGT1	44,611	39,849	4,762
LDGT2	18,627	16,572	2,056
MC	833	714	118
HDGV	1,456	1,240	215
TOTAL	101514	90,588	10926

Table 2.2.-32. Impact of Fuel Benzene Control on Benzene Emissions from Highway Vehicles, by Class, 2030.

Vehicle Class	Reference Case Tons	Control Case Tons	Reduction
LDGV	42,752	38,345	4,407
LDGT1	52,993	47,477	5,516
LDGT2	20,996	18,738	2,259
MC	1,002	861	141
HDGV	1,273	1,081	192
TOTAL	119016	106502	12514

Reductions from the fuel benzene control vary significantly across the U.S., depending on the average level of benzene in gasoline sold, as discussed in Section 2.2.1.2 on air quality modeling inventories. Table 2.2.-33 summarizes impacts of fuel benzene control on the benzene emission inventory for gasoline vehicles in each State in 2030.

Table 2.2.-33. Impacts of Fuel Control on Gasoline Vehicle Benzene by State in 2030.

State	2030 Reference Case Tons	2030 Control Case Tons	2030 Tons Reduced	% Change
ALABAMA	2,260.4	2,013.9	246.4	10.9
ALASKA	1,304.4	895.8	408.7	31.3
ARIZONA	1,788.9	1,631.6	157.4	8.8
ARKANSAS	1,349.2	1,197.4	151.8	11.3
CALIFORNIA	9,422.4	9,387.8	34.6	0.4
COLORADO	2,728.3	2,359.2	369.2	13.5
CONNECTICUT	1,033.1	1,019.1	14.0	1.4
DELAWARE	269.6	265.7	3.9	1.4
DISTRICT OF COLUMBIA	112.0	110.5	1.5	1.3
FLORIDA	4,175.1	3,687.3	487.8	11.7
GEORGIA	4,176.9	3,781.8	395.1	9.5
HAWAII	189.7	188.9	0.7	0.4
IDAHO	1,149.1	969.7	179.5	15.6
ILLINOIS	4,075.3	3,740.6	334.8	8.2
INDIANA	3,392.9	2,956.3	436.6	12.9
IOWA	1,580.3	1,354.9	225.4	14.3
KANSAS	1,385.9	1,154.5	231.4	16.7
KENTUCKY	1,988.4	1,749.9	238.5	12.0
LOUISIANA	1,540.8	1,356.0	184.8	12.0
MAINE	668.5	639.8	28.7	4.3
MARYLAND	1,716.1	1,667.0	49.2	2.9
MASSACHUSETTS	1,690.7	1,667.2	23.4	1.4
MICHIGAN	5,642.0	4,827.3	814.8	14.4
MINNESOTA	4,086.7	3,349.5	737.2	18.0
MISSISSIPPI	967.8	856.5	111.3	11.5
MISSOURI	2,839.5	2,471.7	367.8	13.0
MONTANA	795.0	675.0	120.0	15.1
NEBRASKA	985.5	831.7	153.8	15.6
NEVADA	1,021.5	969.3	52.2	5.1
NEW HAMPSHIRE	641.0	614.6	26.4	4.1
NEW JERSEY	1,858.8	1,833.1	25.6	1.4
NEW MEXICO	1,739.4	1,448.3	291.0	16.7
NEW YORK	4,519.9	4,278.1	241.8	5.3
NORTH CAROLINA	3,922.7	3,521.1	401.6	10.2
NORTH DAKOTA	515.0	430.1	84.9	16.5
OHIO	4,619.9	4,005.6	614.3	13.3
OKLAHOMA	1,808.7	1,609.1	199.6	11.0
OREGON	3,724.9	3,108.3	616.6	16.6
PENNSYLVANIA	4,102.3	3,821.3	281.0	6.8
RHODE ISLAND	324.4	320.0	4.4	1.4
SOUTH CAROLINA	2,038.9	1,833.7	205.2	10.1
SOUTH DAKOTA	523.5	447.6	75.8	14.5
TENNESSEE	2,545.4	2,239.0	306.3	12.0
TEXAS	6,294.5	5,651.4	643.1	10.2
UTAH	1,731.2	1,488.9	242.3	14.0
VERMONT	463.7	428.1	35.6	7.7
VIRGINIA	3,312.0	3,109.4	202.6	6.1
WASHINGTON	5,856.9	4,888.8	968.1	16.5
WEST VIRGINIA	862.5	759.9	102.6	11.9
WISCONSIN	2,693.8	2,397.2	296.6	11.0
WYOMING	581.2	491.5	89.7	15.4

Gasoline Nonroad Equipment – Table 2.2.-34 summarizes the nationwide impact of the fuel benzene control on benzene emissions from gasoline nonroad equipment. As with highway gasoline vehicles, emission benefits vary across the U. S. As can be seen in Table 2.2.-35, these benefits vary from 1 to 31% by State in 2030.

Table 2.2-34. Nationwide Impact of Fuel Benzene Control on Benzene Emissions from Nonroad Gasoline Equipment.

	Tons
2015 Reference Case	41,343
2015 Control Case	35,825
2015 Reduction	5,518
2020 Reference Case	40,161
2020 Control Case	34,717
2020 Reduction	5,444
2030 Reference Case	42,994
2030 Control Case	37168
2030 Reduction	5,826

Portable Fuel Containers –Table 2.2.-36 summarizes MSAT emissions from PFCs with no fuel benzene or federal PFC control (but including State control programs). The fuel benzene control will reduce benzene emissions from PFCs, as summarized in Table 2.2.-37. Again, emission benefits vary across the U. S., as seen in Table 2.2.-38.

Gasoline Distribution –Table 2.2.-39 presents the benzene inventory from gasoline distribution (not including refueling) in 2015 and 2020 with and without the fuel benzene control. Table 2.2.-40 presents the inventory for 2020 at the State level with and without fuel benzene control. More detailed inventory estimates by county are available in the docket for the rule.

Table 2.2.-35. Gasoline Nonroad Equipment Benzene Emission Reductions (Tons) from Fuel Control by State, 2030.

State	2030 Reference Case Tons	2030 Control Case Tons	2030 Tons Reduced	% Change
ALABAMA	1,024.8	830.6	194.2	19.0
ALASKA	188.3	129.4	58.9	31.3
ARIZONA	715.3	615.1	100.2	14.0
ARKANSAS	637.6	514.1	123.5	19.4
CALIFORNIA	4,055.2	4,032.6	22.6	0.6
COLORADO	623.4	525.5	97.9	15.7
CONNECTICUT	412.9	403.5	9.4	2.3
DELAWARE	98.2	95.8	2.4	2.5
DISTRICT OF COLUMBIA	28.1	27.4	0.8	2.8
FLORIDA	3,752.5	3,070.6	682.0	18.2
GEORGIA	1,576.1	1,324.2	251.9	16.0
HAWAII	127.6	126.7	0.9	0.7
IDAHO	285.1	232.3	52.8	18.5
ILLINOIS	1,298.3	1,192.6	105.7	8.1
INDIANA	722.9	605.6	117.4	16.2
IOWA	489.1	404.2	84.9	17.4
KANSAS	309.2	245.4	63.7	20.6
KENTUCKY	483.1	403.6	79.5	16.4
LOUISIANA	1,133.7	896.6	237.1	20.9
MAINE	257.3	238.2	19.0	7.4
MARYLAND	789.2	737.3	52.0	6.6
MASSACHUSETTS	678.8	663.1	15.7	2.3
MICHIGAN	1,585.6	1,288.9	296.7	18.7
MINNESOTA	900.5	708.8	191.7	21.3
MISSISSIPPI	534.4	428.8	105.6	19.8
MISSOURI	778.8	654.7	124.1	15.9
MONTANA	133.6	110.3	23.3	17.5
NEBRASKA	209.1	168.4	40.8	19.5
NEVADA	310.3	279.1	31.2	10.0
NEW HAMPSHIRE	270.3	245.4	24.9	9.2
NEW JERSEY	1,053.7	1,029.4	24.3	2.3
NEW MEXICO	266.5	208.0	58.5	21.9
NEW YORK	2,366.1	2,154.0	212.1	9.0
NORTH CAROLINA	1,654.7	1,382.2	272.5	16.5
NORTH DAKOTA	107.2	86.0	21.2	19.8
OHIO	1,329.4	1,100.3	229.1	17.2
OKLAHOMA	596.0	483.6	112.4	18.9
OREGON	639.2	514.6	124.7	19.5
PENNSYLVANIA	1,516.0	1,353.4	162.6	10.7
RHODE ISLAND	110.5	108.0	2.5	2.2
SOUTH CAROLINA	907.6	749.8	157.8	17.4
SOUTH DAKOTA	109.5	89.0	20.5	18.7
TENNESSEE	739.7	606.4	133.3	18.0
TEXAS	3,156.9	2,688.5	468.5	14.8
UTAH	356.5	294.5	62.0	17.4
VERMONT	134.2	116.4	17.8	13.3
VIRGINIA	1,105.1	990.5	114.7	10.4
WASHINGTON	1,039.3	841.3	198.0	19.0
WEST VIRGINIA	326.6	269.3	57.3	17.5
WISCONSIN	962.0	815.1	146.9	15.3
WYOMING	107.4	87.8	19.6	18.2

Table 2.2.-36. MSAT Emissions (Tons) from Uncontrolled PFCs (No Fuel Benzene Control, No Federal PFC Control, But Including State Programs)

Pollutant	1999	2010	2015	2020	2030
2,2,4-Trimethylpentane	4,870	4,994	5,195	5,573	6,353
Benzene	853	943	992	1,063	1,210
Ethylbenzene	2,135	1,805	1,884	2,021	2,303
n-Hexane	5,417	4,679	4,895	5,250	5,981
MTBE	6,969	0	0	0	0
Naphthalene	1	1	1	1	1
Toluene	10,733	8,764	9,161	9,825	11,195
Xylenes	6,189	5,004	5,226	5,605	6,387
TOTAL	37,167	21,186	27,354	29,338	33,430

Table 2.2.-37. Reduction in Benzene PFC Emissions (Tons) with Fuel Control (No Control on PFC Emissions).

Year	Reference Case	Control Case	Reduction
1999	853	N.A.	N.A.
2015	992	619	373
2020	1,063	664	399
2030	1,210	756	454

Table 2.2.-38. Reduction in Benzene PFC Emissions (Tons) with Fuel Control in 2030 by State (No Additional Control on PFC Emissions).

State	Reference Case Tons	Control Case Tons	Reduction	% Change
ALABAMA	33.1	19.1	14.0	42.3
ALASKA	19.3	11.6	7.7	40.0
ARIZONA	25.8	15.5	10.3	40.0
ARKANSAS	23.7	13.5	10.2	43.0
CALIFORNIA	36.4	35.7	0.7	2.0
COLORADO	31.5	19.8	11.7	37.0
CONNECTICUT	3.5	3.2	0.3	8.0
DELAWARE	1.1	1.0	0.1	8.0
DISTRICT OF COLUMBIA	0.4	0.4	0.0	8.0
FLORIDA	138.2	82.9	55.3	40.0
GEORGIA	42.5	25.5	17.0	40.0
HAWAII	5.1	5.0	0.1	2.0
IDAHO	12.8	8.1	4.7	37.0
ILLINOIS	42.6	32.9	9.6	22.6
INDIANA	38.0	21.4	16.6	43.7
IOWA	20.8	11.2	9.6	46.0
KANSAS	20.8	11.2	9.6	46.0
KENTUCKY	25.3	16.1	9.2	36.4
LOUISIANA	39.2	22.4	16.9	43.0
MAINE	1.7	1.3	0.3	20.0
MARYLAND	7.0	6.2	0.9	12.5
MASSACHUSETTS	5.9	5.4	0.5	8.0
MICHIGAN	64.1	34.6	29.5	46.0
MINNESOTA	40.9	22.1	18.8	46.0
MISSISSIPPI	24.6	14.0	10.6	43.0
MISSOURI	31.7	19.9	11.8	37.2
MONTANA	8.0	5.1	3.0	37.0
NEBRASKA	12.7	6.8	5.8	46.0
NEVADA	11.9	7.8	4.1	34.5
NEW HAMPSHIRE	1.7	1.4	0.3	16.5
NEW JERSEY	8.7	8.0	0.7	8.0
NEW MEXICO	14.0	8.0	6.0	43.0
NEW YORK	17.9	14.4	3.5	19.6
NORTH CAROLINA	54.9	32.9	21.9	40.0
NORTH DAKOTA	4.5	2.4	2.1	46.0
OHIO	33.3	18.0	15.3	46.0
OKLAHOMA	20.8	11.3	9.6	46.0
OREGON	29.9	17.9	12.0	40.0
PENNSYLVANIA	16.3	11.5	4.8	29.5
RHODE ISLAND	0.9	0.9	0.1	8.0
SOUTH CAROLINA	31.5	18.9	12.6	40.0
SOUTH DAKOTA	4.8	2.6	2.2	46.0
TENNESSEE	41.8	22.6	19.2	46.0
TEXAS	42.5	30.6	12.0	28.1
UTAH	16.7	10.5	6.2	37.0
VERMONT	0.8	0.5	0.3	40.0
VIRGINIA	11.5	8.9	2.6	22.5
WASHINGTON	44.5	26.7	17.8	40.0
WEST VIRGINIA	14.3	8.6	5.7	40.0
WISCONSIN	26.0	16.9	9.1	34.9
WYOMING	4.2	2.7	1.6	37.0

Table 2.2.-39. Nationwide Impact of Controls on Emissions of Benzene from Gasoline Distribution in 2015 and 2020.

	2015 Reference Case	2015 Control Case	2015 Reduction	2020 Reference Case	2020 Control Case	2020 Reduction
Tons of Benzene	2,445	1,635	810	2,621	1,772	849

Table 2.2.-40. Reduction in Gasoline Distribution Emissions of Benzene (Tons) with Fuel Benzene Control by State, 2020.

State	Reference Case Tons	Control Case Tons	Reduction	% Change
ALABAMA	34.0	19.6	14.4	42.4
ALASKA	3.0	1.8	1.2	40.0
ARIZONA	40.9	24.6	16.4	40.0
ARKANSAS	16.5	9.4	7.1	43.0
CALIFORNIA	98.0	96.1	2.0	2.0
COLORADO	27.5	17.3	10.2	37.0
CONNECTICUT	18.6	17.1	1.5	8.0
DELAWARE	3.4	3.1	0.3	8.0
DISTRICT OF COLUMBIA	3.4	3.1	0.3	8.0
FLORIDA	88.4	53.1	35.4	40.0
GEORGIA	36.6	22.0	14.6	40.0
HAWAII	3.1	3.1	0.1	2.0
IDAHO	20.2	12.7	7.5	37.0
ILLINOIS	98.6	69.0	29.6	30.0
INDIANA	41.2	23.7	17.5	42.5
IOWA	53.6	29.0	24.7	46.0
KANSAS	70.0	37.8	32.2	46.0
KENTUCKY	48.4	28.4	20.0	41.3
LOUISIANA	108.9	62.1	46.8	43.0
MAINE	21.4	16.3	5.1	23.9
MARYLAND	34.1	28.6	5.5	16.1
MASSACHUSETTS	25.0	23.0	2.0	8.0
MICHIGAN	82.3	44.5	37.9	46.0
MINNESOTA	74.3	40.1	34.2	46.0
MISSISSIPPI	42.6	24.3	18.3	43.0
MISSOURI	26.6	16.6	9.9	37.4
MONTANA	12.0	7.5	4.4	37.0
NEBRASKA	11.1	6.0	5.1	46.0
NEVADA	7.8	5.7	2.1	27.1
NEW HAMPSHIRE	3.9	3.2	0.6	16.7
NEW JERSEY	41.7	38.3	3.3	8.0
NEW MEXICO	26.3	15.0	11.3	43.0
NEW YORK	359.7	313.4	46.3	12.9
NORTH CAROLINA	36.2	21.7	14.5	40.0
NORTH DAKOTA	9.3	5.0	4.3	46.0
OHIO	89.7	48.4	41.3	46.0
OKLAHOMA	61.0	32.9	28.1	46.0
OREGON	118.6	71.2	47.4	40.0
PENNSYLVANIA	72.7	46.1	26.6	36.6
RHODE ISLAND	4.7	4.4	0.4	8.0
SOUTH CAROLINA	19.9	11.9	8.0	40.0
SOUTH DAKOTA	6.5	3.5	3.0	46.0
TENNESSEE	57.9	31.3	26.7	46.0
TEXAS	344.2	243.6	100.6	29.2
UTAH	25.5	16.0	9.4	37.0
VERMONT	1.2	0.7	0.5	40.0
VIRGINIA	42.1	29.8	12.3	29.2
WASHINGTON	57.1	34.3	22.8	40.0
WEST VIRGINIA	55.2	33.1	22.1	40.0
WISCONSIN	23.7	15.1	8.6	36.4
WYOMING	11.8	7.4	4.4	37.0

2.2.2.2.2 Cold Temperature VOC Emission Control

Reductions in MSATs are proportional to reduced NMHC start emissions from vehicles subject to this rule. The magnitude of the reductions from these vehicles operating on a given gasoline is based entirely on the number and duration of events between engine off and engine on (vehicle soak) and the ambient conditions. The emissions reduced are those created by the engine start following the vehicle soak. These parameters are currently modeled by vehicle class and vehicle age in MOBILE6.2.[56, 57, 58, 59] MOBILE6.2 also provides the necessary information to adjust MSAT emission factors to account for geographic and seasonal effects on in-use fuels.

When all the affected vehicle classes meet the new emission standard we expect a 60% reduction of benzene and 1,3-butadiene from gasoline-fueled highway vehicles with GVWR ≤ 6000 lbs and 30% from gasoline-fueled highway vehicles with GVWR > 6000 lbs. This estimate does not include the effects of fuel benzene control. Effects on the trends in the inventories for the affected MSATs are shown in Table 2.2.-41 through Table 2.2.-45.

Table 2.2.-41. Reference Case, Light-Duty Gasoline Vehicles and Trucks, 1999 MSAT Inventory.

Pollutant	Emissions in Tons
1,3-Butadiene	20,868
2,2,4-Trimethylpentane	175,241
Acetaldehyde	21,035
Acrolein	2,234
Benzene	173,474
Ethyl Benzene	69,299
Formaldehyde	54,104
n-Hexane	61,664
MTBE	54,990
Propionaldehyde	2440
Styrene	13,070
Toluene	464,646
Xylenes	262,298
Total MSATs	1,376,002

Table 2.2.-42. Reference and Vehicle Control Case, Light-Duty Gasoline Vehicles and Trucks, 2010 MSAT Inventories.

Pollutant	Reference Case Tons in Calendar Year 2010	Vehicle Control Case Tons in Calendar Year 2010	Reduction in Tons	Percent Reduction
1,3-Butadiene	9,159	8,417	742	8
2,2,4-Trimethylpentane	95,194	88,628	6,566	7
Acetaldehyde	16,680	15,220	1,460	9
Acrolein	1,132	1,041	91	8
Benzene	99,559	91,621	7,939	8
Ethyl Benzene	36,001	33,489	2,512	7
Formaldehyde	23,466	21,371	2,095	9
n-Hexane	32,850	31,590	1,260	4
MTBE	0	0	0	0
Propionaldehyde	1254	1144	110	9
Styrene	6,688	6,107	581	9
Toluene	238,683	220,939	17,744	7
Xylenes	134,742	124,744	9,998	7
Total MSATs	695,408	644,312	51,987	7

Table 2.2.-43. Reference and Vehicle Control Case, Light-Duty Vehicles, 2015 MSAT Inventories.

Pollutant	Reference Case Tons in Calendar Year 2015	Vehicle Control Case Tons in Calendar Year 2015	Reduction in Tons	Percent Reduction
1,3-Butadiene	8,635	7,083	1,552	18
2,2,4-Trimethylpentane	87,857	73,956	13,901	16
Acetaldehyde	16,253	13,123	3,131	19
Acrolein	1,080	887	193	18
Benzene	95,234	78,664	16,570	17
Ethyl Benzene	33,276	27,970	5,305	16
Formaldehyde	22,657	18,298	4,359	19
n-Hexane	27,699	25,034	2,665	10
MTBE	0	0	0	0
Propionaldehyde	1216	985	231	19
Styrene	6,481	5,254	1,227	19
Toluene	223,510	186,031	37,480	17
Xylenes	126,114	104,997	21,117	17
Total MSATs	650,012	542,281	107,731	17

Table 2.2.-44. Reference and Vehicle Control Case, Light-Duty Vehicles, 2020 MSAT Inventories.

Pollutant	Reference Case Tons in Calendar Year 2020	Vehicle Control Case Tons in Calendar Year 2020	Reduction in Tons	Percent Reduction
1,3-Butadiene	9,131	6,592	2,539	28
2,2,4-Trimethylpentane	89,711	66,807	22,904	26
Acetaldehyde	17,345	12,143	5,203	30
Acrolein	1,139	822	317	28
Benzene	99,225	72,128	27,097	27
Ethyl Benzene	33,992	25,268	8,724	26
Formaldehyde	24,007	16,922	7,086	30
n-Hexane	25,765	21,380	4,385	17
MTBE	0	0	0	0
Propionaldehyde	1293	914	379	29
Styrene	6,898	4,880	2,018	29
Toluene	230,933	169,303	61,630	27
Xylenes	130,267	95,543	34,725	27
Total MSATs	669,707	492,700	177,007	26

Table 2.2.-45. Reference and Vehicle Control Case, Light-Duty Vehicles, 2030 MSAT Inventories.

Pollutant	Reference Case Tons in Calendar Year 2030	Vehicle Control Case Tons in Calendar Year 2030	Reduction in Tons	Percent Reduction
1,3-Butadiene	10,798	6,540	4,257	39
2,2,4-Trimethylpentane	104,511	66,317	38,194	37
Acetaldehyde	20,663	12,064	8,599	42
Acrolein	1,347	818	529	39
Benzene	116,742	71,704	45,037	39
Ethyl Benzene	39,603	25,053	14,551	37
Formaldehyde	28,529	16,897	11,632	41
n-Hexane	28,437	21,125	7,312	26
MTBE	0	0	0	0
Propionaldehyde	1540	907	633	41
Styrene	8,207	4,841	3,366	41
Toluene	270,625	167,829	102,796	38
Xylenes	152,647	94,728	57,919	38
Total MSATs	783,648	488,824	294,824	38

State-level reductions in calendar year 2030 benzene inventories are reported in Table 2.2.-46.

Table 2.2.-46. Impacts of Vehicle Control on Light-Duty Gasoline Vehicle Benzene Emissions, by State in 2030

State	2030 Reference Case Benzene Tons in Calendar 2030	2030 Control Case Benzene Tons in Calendar 2030	Reduction (Tons)	Percent Reduction
ALABAMA	2,199.4	1,562.7	636.6	28.9
ALASKA	1,293.1	652.7	640.4	49.5
ARIZONA	1,734.6	1,190.5	544.1	31.4
ARKANSAS	1,323.0	900.4	422.5	31.9
CALIFORNIA	9,286.2	5,634.4	3,651.7	39.3
COLORADO	2,674.7	1,560.6	1,114.1	41.7
CONNECTICUT	1,019.9	540.4	479.6	47.0
DELAWARE	264.8	148.9	115.9	43.8
DISTRICT OF COLUMBIA	109.9	62.1	47.7	43.5
FLORIDA	4,032.2	3,374.8	657.4	16.3
GEORGIA	4,076.8	2,698.4	1,378.4	33.8
HAWAII	183.7	174.7	9.0	4.9
IDAHO	1,132.6	653.4	479.3	42.3
ILLINOIS	4,004.2	2,255.1	1,749.0	43.7
INDIANA	3,335.4	2,035.6	1,299.8	39.0
IOWA	1,564.5	927.2	637.3	40.7
KANSAS	1,362.3	859.7	502.6	36.9
KENTUCKY	1,952.6	1,197.3	755.3	38.7
LOUISIANA	1,502.6	1,122.2	380.4	25.3
MAINE	657.6	358.9	298.7	45.4
MARYLAND	1,689.2	943.6	745.6	44.1
MASSACHUSETTS	1,649.1	816.5	832.6	50.5
MICHIGAN	5,560.1	3,279.8	2,280.3	41.0
MINNESOTA	4,038.3	2,190.2	1,848.0	45.8
MISSISSIPPI	946.8	652.0	294.8	31.1
MISSOURI	2,787.8	1,722.2	1,065.6	38.2
MONTANA	785.0	443.4	341.6	43.5
NEBRASKA	970.8	582.1	388.7	40.0
NEVADA	989.8	627.4	362.4	36.6
NEW HAMPSHIRE	632.5	347.0	285.5	45.1
NEW JERSEY	1,815.8	976.9	838.9	46.2
NEW MEXICO	1,698.0	1,079.3	618.7	36.4
NEW YORK	4,421.5	2,201.2	2,220.3	50.2
NORTH CAROLINA	3,836.4	2,474.0	1,362.4	35.5
NORTH DAKOTA	509.0	282.7	226.3	44.5
OHIO	4,536.7	2,595.6	1,941.1	42.8
OKLAHOMA	1,771.7	1,206.9	564.8	31.9
OREGON	3,631.9	2,270.3	1,361.5	37.5
PENNSYLVANIA	4,026.6	2,235.7	1,790.9	44.5
RHODE ISLAND	320.3	175.6	144.6	45.2
SOUTH CAROLINA	1,998.9	1,358.6	640.3	32.0
SOUTH DAKOTA	516.9	296.1	220.7	42.7
TENNESSEE	2,495.0	1,623.0	872.1	35.0
TEXAS	6,111.9	4,356.2	1,755.7	28.7
UTAH	1,705.9	1,041.8	664.2	38.9
VERMONT	457.1	246.7	210.4	46.0
VIRGINIA	3,271.3	1,977.9	1,293.4	39.5
WASHINGTON	5,778.8	3,564.6	2,214.2	38.3
WEST VIRGINIA	852.8	489.6	363.2	42.6
WISCONSIN	2,651.4	1,407.8	1,243.6	46.9
WYOMING	573.9	329.5	244.4	42.6
2030 Benzene Totals	116,741.6	71,704.3	45,037.3	38.6

2.2.2.2.3 Portable Fuel Container Control

The effect of PFC control on nationwide MSAT emissions are reported in Tables 2.2.-47 through 2.2.-50. Table 2.2.-51 reports benzene reductions by State in 2030 as a result of federal PFC control.

Table 2.2.-47. Estimated Reductions in MSAT Emissions from PFC Control, 2010 (No Fuel Benzene Control).

Pollutant	Reference Case	Control Case	Reduction in Tons	Percent Reduction
2,2,4-Trimethylpentane	4,994	4,039	955	19
Benzene	943	743	201	21
Ethyl Benzene	1,805	1,450	355	20
n-Hexane	4,679	3,742	937	20
MTBE	0	0	0	0
Naphthalene	1	1	0	19
Toluene	8,764	7,021	1,743	20
Xylenes	5,004	4,015	989	20
Total	**26,189**	**21,010**	**5,179**	**20**

Table 2.2.-48. Estimated Reductions in MSAT Emissions from PFC Control, 2015 (No Fuel Benzene Control).

Pollutant	Reference Case	Control Case	Reduction in Tons	Percent Reduction
2,2,4-Trimethylpentane	5,195	2,005	3,190	61
Benzene	992	320	672	68
Ethyl Benzene	1,884	695	1,189	63
n-Hexane	4,895	1,750	3,145	64
MTBE	0	0	0	0
Naphthalene	1	0	0	61
Toluene	9,161	3,316	5,846	64
Xylenes	5,226	1,912	3,314	63
Total	**27,355**	**9,998**	**17,357**	**63**

Table 2.2.-49. Estimated Reductions in MSAT Emissions from PFC Control, 2020 (No Fuel Benzene Control).

Pollutant	Reference Case	Control Case	Reduction in Tons	Percent Reduction
2,2,4-Trimethylpentane	5,573	2,163	3,410	61
Benzene	1,063	345	718	68
Ethyl Benzene	2,021	750	1,271	63
n-Hexane	5,250	1,888	3,362	64
MTBE	0	0	0	0
Naphthalene	1	0	0	61
Toluene	9,825	3,577	6,248	64
Xylenes	5,605	2,063	3,543	63
Total	**29,338**	**10,785**	**18,553**	**63**

Table 2.2.-50. Estimated Reductions in MSAT Emissions from PFC Control, 2030 (No Fuel Benzene Control).

Pollutant	Reference Case	Control Case	Reduction in Tons	Percent Reduction
2,2,4-Trimethylpentane	6,353	2,486	3,867	61
Benzene	1,210	396	814	67
Ethyl Benzene	2,303	862	1,442	63
n-Hexane	5,981	2,169	3,812	64
MTBE	0	0	0	0
Naphthalene	1	0	1	61
Toluene	11,195	4,110	7,085	63
Xylenes	6,387	2,370	4,017	63
Total	**33,430**	**12,394**	**21,036**	**63**

Table 2.2.-51. Reductions in Benzene Emissions (Tons) with PFC Control by State, 2030 (No Fuel Benzene Control).

State	Reference Case	Control Case	Reduction	% Change
ALABAMA	33.1	6.8	26.3	79.5
ALASKA	19.3	3.7	15.6	80.9
ARIZONA	25.8	7.3	18.6	71.8
ARKANSAS	23.7	4.3	19.4	82.0
CALIFORNIA	36.4	36.4	0.0	0.0
COLORADO	31.5	11.1	20.4	64.9
CONNECTICUT	3.5	3.0	0.4	12.8
DELAWARE	1.1	0.9	0.3	22.5
DISTRICT OF COLUMBIA	0.4	0.3	0.1	32.3
FLORIDA	138.2	30.0	108.3	78.3
GEORGIA	42.5	11.7	30.8	72.4
HAWAII	5.1	0.9	4.2	82.4
IDAHO	12.8	3.8	9.0	70.7
ILLINOIS	42.6	14.3	28.3	66.5
INDIANA	38.0	9.7	28.3	74.4
IOWA	20.8	4.7	16.1	77.5
KANSAS	20.8	5.3	15.5	74.5
KENTUCKY	25.3	5.9	19.3	76.6
LOUISIANA	39.2	6.3	32.9	83.9
MAINE	1.7	1.2	0.4	26.4
MARYLAND	7.0	5.5	1.6	22.1
MASSACHUSETTS	5.9	4.8	1.0	17.6
MICHIGAN	64.1	16.9	47.1	73.6
MINNESOTA	40.9	11.0	29.9	73.1
MISSISSIPPI	24.6	3.7	20.9	85.1
MISSOURI	31.7	8.4	23.3	73.4
MONTANA	8.0	2.1	6.0	74.2
NEBRASKA	12.7	3.1	9.5	75.2
NEVADA	11.9	3.2	8.7	73.1
NEW HAMPSHIRE	1.7	1.3	0.4	24.4
NEW JERSEY	8.7	7.0	1.7	19.5
NEW MEXICO	14.0	3.8	10.2	73.0
NEW YORK	17.9	13.7	4.2	23.5
NORTH CAROLINA	54.9	13.1	41.7	76.1
NORTH DAKOTA	4.5	1.2	3.4	73.9
OHIO	33.3	20.0	13.3	39.9
OKLAHOMA	20.8	5.0	15.8	75.9
OREGON	29.9	9.2	20.6	69.1
PENNSYLVANIA	16.3	11.6	4.7	28.7
RHODE ISLAND	0.9	0.8	0.2	18.9
SOUTH CAROLINA	31.5	6.5	25.0	79.4
SOUTH DAKOTA	4.8	1.2	3.6	75.1
TENNESSEE	41.8	8.2	33.6	80.3
TEXAS	42.5	26.2	16.3	38.4
UTAH	16.7	4.5	12.1	72.7
VERMONT	0.8	0.6	0.2	26.0
VIRGINIA	11.5	8.8	2.7	23.6
WASHINGTON	44.5	14.7	29.8	66.9
WEST VIRGINIA	14.3	3.2	11.1	77.5
WISCONSIN	26.0	8.1	17.9	69.0
WYOMING	4.2	1.2	3.0	70.5

2.2.2.2.4 Cumulative Reductions of Controls

Air toxic emissions from light-duty vehicles depend on both fuel benzene content and vehicle hydrocarbon emission controls. Similarly, the air toxic emissions from PFCs depend on both fuel benzene content and the PFC emission controls. Tables 2.2.-52 and 2.2.-53 summarize the expected reductions in benzene and MSAT emissions, respectively, from the combined effects of our vehicle, fuel, and PFC controls.

Table 2.2.-54 summarizes the cumulative benzene emission reductions from these controls on highway gasoline vehicles, nonroad gasoline vehicles, PFCs, and gasoline distribution at the State level in 2030.

Table 2.2.-55 presents the impact of controls on total benzene emissions from mobile sources and PFCs, and the impacts on total benzene emissions from all sources. Table 2.2.-56 presents the cumulative impact of controls on total emissions of MSATs from mobile sources and PFCs, as well as the impact on total emissions of MSATs from both mobile and stationary sources. As discussed previously, the fuel benzene control reduces stationary source emissions of benzene associated with gasoline distribution.

Table 2.2-52. Estimated Reductions in Benzene Emissions from All Control Measures by Sector, 2015 to 2030.

Benzene	1999	2015			2020			2030		
		Without Rule (tons)	With Rule (tons)	Reduction (tons)	Without Rule (tons)	With Rule (tons)	Reduction (tons)	Without Rule (tons)	With Rule (tons)	Reduction (tons)
Gasoline Onroad Mobile Sources	183,660	97,789	71,688	26,101	101,514	65,878	35,636	119,016	65,601	53,415
Gasoline Nonroad Mobile Sources	68,589	41,343	35,825	5,518	40,161	34,717	5,444	42,994	37,167	5,827
PFCs	853	992	215	777	1,063	232	831	1,210	267	944
Gasoline Distribution	1,984	2,445	1,635	810	2,621	1,772	849	2,621	1,772	849
Total	255,086	142,569	109,363	33,206	145,359	102,599	42,760	165,841	104,807	61,035

Table 2.2.-53. Estimated Reductions in MSAT Emissions from All Control Measures by Sector, 2015 to 2030

MSAT	1999	2015			2020			2030		
		Without Rule (tons)	With Rule (tons)	Reduction (tons)	Without Rule (tons)	With Rule (tons)	Reduction (tons)	Without Rule (tons)	With Rule (tons)	Reduction (tons)
Gasoline Onroad Mobile Sources	1,452,739	675,781	558,666	117,115	693,189	507,782	185,408	808,141	505,074	303,067
Gasoline Nonroad Mobile Sources	806,725	449,422	443,973	5,449	406,196	400,816	5,380	412,617	406,856	5,761
PFCs	37,166	27,355	9,893	17,462	29,338	10,672	18,666	33,430	12,264	21,166
Gasoline Distribution	57,765	62,870	62,059	811	64,942	64,092	850	64,942	64,092	850
Total	2,354,395	1,215,428	1,074,591	140,837	1,193,665	983,362	210,303	1,319,130	988,286	330,844

Table 2.2.-54. Cumulative Benzene Emission Reductions From All Controls at the State Level in 2030.

	Gasoline Highway Vehicles		Nonroad Gasoline Engines		PFCs		Gasoline Distribution		Total	
State	**Tons Reduced**	**%**	**Tons Reduced**	**%**	**Tons Reduced**	**%**	**Tons Reduced**	**%**	**Tons Reduced**	**%**
ALABAMA	826.3	36.6	194.2	19.0	29.1	88.2	14.4	42.4	1,064.0	31.7
ALASKA	849.8	65.1	58.9	31.3	17.1	88.5	1.2	40.0	926.9	61.2
ARIZONA	665.3	37.2	100.2	14.0	21.5	83.1	16.4	40.0	803.4	31.2
ARKANSAS	534.7	39.6	123.5	19.4	21.3	89.7	7.1	43.0	686.5	33.9
CALIFORNIA	3,675.9	39.0	22.6	0.6	0.7	2.0	2.0	2.0	3,701.2	27.2
COLORADO	1,348.7	49.4	97.9	15.7	24.5	77.9	10.2	37.0	1,481.2	43.4
CONNECTICUT	488.0	47.2	9.4	2.3	0.7	19.8	1.5	8.0	499.6	34.0
DELAWARE	118.3	43.9	2.4	2.5	0.3	28.7	0.3	8.0	121.4	32.6
DISTRICT OF COLUMBIA	48.7	43.5	0.8	2.8	0.2	37.7	0.3	8.0	49.9	34.7
FLORIDA	1,090.6	26.1	682.0	18.2	120.2	87.0	35.4	40.0	1,928.2	23.6
GEORGIA	1,667.6	39.9	251.9	16.0	35.4	83.4	14.6	40.0	1,969.5	33.8
HAWAII	9.8	5.1	0.9	0.7	4.2	82.7	0.1	2.0	15.0	4.6
IDAHO	588.6	51.2	52.8	18.5	10.4	81.5	7.5	37.0	659.3	44.9
ILLINOIS	1,966.1	48.2	105.7	8.1	31.5	74.0	29.6	30.0	2,132.9	38.7
INDIANA	1,591.8	46.9	117.4	16.2	32.5	85.6	17.5	42.5	1,759.2	41.9
IOWA	780.9	49.4	84.9	17.4	18.3	87.9	24.7	46.0	908.8	42.4
KANSAS	658.6	47.5	63.7	20.6	18.0	86.3	32.2	46.0	772.5	43.3
KENTUCKY	915.2	46.0	79.5	16.4	21.5	85.1	20.0	41.3	1,036.1	40.7
LOUISIANA	528.2	34.3	237.1	20.9	35.6	90.8	46.8	43.0	847.8	30.0
MAINE	315.5	47.2	19.0	7.4	0.7	41.1	5.1	23.9	340.3	35.9
MARYLAND	776.5	45.2	52.0	6.6	2.2	31.8	5.5	16.1	836.2	32.8
MASSACHUSETTS	845.7	50.0	15.7	2.3	1.4	24.2	2.0	8.0	864.8	36.0
MICHIGAN	2,799.1	49.6	296.7	18.7	54.9	85.7	37.9	46.0	3,188.6	43.2
MINNESOTA	2,270.1	55.5	191.7	21.3	35.0	85.5	34.2	46.0	2,530.9	49.6
MISSISSIPPI	378.9	39.2	105.6	19.8	22.5	91.5	18.3	43.0	525.4	33.5
MISSOURI	1,316.8	46.4	124.1	15.9	26.4	83.3	9.9	37.4	1,477.3	40.2
MONTANA	413.0	52.0	23.3	17.5	6.7	83.7	4.4	37.0	447.5	47.2
NEBRASKA	487.8	49.5	40.8	19.5	11.0	86.6	5.1	46.0	544.6	44.7
NEVADA	402.7	39.4	31.2	10.0	9.8	82.4	2.1	27.1	445.8	33.0

	Gasoline Highway Vehicles		Nonroad Gasoline Engines		PFCs		Gasoline Distribution		Total	
State	**Tons Reduced**	**%**	**Tons Reduced**	**%**	**Tons Reduced**	**%**	**Tons Reduced**	**%**	**Tons Reduced**	**%**
NEW HAMPSHIRE	301.2	47.0	24.9	9.2	0.6	36.9	0.6	16.7	327.4	35.7
NEW JERSEY	855.1	46.0	24.3	2.3	2.3	26.0	3.3	8.0	885.1	29.9
NEW MEXICO	814.4	46.8	58.5	21.9	11.8	84.6	11.3	43.0	896.0	43.8
NEW YORK	2,354.8	52.1	212.1	9.0	6.9	38.5	46.3	12.9	2,620.1	36.1
NORTH CAROLINA	1,648.3	42.0	272.5	16.5	47.0	85.6	14.5	40.0	1,982.3	35.0
NORTH DAKOTA	276.2	53.6	21.2	19.8	3.9	85.9	4.3	46.0	305.6	48.0
OHIO	2,326.7	50.4	229.1	17.2	22.5	67.5	41.3	46.0	2,619.6	43.1
OKLAHOMA	717.4	39.7	112.4	18.9	18.1	87.0	28.1	46.0	876.0	35.2
OREGON	1,774.1	47.6	124.7	19.5	24.3	81.5	47.4	40.0	1,970.6	43.7
PENNSYLVANIA	1,963.3	47.9	162.6	10.7	8.1	49.7	26.6	36.6	2,160.6	37.9
RHODE ISLAND	147.3	45.4	2.5	2.2	0.2	25.4	0.4	8.0	150.4	34.1
SOUTH CAROLINA	791.2	38.8	157.8	17.4	27.6	87.6	8.0	40.0	984.6	32.8
SOUTH DAKOTA	267.2	51.0	20.5	18.7	4.2	86.6	3.0	46.0	294.9	45.8
TENNESSEE	1,093.5	43.0	133.3	18.0	37.4	89.4	26.7	46.0	1,290.9	38.1
TEXAS	2,255.3	35.8	468.5	14.8	23.7	55.7	100.6	29.2	2,848.0	28.9
UTAH	821.5	47.5	62.0	17.4	13.8	82.8	9.4	37.0	906.7	42.6
VERMONT	230.9	49.8	17.8	13.3	0.5	55.6	0.5	40.0	249.7	41.6
VIRGINIA	1,427.6	43.1	114.7	10.4	4.7	40.8	12.3	29.2	1,559.2	34.9
WASHINGTON	2,848.3	48.6	198.0	19.0	35.7	80.2	22.8	40.0	3,104.8	44.4
WEST VIRGINIA	425.9	49.4	57.3	17.5	12.3	86.5	22.1	40.0	517.7	41.1
WISCONSIN	1,417.3	52.6	146.9	15.3	20.7	79.8	8.6	36.4	1,593.5	43.0
WYOMING	298.3	51.3	19.6	18.2	3.4	81.4	4.4	37.0	325.7	46.2

Table 2.2-55. Impact of Controls on Total Benzene Emissions From Mobile Sources and All Sources.

	Mobile Source and PFC Tons Reduced	Mobile Source and PFC Tons, Reference Case	% of Mobile Source and PFC Tons Reduced	Total Tons Reduced From All Sources	Total Mobile and Stationary Tons, Reference Case	% of Total Benzene Reduced
2015						
Fuel Benzene Control	16,804	140,124	12	17,614	256,755	7
Vehicle Control	16,570	140,124	12	16,570	256,755	7
Fuel, Vehicle, and PFC Control	32,396	140,124	23	33,206	256.755	13
2020						
Fuel Benzene Control	16,768	142,738	12	17,617	262,828	7
Vehicle Control	27,097	142,738	19	27,097	262,828	10
Fuel, Vehicle, and PFC Control	41,911	142,738	29	42,760	262,828	16
2030						
Fuel Benzene Control	18,796	163,220	12	19,645	283,310	7
Vehicle Control	45,037	163,220	28	45,037	283,310	16
Fuel, Vehicle, and PFC Control	60,186	163,220	37	61,035	283,310	22

Table 2.2.-56. Cumulative Impact of Controls on Total MSAT Emissions From Mobile Sources and PFCs, and From All Sources.

	Mobile Source and PFC Tons Reduced	Mobile Source and PFC Tons, Reference Case	% of Mobile and PFC Tons Reduced	Total Tons Reduced	Total Mobile and Stationary Tons	% of Mobile and Stationary Tons Reduced
2015	140,726	1,215,146	12	141,536	2,636,063	5
2020	210,173	1,193,281	18	211,022	2,733,020	8
2030	330,713	1,318,746	25	331,562	2,858,485	12

2.3 Potential Implications of New Emissions Data for Inventories

2.3.1 Newer Technology Light Duty Vehicles

MOBILE6.2 explicitly estimates emissions for the following air toxic compounds: benzene, 1,3-butadiene, formaldehyde, acetaldehyde, MTBE, and acrolein.[60, 61] MOBILE6.2 estimates air toxics emission factors by multiplying an air toxic to VOC (volatile organic compound) ratio by MOBILE6.2 VOC. For light-duty gasoline vehicles and trucks, the product for exhaust emissions is then multiplied by an off-cycle adjustment factor, which accounts for the difference in toxic fractions between Federal Test Procedure (FTP) and Unified Cycle (UC) operation.

Toxic to VOC ratios vary by technology group, vehicle type, whether a vehicle is a normal or high emitter (same definition as MOBILE6.2), and fuel characteristics. Evaporative toxic/VOC ratios do not vary among gasoline vehicle classes. Since toxic emission rates are a product of toxic/VOC emission ratios and VOC emission rates, anything that reduces VOC will also result in toxic emission reductions. Toxic/VOC ratios for individual technology group/vehicle type/emitter class combinations are determined using a series of algorithms which calculate the ratios based on fuel parameter inputs. These algorithms were derived from tests on 1990 model year technology vehicles and form the basis of the Complex Model for Reformulated Gasoline. MOBILE6.2 assumes that the same ratios are applicable to all post-1990 technology vehicles, including advanced technology low emission vehicles (LEVs) meeting Tier 2 standards.[62]

Eastern Research Group, under contract to EPA, recently compared exhaust emissions data from newer technology vehicles to see if the toxics to VOC fractions estimated from these data were statistically different from ratios predicted by MOBILE6.2. To make these comparisons, we used data collected by EPA Office of Research and Development/National Exposure Research Laboratory on 23 1998-2003 vehicles, the California Air Resources Board (46 vehicles) and Southwest Research Institute (3 vehicles). The contractor report and the data used are available in the docket for this rule.[63] The data from EPA's Office of Research and Development have been published.[64]

The conclusions from t-test comparisons were as follows:

1) When the off-cycle adjustment for benzene is factored out of the model results, MOBILE6.2 predicts statistically higher toxic fractions than one gets from the California Air Resources Board and Southwest Research Institute data, although for the large California dataset, the difference is only 10%. The fractions from the EPA Office of Research and Development data are higher than predicted by MOBILE6.2, but the difference is not statistically significant.

2) MOBILE6.2 is over-predicting toxic fractions for 1,3-butadiene.

3) The available data do not support a conclusion that MOBILE6.2 underestimates or overestimates fractions for MTBE, formaldehyde, acetaldehyde or acrolein.

There is a significant amount of scatter in the available test data, which makes it difficult to draw strong conclusions from the statistical comparisons. Also data are very limited for high emitters and off-cycle operation, which make a large contribution to total emissions. Nonetheless, at this point it appears that MOBILE6.2 toxic to VOC fractions for benzene, MTBE, formaldehyde, acetaldehyde, and acrolein are reasonably accurate for newer technology vehicles, but that fractions used for 1,3-butadiene are overestimating emissions for this pollutant.

The recent Energy Policy Act passed by Congress requires EPA to develop a new fuel effects model that reflects a 2007 fleet. The collection of a large amount of data and substantial analytical work is needed to meet this requirement, and to update the algorithms used in the current Complex Model and MOBILE6.2. As part of this ongoing effort, EPA is reviewing engine exhaust data, which includes air toxic emissions, from the CRC (Coordinating Research Council) E-67 study on engine emissions from light-duty vehicles using ethanol fuels.[65] Likewise, work is underway in a collaborative test program between EPA and members of the Alliance of Automobile Manufacturers to examine emissions of both regulated pollutants and air toxics from Tier 2 compliant vehicles. The current program focuses on changes in fuel sulfur, vapor pressure, and benzene levels, and will provide data for the air toxics rulemaking process as well as inform the design of a more comprehensive program covering a wider range of fuel properties and vehicle certification levels.

2.3.2 Heavy-Duty Vehicles (CRC E-55/E-59)

The primary objective of the E-55/59 research program was to quantify gaseous and PM emissions from primarily in-use heavy-duty diesel trucks in California’s South Coast Air Basin, in support of emissions inventory development.[66] A second program objective was to quantify the influence of tampering and mal-maintenance on emissions from these vehicles. The program was conducted in four Phases (denoted as 1, 1.5, 2 and 3). The Phase 1 test fleet consisted of 25 heavy heavy-duty diesel trucks (HHDDT), selected to match a distribution of model years (MY) and to reflect engines in common use in California. In Phase 1.5 an additional twelve HHDDT were studied, with a thirteenth truck tested at idle alone. The Phase 2 test fleet consisted of ten HHDDT and nine medium heavy-duty trucks (MHDT), which included seven diesel-fueled medium heavy-duty trucks (MHDDT) and two gasoline-fueled medium heavy-duty trucks (MHDGT). Phase 3 gathered data from nine HHDDT, eight MHDDT, and two MHDGT. The Phase 2 and 3 data added post-2002 MY HHDDT (at 2.5 g/bhp-hr NO_x standard) to the program.

Sampling for chemical speciation was performed on thirteen HHDDT in Phase 1 and on five HHDDT and one MHDDT in Phase 2. However, only three of the thirteen Phase 1 trucks had their exhaust samples analyzed for air toxic emissions, and the remaining samples were being archived. Toxics species were measured from five

HHDDT and one MHDDT (medium HDDTs) in the Phase 2 test fleet. PM data were acquired in Phases 1.5, 2 and 3. Exhaust data were acquired for methane and VOC. Semi-volatile organic compounds and PM soluble fractions were captured and analyzed, along with carbonyls and nitrosamines. Ions and elemental/organic carbon (EC/OC) split were determined from quartz filters. The ion and metal analyses varied widely between trucks.

These data will be incorporated into EPA's MSAT inventories, and will help address limitations discussed in Sections 2.1.4 and 2.2.1.1.5.

2.3.3 Small Spark Ignition Engines

The National Mobile Inventory Model (NMIM) calculates air toxic emissions for small Spark Ignition (SI) engines by multiplying compound-specific fractions with volatile organic carbon (VOC) or particulate matter (PM) emission outputs from EPA's NONROAD model. These fractions were used in the 1999 National Air Toxics Assessment (NATA). These data were all obtained from a small number of uncontrolled engines.[67,68,69,70,71] In fiscal year 2004 EPA tested a mixture of in-use and new pre-control and Phase 1 small hand held SI trimmers, chain saws and a leaf blower.[72] In the same time period EPA performed engine tests on Phase I residential four-stroke lawn mowers. The emission data from both programs may impact future versions of NMIM and the inventories it calculates.

EPA tested four pre-control, nine Phase 1, two California-certified, and eight Phase 2 handheld engines. Five of the Phase 2 engines were new. All tests were fueled by either of two summer grades of gasoline. One was a gasoline ethanol blend meant to represent a reformulated gasoline and the other a conventional gasoline. All but one of the engines were two-cycle designs. However, the four-cycle engine was designed to operate on a typical two-cycle fuel lubricating oil mixture. All the test engines require that lubricating oil be mixed and consumed with the fuel. The program therefore used two different types of lubricating oil, one a mineral-based product and the other a "low smoke" synthetic. Both oils were commercially available. The testing was done over the Composite Two Mode (C2M) duty cycle. Table 2.3.-1 compares the emission factors used in NONROAD and the fractions used in NMIM with those based on the testing.

NONROAD and NMIM have not been adjusted to use the new data, but some increase in projected benzene inventories is likely once this occurs. In all but one engine and fuel combination the benzene/VOC fraction is greater than that currently used in NMIM. It is significant that two-cycle engines have a large proportion of their fuel being emitted in an unburned state. A reduction in fuel benzene content will have a significant effect on benzene emissions from them.

The other MSAT fractions are found in Table 2.3.-2. Some of the measured values are more consistent with NMIM values, but some are not (e.g., xylenes).

The second EPA test program involved six new Phase 2 four cycle lawn mower engines. These data are unpublished. The engines were tested after 20 hours of operation. The testing was done using the certification test procedure on certification gasoline. Formaldehyde and acetaldehyde were the only MSATs measured in the test program. A comparison of NMIM fractions and measured fractions are in Table 2.3.-3.

The measured values are similar to the values used in NMIM. Incorporation of the new test data would not result in a dramatic change in inventories from these engines and use types.

Table 2.3.-1. Comparison between NONROAD Outputs and NMIM MSAT Fractions and Averaged Test Data for PM, VOC and Benzene from EPA Testing of 18 Handheld SI Engines Aggregated by Use, Engine Class, Emission Standard (Phase), Catalyst, and Engine Cycle

Type	Class	Condition	Phase	Catalyst Equipped	Engine Cycle	NONROAD PM10 EF (g/bhp)	Average Tested PM2.5 (g/bhp)	NONROAD HC EF (g/bhp)	Average Tested THC (g/bhp)	NMIM Benzene Fraction	Average Tested Benzene Fraction
BLOWER	V	New	2	YES	2	7.70	0.028	40.15	24.842	0.024	0.038
CHAIN SAW	IV	New	2	YES	2	7.70	0.228	26.87	30.254	0.080	0.022
CHAIN SAW	IV	Used	0	NO	2	9.24	3.072	313.20	185.976	0.080	0.016
CHAIN SAW	IV	Used	1	NO	2	9.93	2.051	231.84	110.567	0.080	0.014
CHAIN SAW	IV	Used	2	NO	2	9.93	1.483	42.66	98.066	0.080	0.014
CHAIN SAW	V	Used	1	NO	2	9.75	1.330	152.00	80.026	0.080	0.016
STRING TRIMMER	III	Used	0	NO	2	9.24	4.915	313.20	265.205	0.011	0.019
STRING TRIMMER	III	Used	1	NO	2	9.55	7.519	272.79	243.167	0.011	0.013
STRING TRIMMER	IV	New	2	YES	2	7.70	0.641	26.87	31.581	0.011	0.028
STRING TRIMMER	IV	New	2	NO	4	0.06	0.231	25.83	12.791	0.011	N.A.
STRING TRIMMER	IV	Used	0	NO	2	9.24	3.093	313.20	221.354	0.011	0.015
STRING TRIMMER	IV	Used	1	NO	2	9.93	3.856	231.84	154.140	0.011	0.017

Table 2.3.-2. NMIM MSAT Fractions versus Fractions from EPA Testing of 18 Handheld SI Engines

			Formaldehyde		Acetaldehyde		Acrolein		Propionaldehyde		Toluene		2,2,4-Trimethypentane		Xylene	
Type	Standard	Fuel	NMIM	Tested	NMIM	Tested	NMIM	Tested	NMIM	Tested	NMIM	Tested	NMIM	Tested	NMIM	Tested
BLOWER	Ph2	CG									0.0978	0.0979	0.0372	0.0122	0.1075	0.0224
SAW		CG	0.0068	0.0050	0.0013	0.0011	0.0004	0.0003	0.0001	0.0002	0.0598	0.0998	0.0372	0.0490	0.0931	0.0166
SAW	Ph1	CG	0.0068	0.0042	0.0013	0.0009	0.0004	0.0003	0.0003	0.0002	0.0598	0.1064	0.0372	0.0487	0.0931	0.0151
SAW	Ph1	RFG	0.0068	0.0053	0.0013	0.0046	0.0004	0.0004	0.0004	0.0002	0.0598	0.1105	0.0372	0.0280	0.0931	0.0231
SAW	Ph2	CG	0.0068	0.0052	0.0013	0.0011	0.0004	0.0004	0.0004	0.0002	0.0598	0.1065	0.0372	0.0409	0.0931	0.0177
SAW	Ph2	RFG	0.0068	0.0056	0.0013	0.0055	0.0004	0.0004	0.0004	0.0002	0.0598	0.0955	0.0372	0.0252	0.0931	0.0228
TRIMMER		CG	0.0029	0.0072	0.0006	0.0016	0.0003	0.0006	0.0004	0.0002	0.0978	0.1049	0.0372	0.0437	0.1075	0.0174
TRIMMER		RFG	0.0029	0.0077	0.0006	0.0066	0.0003	0.0006	0.0004	0.0002	0.0890	0.0891	0.0372	0.0242	0.0978	0.0232
TRIMMER	Ph1	CG									0.0978	0.1093	0.0372	0.0432	0.1075	0.0204
TRIMMER	Ph1	CG	0.0029	0.0039	0.0006	0.0009	0.0003	0.0003	0.0003	0.0002	0.0978	0.1000	0.0372	0.0497	0.1075	0.0163
TRIMMER	Ph1	RFG									0.0890	0.1096	0.0372	0.0249	0.0978	0.0299
TRIMMER	Ph1	RFG	0.0029	0.0045	0.0006	0.0046	0.0003	0.0003	0.0004	0.0002	0.0890	0.0906	0.0372	0.0279	0.0978	0.0238
TRIMMER	Ph2	CG	0.0029	0.0050	0.0006	0.0010	0.0003	0.0003	0.0006	0.0002	0.0978	0.1303	0.0372	0.0559	0.1075	0.0205
TRIMMER	Ph2	RFG	0.0029	0.0080	0.0006	0.0073	0.0003	0.0005	0.0009	0.0002	0.0890	0.1014	0.0372	0.0326	0.0978	0.0235

Table 2.3.-3. Comparison of NMIM Acetaldehyde and Formaldehyde to VOC fractions with Measured Fractions from OTAQ Test Program

MSAT	NMIM Fraction	Average Measured Fraction
Acetaldehyde	0.00440	0.00396
Formaldehyde	0.01256	0.01541

2.3.4 Nonroad CI engines

The Agency conducted three separate emission test programs measuring exhaust emissions from fifteen nonroad diesel engines and in-use pieces of nonroad diesel equipment.[73,74,75] The engines tested derived from construction, utility and agricultural equipment applications for the most part and ranged from seven horsepower (hp) up through 850 hp (425 hp, as tested). The test fuels used varied by sulfur concentration from nonroad-grade diesel fuels at 2500 and 3300 ppm sulfur to a nominal "D-2" diesel at 350 ppm sulfur and, lastly, to an ultra-low sulfur diesel, measured at less than 10 ppm sulfur. Test engines were run over both steady-state and transient duty cycles. Several of the transient cycles were application-specific, having been based on rubber-tire loader or excavator operations, for example. Criteria pollutants in the exhaust emissions were quantified for each test engine as well as sulfate, ammonia, N_2O and a range of C_1 - C_{12} compounds (aldehydes, ketones, alcohols, etc.). Emissions of several additional air toxic compounds were identified in two of the three programs. These emission species included benzene, toluene, ethylbenzene, xylenes, polyaromatic hydrocarbons (PAH), nitrated-PAHs and several metals. Emission results were summarized in both grams/hour and grams/brake-horsepower/hour.

With this new emission data, the Agency has begun an effort to update the toxics portion of its NMIM model. EPA will also address differences between Tier 1 and unregulated NR diesel emissions, the impact of diesel fuel sulfur level on engine emissions, whether any adjustments to default modeling TAFs (transient adjustment factors) used in the NONROAD emissions model are warranted by the new data and the necessity for creating category- and power-specific TAFs for NONROAD.

2.4 Description of Current Mobile Source Emissions Control Programs that Reduce MSATs

As described above, existing mobile source control programs will reduce MSAT emissions (not including diesel PM) by 60% between 1999 and 2020. Diesel PM from mobile sources will be reduced by 75% between 2001 and 2030. The mobile source programs include controls on fuels, highway vehicles, and nonroad equipment. These programs are also reducing hydrocarbons and PM more generally, as well as oxides of nitrogen. The sections immediately below provide general descriptions of these programs, as well as voluntary programs to reduce mobile source emissions, such as the National Clean Diesel Campaign and Best Workplaces for Commuters.SM

2.4.1 Fuels Programs

Several federal fuel programs reduce MSAT emissions. Some of these programs directly control air toxics, such as the reformulated gasoline (RFG) program's benzene content limit and required reduction in total toxics emissions, and the anti-backsliding requirements of the anti-dumping and current MSAT programs, which require that gasoline cannot get dirtier with respect to toxics emissions. Others, such as the gasoline sulfur program, control toxics indirectly by reducing hydrocarbon and related toxics emissions. Some fuel programs will have a mixed impact on the species and quantity of MSAT emissions expected with the introduction of these new fuels into commerce.

2.4.1.1 RFG

The RFG program contains two direct toxics control requirements. The first is a fuel benzene standard, requiring RFG to average no greater than 0.95 volume percent benzene annually (on a refinery or importer basis). The RFG benzene requirement includes a per-gallon cap on fuel benzene level of 1.3 volume percent. In 1990, when the Clean Air Act was amended to require reformulated gasoline, fuel benzene averaged 1.60 volume percent. For a variety of reasons, including other regulations, chemical product prices and refining efficiencies, most refiners and importers have achieved significantly greater reductions in benzene than required by the program. In 2003, RFG benzene content averaged 0.62 percent. The RFG benzene requirement includes a per-gallon cap on fuel benzene level of 1.3 volume percent.

The second RFG toxics control requires that RFG achieve a specific level of toxics emissions reduction. The requirement has increased in stringency since the RFG program began in 1995, when the requirement was that RFG annually achieve a 16.5% reduction in total (exhaust plus evaporative) air toxics emissions. Currently, a 21.5%

reduction is required. These reductions are determined using the Complex Model. As mentioned above, for a variety of reasons most regulated parties have overcomplied with the required toxics emissions reductions. During the 1998-2000 timeframe, RFG achieved, on average, a 27.5% reduction in toxics emissions.

2.4.1.2 Anti-dumping

The anti-dumping regulations were intended to prevent the dumping of "dirty" gasoline components, which were removed to produce RFG, into conventional gasoline (CG). Since the dumping of "dirty" gasoline components, for example, benzene or benzene-containing blending streams, would show up as increases in toxics emissions, the anti-dumping regulations require that a refiner's or importer's CG be no more polluting with respect to toxics emissions than the refiner's or importer's 1990 gasoline. The anti-dumping program considers only exhaust toxics emissions and does not include evaporative emissions.[C] Refiners and importers have either a unique individual anti-dumping baseline or they have the statutory anti-dumping baseline if they did not fulfill the minimum requirements for developing a unique individual baseline. In 1990, average exhaust toxics emissions (as estimated by EPA's Complex Model) were 104.5 mg/mile[D]; in 2004, CG exhaust toxics emissions averaged 90.7 mg/mile. Although CG has no benzene limit, benzene levels have declined significantly from the 1990 level of 1.6 volume percent to 1.1 volume percent for CG in 2004.

2.4.1.3 2001 Mobile Source Air Toxics Rule (MSAT1)

As discussed above, both RFG and CG have, on average, exceeded their respective toxics control requirements. In 2001, EPA issued a mobile source air toxics rule (MSAT1, for the purposes of this second proposal), as discussed in section I.D. The intent of MSAT1 is to prevent refiners and importers from backsliding from the toxics performance that was being achieved by RFG and CG. In order to lock in superior levels of control, the rule requires that the annual average toxics performance of gasoline must be at least as clean as the average performance of the gasoline produced or imported during the three-year period 1998-2000. The period 1998-2000 is called the baseline period. Toxics performance is determined separately for RFG and CG, in the same manner as the toxics determinations required by the RFG[76] and anti-dumping rules.

Like the anti-dumping provisions, MSAT1 utilizes an individual baseline against which compliance is determined. The average 1998-2000 toxics performance level, or baseline, is determined separately for each refinery and importer.[E] To establish a unique individual MSAT1 baseline, EPA requires each refiner and importer to submit documentation supporting the determination of the baseline. Most refiners and many

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[C] See RFG rule for why evaporative emissions are not included in the anti-dumping toxics determination.

[D] Phase II

[E] Except for those who comply with the anti-dumping requirements for conventional gasoline on an aggregate basis, in which case the MSAT1 requirements for conventional gasoline must be met on the same aggregate basis (40 CFR Part 80, Subpart E).

importers in business during the baseline period had sufficient data to establish an individual baseline. An MSAT1 baseline volume is associated with each unique individual baseline value. The MSAT1 baseline volume reflects the average annual volume of such gasoline produced or imported during the baseline period. Refiners and importers who did not have sufficient refinery production or imports during 1998-2000 to establish a unique individual MSAT1 baseline must use the default baseline provided in the rule.

The MSAT1 program began with the annual averaging period beginning January 1, 2002. Since then, the toxics performance for RFG has improved from a baseline period average of 27.5% reduction to 29.5% reduction in 2003. Likewise, CG toxics emissions have decreased from an average of 95 mg/mile during 1998-2000 to 90.7 mg/mile in 2003.

2.4.1.4 Gasoline Sulfur

Beginning in 2006, EPA's gasoline sulfur program[77] requires that sulfur levels in gasoline can be no higher than 80 ppm as a per gallon cap and must average 30 ppm annually. When the program is fully effective, gasoline will have 90 percent less sulfur than before the program. Reduced sulfur levels are necessary to ensure that vehicle emission control systems are not impaired. These systems effectively reduce non-methane organic gas (NMOG) emissions, of which some are air toxics as well as emissions of NOx. With lower sulfur levels, emission control technologies can work longer and more efficiently. Both new and older vehicles benefit from reduced gasoline sulfur levels.

2.4.1.5 Gasoline Volatility

A fuel's volatility defines its evaporation characteristics. A gasoline's volatility is commonly referred to as its Reid vapor pressure, or RVP. Gasoline summertime RVP ranges from about 6 to 9 psi and wintertime RVP, when additional volatility is required for starting in cold temperatures, ranges from about 9 to14 psi. Gasoline vapors contain a subset of the liquid gasoline components and thus can contain toxics compounds, such as benzene. Since 1989, EPA has controlled summertime gasoline RVP primarily as a VOC and ozone precursor control, resulting in additional toxics pollutant reductions.

2.4.1.6 Diesel Fuel

In early 2001, EPA issued rules requiring that diesel fuel for use in highway vehicles contain no more than 15 ppm sulfur beginning June 1, 2006. [78] This program contains averaging, banking and trading provisions during the transition to the 15 ppm level, as well as other compliance flexibilities. In June 2004, EPA issued rules governing the sulfur content of diesel fuel used in nonroad diesel engines.[79] In the nonroad rule, sulfur levels are limited to a maximum of 500 ppm sulfur beginning in 2007 (current levels are approximately 3000 ppm). In 2010, nonroad diesel sulfur levels must not exceed 15 ppm.

EPA's diesel fuel requirements are part of a comprehensive program to combine engine and fuel controls to achieve the greatest emission reductions. The diesel fuel provisions will enable the use of advanced emission-control technologies on diesel vehicles and engines. The diesel fuel requirements will also provide immediate public health benefits by reducing PM emissions from current diesel vehicles and engines.

2.4.1.7 Phase-Out of Lead in Gasoline

One of the first programs to control toxic emissions from motor vehicles was the removal of lead from gasoline. Beginning in the mid-1970s, unleaded gasoline was phased in to replace leaded gasoline. The phase-out of leaded gasoline was completed January 1, 1996, when lead was banned from motor vehicle gasoline.

2.4.2 Highway Vehicle and Engine Programs

The 1990 Clean Air Act Amendments set specific emission standards for hydrocarbons and for PM. Air toxics are present in both of these pollutant categories. As vehicle manufacturers develop technologies to comply with the hydrocarbon (HC) and particulate standards (e.g., more efficient catalytic converters), air toxics are reduced as well. Since 1990, we have developed a number of programs to address exhaust and evaporative hydrocarbon emissions and PM emissions. Table 2.4-1 shows current mobile source programs for highway vehicles.

Two of our recent initiatives to control emissions from motor vehicles and their fuels are the Tier 2 control program for light-duty vehicles and the 2007 heavy-duty engine rule. Together these two initiatives define a set of comprehensive standards for light-duty and heavy-duty motor vehicles and their fuels. In both of these initiatives, we treat vehicles and fuels as a system. The Tier 2 control program establishes stringent tailpipe and evaporative emission standards for light-duty vehicles and a reduction in sulfur levels in gasoline fuel beginning in 2004.[80] The 2007 heavy-duty engine rule establishes stringent exhaust emission standards for new heavy-duty engines and vehicles for the 2007 model year as well as reductions in diesel fuel sulfur levels starting in 2006.[81] Both of these programs will provide substantial emissions reductions through the application of advanced technologies. We expect 90% reductions in PM from new diesel engines compared to engines under current standards.

Some of the key earlier programs controlling highway vehicle and engine emissions are the Tier 1 and NLEV standards for light-duty vehicles and trucks; enhanced evaporative emissions standards; the supplemental federal test procedures (SFTP); urban bus standards; and heavy-duty diesel and gasoline standards for the 2004/2005 time frame.

Table 2.4-1. Current On-Highway Engine and Vehicle Programs Providing Significant Additional MSAT Reductions.

Category	Rule & FRM Date	Implementation Schedule	VOC Standards*	PM Standards
Light-duty cars and trucks	Tier 2 (including low sulfur fuel and enhanced evaporative emissions regulations) February 10, 2000	2004 - 2009	x	x
	NLEV (National Low-Emitting Vehicle)	1999 - 2003	x	x
	SFTP (Supplemental FTP) Procedures	2001 (start)	x	
Heavy-duty trucks	2004 Heavy-duty Rule October 6, 2000	2004 - 2007	x	x
	2007 Heavy-duty Rule (including low sulfur fuel) January 18, 2001	2007 - 2010	x	x
Urban Buses	HD Diesel Retrofit	1994 - 1998		x
Highway motorcycles	December 2003	2006 - 2010	x	

* Standards in various forms including HC, NMHC, NMOG, and NOx+NMHC

Table 2.4-2 Current Nonroad Engine/Vehicle Programs.

Category	Rule & FRM Date	Implementation Schedule	VOC Standards*	PM Standards
Land-based diesel	Tier 2, October 23, 1998	2001-2006	x	x
	Tier 3, October 23, 1998	2006-2008	x	x
	Tier 4 (w/ low sulfur fuel) June 29, 2004	2008-2014	x	x
Locomotives	Tier 0, Tier 1, Tier 2 April 16, 1998	2002 – 2005	x	x
Marine	Spark-ignition Gasoline Engine Standards, October 4, 1996	1998 - 2006	x	
	Diesel Engines, less than 50hp	1999 - 2005		x
	Recreational Diesel, November 8, 2002	Starting 2006/2009	x	x
	Commercial Diesel, February 28, 2003	Starting 2004/2007	x	x
Large spark-ignition engines	Tier 1 Standards Tier 2 Standards November 8, 2002	2004 - 2006 2007, and later	x	
Small spark-ignition engines	Phase 1 Standards,	1997 - 2007	x	
	Handheld Phase 2 Standards, April 25, 2000	2002 - 2007	x	
	Non-handheld Phase 2 Standards, March 30, 1999	2001 - 2007		
Aircraft (NOx Std in 2005; Smoke Std in 1982)		No current/recent standards for VOC or PM		
Recreational vehicles	November 8, 2002	2006 - 2012	x	

* Standards in various forms including HC, NMHC, NMOG, and NOx+NMHC

2.4.3 Nonroad Engine Programs

There are various categories of nonroad engines, including land-based diesel engines (e.g., farm and construction equipment), small land-based spark-ignition (SI) engines (e.g., lawn and garden equipment, string trimmers), large land-based SI engines (e.g., forklifts, airport ground service equipment), marine engines (including diesel and SI, propulsion and auxiliary, commercial and recreational), locomotives, aircraft, and recreational vehicles (off-road motorcycles, “all terrain” vehicles and snowmobiles). Table 2.4-2 shows current mobile source programs for nonroad engines. Brief summaries of our current and anticipated programs for these nonroad categories follow. As with highway vehicles, the VOC standards we have established for nonroad engines will also significantly reduce VOC-based toxics from nonroad engines. In addition, the standards for diesel engines (in combination with the stringent sulfur controls on nonroad diesel fuel) will significantly reduce diesel PM and exhaust organic gases, which are mobile source air toxics.

In addition to the engine-based emission control programs described below, fuel controls will also reduce emissions of air toxics from nonroad engines. For example, restrictions on gasoline formulation (the removal of lead, limits on gasoline volatility and RFG) are projected to reduce nonroad MSAT emissions because most gasoline-fueled nonroad vehicles are fueled with the same gasoline used in on-highway vehicles. An exception to this is lead in aviation gasoline. Aviation gasoline, used in general (as opposed to commercial) aviation, is a high octane fuel used in a relatively small number of aircraft (those with piston engines). Such aircraft are generally used for personal transportation, sightseeing, crop dusting and similar activities.

2.4.3.1 Land-based Diesel Engines

We recently finalized stringent new emissions standards for land-based nonroad diesel engines, used in agricultural and construction equipment as well as many other applications (although the standards do not apply to locomotive engines, mining equipment or marine engines).[82] These standards are similar in stringency to the 2007 highway diesel engine standards, and are likewise enabled by stringent controls on sulfur levels is diesel fuel, as explained earlier in section 2.4.1.6. The new engine standards, starting in 2008, will reduce PM from new 2008 nonroad diesel engines by about 95 percent compared to engines under today’s standards. The fuels controls are scheduled to begin in mid-2007.

2.4.3.2 Land-Based SI Engines

The category of land-based nonroad SI engines is comprised of a broad mix of service and recreational equipment with engines which range from less than 10 horsepower to several hundreds of horsepower. Most of these engines have been subject to one or more tiers of engine emission controls for some time, while others in the category, such as recreational vehicles, are just coming under engine emission control regulations in 2006.

2.4.3.2.1 Large Land-Based SI Engines

Since the MSAT1 rule was published, we have also finalized emissions standards for SI engines above 25 hp used in commercial applications.[83] Such engines are used in a variety of industrial equipment such as forklifts, airport ground service equipment, generators and compressors. The Tier 1 standards went into effect in 2004 and the Tier 2 standards will start in 2007, providing additional emissions reductions. These standards will provide about a 90 percent reduction in HC emissions on average for new engines versus Tier 1 controlled engines.

2.4.3.2.2 Recreational Vehicles

In 2006, new recreational vehicles, which include snowmobiles, off-road motorcycles and “all terrain vehicles”, began a first tier of engine emission standards. These standards require significant reductions in HC emissions from new engines, ranging from 50 to 86 percent compared to pre-controlled engines.[84]

2.4.3.2.3 Small Land-Based SI Engines

Small land-based spark-ignition (small SI) engines at or below 25 hp may be either handheld or non-handheld and are used primarily in lawn and garden equipment such as walk-behind and tractor mowers, string trimmers, chain saws and other similar equipment. Our Phase 1 exhaust emission controls for this category of engines took effect beginning in 1997 and are projected to result in a roughly 32 percent reduction in VOC emissions for new engines, on average, versus pre-controlled engines.[85] We also have Phase 2 regulations for these engines which, when fully phased-in, are projected to result in additional combined HC and NOx exhaust emission reductions beyond the Phase 1 levels of 60 percent for new non-handheld engines and of 70 percent for new handheld engines.[86] We are currently developing a proposal for new combined HC and NOx exhaust standards for Phase 3 non-handheld small SI engines that should be approximately 35 to 40 percent lower than present Phase 2 standards for this class of engine. Further, we also expect to propose new evaporative emission standards for small SI engines and equipment to control fuel hose permeation, fuel tank permeation, diurnal and running loss emissions.

Phase 3 standards for Small SI engines are expected to achieve toxics benefits through reduction of engine VOC emissions from three sources. The new standards would result in fewer evaporative VOC and, therefore, air toxics emissions by lowering hose and tank permeation losses for these types of equipment. Phase 3 engines will also have lower exhaust VOC emissions under these new standards. Finally, Phase 3 Small SI engines are expected to achieve a small fuel economy benefit during operation. While small, VOC emission savings from increased fuel economy will feed back through a reduced number of gallons of fuel kept onboard these engines during operation. This will result in less VOC from tank/hose permeation, and less fuel burned overall will mean fewer exhaust emissions

2.4.3.3 Marine Engines

Marine engines cover a very wide range of products, from 10-horsepower outboard engines to 100,000-horsepower engines on oceangoing vessels. We have active emission-control programs to address the need for emission controls for every kind of marine engine.

2.4.3.3.1 Marine SI Engines

For gasoline-fueled outboard and personal-watercraft engines, we adopted an initial phase of exhaust standards which became fully implemented with the 2006 model year. These standards have led to a major technology shift in this category of engines to four-stroke engines and advanced-technology two-stroke engines, for an estimated 75 percent reduction in HC emissions from uncontrolled levels.[87] We are developing a proposal to adopt new, more stringent exhaust standards for these engines that would further reduce emissions from this class of engines by an additional 60 percent or more from the initial phase of standards .

Another class of marine SI engine, referred to as stern drive and inboard engines, uses automotive-type engines. These engines have uncontrolled emission rates that are well below the current standards that apply to outboard and personal-watercraft engines. These engines are not currently subject to emission standards, but we intend to include new emission standards for these engines in an upcoming marine SI engine proposal.[88] These new standards would likely be based on the application of catalyst technology to substantially reduce HC and NOx emissions from the operation of these engines.

The proposals mentioned above will also cover fuel evaporative emission standards for fuel lines, fuel tanks and diurnal venting emissions for vessels powered by gasoline-fueled engines in both of these engine classes.

2.4.3.3.2 Marine Diesel Engines

We have adopted emission standards for marine diesel engines in four separate rulemakings. All of these standards are based on in-engine controls and do not require aftertreatment. First, we adopted two tiers of standards for marine engines below 50 horsepower that apply equally to land-based and marine engines. These standards were phased in from 1999 to 2005. Second, we adopted emission standards for commercial marine diesel engines with per-cylinder engine displacement up to 30 liters. These standards are comparable to the standards for land-based nonroad diesel engines that apply in the same time frame, with several adjustments to test procedures and compliance provisions appropriate for marine engines.[89] The emission standards generally apply in 2007 for locomotive-size engines and in 2004 for smaller engines. Third, the emission standards adopted for recreational marine diesel engines are very similar to the comparable commercial engines, with implementation scheduled two years after the commercial standards take effect. All the emission standards in these three rulemakings targeted reductions in NOx and PM emissions. Finally, we adopted standards to control NOx emissions at levels consistent with the requirements from the International Maritime Organization (IMO), but we adopted these as EPA standards under the Clean Air Act to make them mandatory for all engines with per-cylinder displacement above 2.5 liters installed on U.S.-flag vessels starting in the 2004 model year. We are in the process of reviewing the emission standards for all sizes of marine diesel engines and expect to propose new requirements in the near future.

EPA is also investigating the possibility of designating U.S. coastal areas as SOx (oxides of sulfur) Emission Control Areas (SECAs) under the IMO. Such a designation would trigger a requirement for any vessel entering such an area to use reduced-sulfur fuel or operate exhaust scrubbers to prevent SOx emissions.

2.4.3.4 Locomotives

Our regulations for locomotive engines consist of three tiers of standards, applicable depending on the date a locomotive or a particular engine was originally manufactured.[90] The first set of standards (Tier 0) applies to locomotives and their locomotive engines originally manufactured from 1973 through 2001, starting from the time the engine was manufactured or later at "remanufacture."[F] The second set of standards (Tier 1) applies to locomotives and their engines manufactured from 2002 through 2004 and again at engine manufacture or rebuild. The third set of standards (Tier 2) applies to locomotive engines manufactured in 2005 and later. The Tier 0 and Tier 1 regulations were primarily intended to reduce NOx emissions. The Tier 2 regulations are projected to result in 50 percent reductions in VOC and diesel PM as compared to unregulated engine emission levels, as well as additional NOx reductions beyond the Tier 0 and Tier 1 regulations. We are currently developing a new tier of more stringent emissions standards for locomotive engines.

2.4.3.5 Aircraft

A variety of emission regulations have been applied to commercial gas turbine aircraft engines, beginning with limits on smoke and fuel venting in 1974. In 1984, limits were placed on the amount of unburned HC that gas turbine engines can emit per landing and takeoff cycle. In 1997, we adopted standards that were equivalent to the existing International Civil Aviation Organization (ICAO) NOx and CO emission standards for gas turbine engines. In 2005, we tightened the NOx emission standards to levels that are equivalent to the ICAO standards that became effective in 2004. These actions have resulted in minimal emissions reductions, and have largely served to prevent increases in aircraft emissions. We continue to explore ways to reduce emissions from aircraft throughout the nation.

2.4.4 Voluntary Programs

In addition to the fuel and engine control programs described above, we are actively promoting several voluntary programs to reduce emissions from mobile sources, such as the National Clean Diesel Campaign, anti-idling measures, and Best Workplaces for Commuters. While the stringent emissions standards described above apply to new highway and nonroad diesel engines, it is also important to reduce emissions from the existing fleet of about 11 million diesel engines. EPA has launched a comprehensive initiative called the National Clean Diesel Campaign, one component of which is to promote the reduction of emissions in the existing fleet of engines through a variety of

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[F] To "remanufacture" an engine is to rebuild that engine to "new condition" at the end of four-to-eight year long maintenance cycles.

cost-effective and innovative strategies. The goal of the Campaign is to reduce emissions from the 11 million existing engines by 2014. Emission reduction strategies include switching to cleaner fuels, retrofitting engines through the addition of emission control devices and engine replacement. For example, installing a diesel particulate filter achieves diesel particulate matter reductions of approximately 90 percent (when combined with the use of ultra low sulfur diesel fuel). The Energy Policy Act of 2005 includes grant authorizations and other incentives to help facilitate voluntary clean diesel actions nationwide.

The National Clean Diesel Campaign is focused on leveraging local, state, and federal resources to retrofit or replace diesel engines, adopt best practices and track and report results. The Campaign targets five key sectors: school buses, ports, construction, freight and agriculture. Almost 300 clean diesel projects have been initiated through the Campaign. These projects will reduce more than 20,000 PM lifetime tons. PM and NOx reductions from these programs will provide nearly $5 billion in health benefits.

Reducing vehicle idling provides important environmental benefits. As a part of their daily routine, truck drivers often keep their vehicles running at idle during stops to provide power, heat and air conditioning. EPA's SmartWay Transport Partnership is helping the freight industry to adopt innovative idle reduction technologies and to take advantage of proven systems that provide drivers with basic necessities without idling the main engine. To date, there are 80 mobile and stationary idle-reduction projects throughout the country. Emission reductions, on an annual basis, from these programs are in excess of 157,000 tons of CO_2, 2,000 tons of NO_X and 60 tons of PM; over 14 million gallons of fuel are being saved annually. The SmartWay Transport Partnership also works with the freight industry by promoting a wide range of new technologies such as advanced aerodynamics, single-wide tires, weight reduction, speed control and intermodal shipping.

Daily commuting represents another significant source of emissions from motor vehicles. EPA's Best Workplaces for Commuters^{SM} program is working with employers across the country to reverse the trend of longer, single-occupancy vehicle commuting. OTAQ recognizes employers that have met the *National Standard of Excellence for Commuter Benefits* by adding them to the List of Best Workplaces for Commuters^{SM}. These companies offer superior commuter benefits such as transit subsidies for rail, bus, and vanpools and promote flexi-place and telework. Emergency Ride Home programs provide a safety net for participants. More than 1,600 employers representing 3.5 million U.S. workers have been designated Best Workplaces for Commuters^{SM}.

Much of the growth in the Best Workplaces for Commuters^{SM} program has been through metro area-wide campaigns. Since 2002, EPA has worked with coalitions in over 14 major metropolitan areas to increase the penetration of commuter benefits in the marketplace and the visibility of the companies that have received this distinguished designation. Another significant path by which the program has grown is through Commuter Districts including corporate and industrial business parks, shopping malls, business improvement districts and downtown commercial areas. To date EPA has granted the Best Workplaces for Commuters^{SM} “District” designation to over twenty locations across the country including sites in downtown Denver, Houston, Minneapolis, Tampa, and Boulder.

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Chapter 3: Air Quality and Resulting Health and Welfare Effects of Air Pollution from Mobile Sources

3.1 Air Quality and Exposure Measurements

3.1.1 Ambient Monitoring

Ambient air toxics data are useful for identifying pollutants of greatest concern, areas of unhealthy ambient air toxics concentrations, and air toxics trends; evaluating and improving models; and assessing the effectiveness of air toxics reduction strategies. Ambient air toxics data though have limitations for use in risk assessments. While EPA, states, tribes, and local air regulatory agencies collect monitoring data for a number of toxic air pollutants, both the chemicals monitored and the geographic coverage of the monitors vary from state to state.[1] In recent years, the US EPA and states have initiated more extensive monitoring of air toxics to assist in air pollution management through measurement and mitigation.[2] EPA is working with its regulatory partners to build upon the existing monitoring sites to create a national monitoring network for a number of toxic air pollutants. The goal is to ensure that those compounds that pose the greatest risk are measured. In 2004, EPA published a draft National Air Toxics Monitoring Strategy to advance this goal.[3] The National Air Toxics Trends Station (NATTS) monitoring network is currently in place, consisting of 23 sites in 22 urban areas nationally.[4]

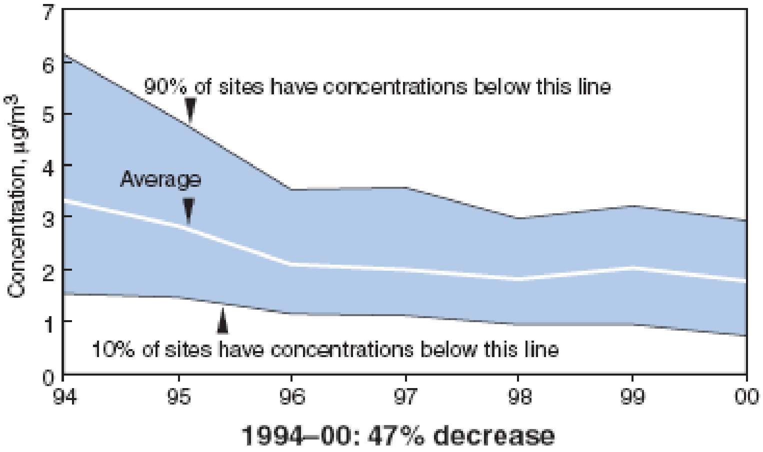
The available monitoring data help air pollution control agencies track trends in toxic air pollutants in various locations around the country. EPA conducted a pilot city monitoring project in 2001 that included sampling in four urban areas and six small city/rural areas (see Figure 3.1-1). This program helped answer several important national network design questions (e.g., sampling and analysis precision, sources of variability, and minimal detection levels).

Figure 3.1-1. Map of Ten Cities in Monitoring Pilot Project

Building on the pilot program, the US EPA and states established a national air toxics monitoring program beginning with a 10-city pilot program, which now consists of the NATTS, and numerous community-scale monitoring studies.[5] To guide development of the monitoring program, a qualitative data analysis project was begun in 2001 and the first phase was completed in 2004. The analysis showed that typical urban concentration ranges for most VOCs are approximately an order of magnitude (or more) higher than the background concentrations. Because air toxics concentrations vary spatially, other monitoring networks are needed to provide additional, especially rural, concentrations. Extrapolation for most air toxics beyond the urban scale is not recommended without a network of rural measurements capable of capturing gradients between urban and rural areas. For the latest information on national air toxics monitoring, see www.epa.gov/ttn/amtic/airtxfil.html.

Figure 3.1-2 shows measurements of benzene taken from 95 urban monitoring sites around the country. These urban areas generally have higher levels of benzene than other areas of the country. Measurements taken at these sites show, on average, a 47% drop in benzene levels from 1994 to 2000. During this period, EPA phased in new (so-called "tier 1") car emission standards; required many cities to begin using cleaner-burning gasoline; and set standards that required significant reductions in benzene and other pollutants emitted from oil refineries and chemical processes.

Figure 3.1-2. Ambient Benzene, Annual Average Urban Concentrations, Nationwide, 1994-2000



Following is a summary of analyses recently performed on ambient measurements of air toxics to identify pollutants and geographic areas of concern and to evaluate trends. Use of monitoring data to evaluate and improve models is discussed in Section 3.2.

EPA recently completed a study of the spatial and temporal trends in ambient air toxics data within the NATTS and other networks from 1990-2003.[6] Most data came from urban monitors. Nationally, citywide average annual concentrations of benzene, formaldehyde, and acetaldehyde, varied by about a factor of five, and 1,3-butadiene by more than 10 times. The coefficient of variation[a] of annual average concentrations between different monitors within the same city averaged 0.37 for benzene, 0.45 for 1,3-butadiene. Between cities, the coefficient of variation could vary substantially. Different pollutants showed different seasonal trends, with average concentrations of benzene and 1,3-butadiene being highest in colder seasons, while average concentrations of formaldehyde and acetaldehyde were higher during warm seasons, reflecting the high photochemical production of aldehydes. The concentrations of benzene, butadiene, and acetaldehyde fell substantially over different time periods. From 1990-2003, benzene concentrations fell by 57%. Insufficient data existed in earlier years to analyze 1,3-butadiene and acetaldehyde. Formaldehyde increased by 134% over this period, although changes in sampling methodology at some sites around 1995 make this quantification suspect. From 1995-2003, the average annual changes in benzene, 1,3-butadiene, formaldehyde, and acetaldehyde were -47%, -54%, +11%, and -12%. From 1998-2003, the changes were -21%, -46%, +17%, and -4%, respectively. For benzene, these trends were statistically significant, but formaldehyde and acetaldehyde trends after 1995 were not.

One recent publication evaluated the trends in ambient concentrations of benzene and 1,3-butadiene in the Houston, TX metropolitan area.[7] Using data from two air monitoring networks, a state-based network and the Photochemical Assessment Monitoring Systems, the study constructed a statistical model, controlling for meteorology and seasonality, to evaluate trends in ambient toxics over the 1997-2004 time period. Averaged over state monitoring sites with data across the time period, the model estimated 1.7% and 3.7% average annual decrease in ambient benzene and 1,3,-butadiene, respectively. Mobile source and point source emission reductions contributed roughly equally to this change. Examining long-term average concentration differences across monitoring sites, benzene varied by roughly two-fold across monitors while 1,3-butadiene varied roughly six-fold across monitors. This may be attributable to the substantial contribution of industrial sources to the local 1,3-butadiene inventory, while the benzene inventory is dominated by mobile sources. The study also evaluated differences in weekday and weekend concentration, with the model predicting significant meteorologically-adjusted concentration weekday increases relative to weekend only during the 6-9 A.M. morning rush hour period.

A recent study from San Francisco, CA evaluated trends in ambient benzene emissions and air quality throughout the 1990's.[8] The study noted substantial decreases in benzene emissions and ambient concentrations. Unique to the study was the attribution of components of these reduction to specific regulatory programs related to vehicles and fuels. In particular, the study attributed a 1-year drop of 54% in benzene emission rates to a combination of the introduction of California phase 2 RFG (attributed a 50% decrease) and fleet turnover (attributed a 4% decrease). During the same year (1995-1996), a 42% reduction in the ambient concentration of benzene was also observed. Fleet turnover effects were shown to be cumulative over time. The study indicates that in San Francisco both fuel and vehicle effects are important

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[a] A "coefficient of variation" is a measure of variability, and for a set of data is defined as the standard deviation over the mean.

contributors to changes in emissions and ambient concentrations of benzene.

New York State has a systematic program in place that has been measuring air toxics since the 1990s.[9] The network of monitors is located throughout urban, industrial, residential and rural locations. The New York State Department of Environmental Conservation recently examined the spatial and temporal characteristics of benzene by analyzing five of the 32 total network sites across the state (see Table 3.1-1). Spatial trends show a wide range of annual average benzene concentrations, with the lowest value at a rural site and the highest at an industrial site. The recent 3-year period of 2001-2003 was also compared with the longer 1990-2003 period. The 3-year period exhibits a decrease in mean concentration compared to the entire period, indicating that benzene concentrations are decreasing over New York State throughout this period. The mean annual rate of change in the period 1990 to 2003 was determined using linear regression and moving average (KZ filter) on the concentration data. The analysis indicated that site-specific ambient concentration levels of benzene decreased by 50% or more during 1990 to 2003. These decreases occurred in ozone nonattainment areas that had reformulated gasoline (RFG) requirements as well as in the rest of the state. The downward trend can be attributed to regulatory measures aimed at reducing toxic emissions from industrial sources, replacement of older higher emitting vehicles with vehicles meeting more stringent EPA standards for hydrocarbon emissions, as well as the adoption of RFG in 1995 and 1999 for the 1-hour ozone nonattainment areas in New York State. Since trends were observed for sites that were not part of the RFG program, decreases may also be attributed to the improvement in vehicle emissions technology and the state-wide adoption of the California Low Emission Vehicle program.

A similar downward trend was observed in California. In California, the Air Resources Board (ARB) maintains an Almanac of Emissions and Air Quality.[10] The Almanac summarizes statewide emissions, statewide annual average concentrations (calculated as a mean of monthly means), and statewide average health risks for selected air toxics. Currently there are data available for ten air toxics in California, including benzene. The ARB network consists of 18 air quality monitoring stations. The data collected, analyzed, and reported reflect a spatial average; therefore, ambient concentrations for individual locations may be higher or lower. Estimates show that approximately 84% of the benzene emitted in California comes from motor vehicles, including evaporative leakage and unburned fuel exhaust. The predominant sources of total benzene emissions in the atmosphere are gasoline fugitive emissions and gasoline motor vehicle exhaust. Approximately 49% of the statewide benzene emissions can be attributed to on-road motor vehicles, with an additional 35% attributed to other mobile sources such as recreational boats, off-road recreational vehicles, and lawn and garden equipment. Currently, the benzene content of gasoline is less than 1%. Some of the benzene in the fuel is emitted from vehicles as unburned fuel. Benzene is also formed as a partial combustion product of larger aromatic fuel components. Industry-related stationary sources contribute 15% and area-wide sources contribute 1% of the statewide benzene emissions. The primary stationary sources of reported benzene emissions are crude petroleum and natural gas mining, petroleum refining, and electric generation. The primary area-wide sources include residential combustion of various types such as cooking and water heating. The primary natural sources are petroleum seeps that form where oil or natural gas emerge from subsurface sources to the ground or water surface. The statewide benzene levels have shown generally steady improvement since 1990. To examine the trend in benzene while minimizing the influences of weather on the trend, the statewide average benzene concentration for 1990-1992 was compared to that for 2001-2003. The result was a 72% decrease in benzene concentration. These downward trends for benzene and other air toxics are a result of many control measures implemented to reduce emissions.

Another recent evaluation of hazardous air pollutant (HAP) trends was conducted for selected metropolitan areas.[11] Researchers retrieved historical concentration and emissions data from the US EPA for Boston, New York City, Philadelphia, Tampa Bay, Detroit, Dallas, St. Louis, Denver, Los Angeles, and Seattle, chosen for each of EPA's ten regions. Annual and seasonal trends were generated to evaluate reductions in HAP emissions and ambient concentrations during the time period 1990-2003. Several air toxics were targeted, including benzene. To evaluate the trends, average concentrations from 1990-1994 were compared to 2002-2003 (these time periods were chosen due to availability of data). The results showed that over 85% of the metropolitan area-HAP combinations decreased in their HAP concentrations, while less than 15% realized an increase. For example, Table 3.1-2 shows that benzene concentrations decreased in seven of the ten metropolitan areas (range 19 to 79%).

Each of these analyses consistently illustrates the significant reductions in national annual average concentrations of benzene and other air toxics. The air pollution management efforts of the US EPA and states have been effective in reducing ambient concentrations of air toxics over time. Additional reductions are expected with the implementation of additional regulatory measures such as this one. It should be noted that due to the limited spatial and temporal coverage of air toxics monitoring networks, using ambient monitors to represent exposure adds substantial uncertainty in exposure assessment.

Table 3.1-1. Site Descriptions of the Monitoring Stations Along with Mean Benzene Concentration from 1990-2003 and 2001-2003, for Monitoring Stations in New York State.

	Lackawanna	**Eastern District High School**	**Troy**	**Niagara Falls**	**Whiteface Mountain Base Lodge**
Site Character	Industrial	Urban	Small Urban	Urban Industrial	Rural
Location Area	Buffalo	Brooklyn	Hudson Valley	Niagara	Essex
2000 Population (thousands)	950	2465	153	220	39
Annual Vehicle Miles Traveled (million miles)	8250	4246	1413	1546	577
Period 1990-2003 Mean Concentration (μg/m^3)	5.09	2.85	2.31	1.80	0.86
Period 2001-2003 Mean Concentration (μg/m^3)	2.26	2.05	1.68	1.08	0.54

3.1.2 Population-Based (Representative) Exposure Measurements

In addition to measurements of outdoor concentrations, an important component of understanding human exposure to air toxics is the body of studies that employ survey techniques to assess microenvironmental and representative populations' exposures. Typically, these studies are designed to represent a discrete geographic area. The personal exposure concentration summaries from these studies are shown in Table 3.1-3.

The National Human EXposure Assessment Survey (NHEXAS) was a series of population-based exposure studies. The states in EPA Region 5 were the focus of one NHEXAS study, which was conducted in mid-1990.[12] Nearly 400 personal and indoor air samples were obtained from both smokers and non-smokers, along with a smaller number of outdoor air samples in residential areas. Measurements took place over 6 days per subject. Overall, average personal exposure to benzene was 7.52 μg/m^3, with indoor air concentrations averaging 7.21 μg/m3. Outdoor air concentrations averaged 3.61 μg/m^3. Personal air concentrations were significantly associated with indoor air concentrations, as well as blood concentrations. The preliminary results of the NHEXAS pilot study in Arizona, another study area, indicate that among the 179 statistically-sampled homes, median indoor concentrations were 1.3 μg/m^3 during the mid-1990's, while outdoor concentrations were 1.0 μg/m^3.[13] Furthermore, reported results from the Arizona study indicate that fuel-related VOCs are elevated in homes with attached garages.

In another study based on a random population-based sample of an urban population, 37 non-smoking residents of South Baltimore, MD were equipped with passive monitors to assess 3-day average personal exposure to VOCs, in addition to indoor and outdoor air.[14] Monitoring took place in 2000 and 2001. Modeled air quality data from the ASPEN dispersion model, employed in EPA's National Air Toxics Assessment for 1996, were also obtained for the study area. Overall, median outdoor modeled concentrations of benzene and other fuel-related VOCs corresponded well with measured data in the area (correlation coefficient of median VOC concentrations = 0.97). Average personal exposure to benzene was 4.06 μg/m^3, while 95th percentile values were 7.30 μg/m^3. For indoors, the respective values were 3.70 and 8.34 μg/m^3, while for outdoors the values were 1.84 and 3.14 μg/m^3. Overall, the study provides evidence that modeling outdoor benzene concentrations using ASPEN, as is done in this rule, provides adequate representation of outdoor values. However, indoor and personal exposures are also influenced by other sources, as is described in the section on attached garages.

While not a population-based study, the recently-completed Relationships of Indoor, Outdoor and Personal Air (RIOPA) study provides a depiction of indoor, outdoor, and personal concentrations of benzene and other toxics in three regions with differing source mixtures.[15] 100 non-smoking homes in each of Los Angeles, CA, Houston, TX, and Elizabeth, NJ were selected for sampling in areas representing locations dominated by emissions from mobile sources, stationary sources, and a mixture of sources, respectively. In the adult sample, average personal exposures to benzene were 3.64 μg/m^3, with a 95th percentile of 10.7 μg/m^3. Respective statistics for indoor air were 3.50 $\mu g/m^3$ and 10.0 $\mu g/m^3$, while outdoor statistics were 2.15 and 5.16 $\mu g/m^3$.

Few studies have systematically addressed exposures among representative samples of children. Several have been done in Minnesota, with others in New York, Los Angeles, and Baltimore areas.

For the Minnesota Children's Pesticide Exposure Study (MNCPES), conducted in urban and rural areas in the vicinity of Minneapolis-St. Paul, MN,[16] all monitoring used the same 6-day monitoring duration as used in the Region 5 NHEXAS study. In the first phase of the study, a statistically representative sample of 284 homes with children underwent air monitoring for VOCs. Low-income and minority homes were over sampled to ensure representation. Indoor benzene concentrations averaged 4.6 $\mu g/m^3$, with the data skewed toward higher concentrations. The 95th percentile concentration was 12.7 $\mu g/m^3$. Homes with attached garages had significantly higher concentrations of benzene indoors ($p < 0.0001$). In the second phase of the study, a subset of 100 children underwent intensive monitoring of personal, indoor, and outdoor air as well as activity tracking via diary. Overall personal exposures were 4.8 $\mu g/m^3$, with a 95th percentile of 9.1 $\mu g/m^3$. Indoor concentrations in the intensive period averaged 3.9 $\mu g/m^3$ and outdoor averaged 3.3 $\mu g/m^3$. Regression analysis indicated that personal exposures generally were higher than the time-weighted average of indoor and outdoor air. Furthermore, personal exposures to benzene and toluene were elevated for children living in a home with an attached garage, but only the relationship for toluene was significant at the 95% confidence level.

Table 3.1-2. Benzene Emission (Tons Per Year) and Concentration ($\mu g/m^3$) Comparison

Metropolitan Area	1990 Emissions	2002 Emissions	% Change in Emissions	1990-1994 Average Concentration	2002-2003 Average Concentration	% Change in Concentration
Boston	6262	2229	-64.4	3.93	0.81	-79.5
New York City	16653	7512	-54.9	3.24	1.35	-58.5
Philadelphia	5961	2577	-56.8	3.60	1.26	-64.9
Tampa Bay	3103	2408	-22.4	NA	NA	NA
Detroit	6480	4388	-32.3	4.19	3.40	-18.7
Dallas	7933	2832	-64.3	1.21	0.78	-35.8
St. Louis	4358	2304	-47.1	5.16	1.43	-72.3
Denver	2800	1913	-31.7	NA	2.75	NA
Los Angeles	19762	4168	-78.9	8.97	2.34	-73.9
Seattle	5844	4315	-26.2	NA	1.39	NA

In another study, students recruited from an inner-city school in Minneapolis, MN participated in an exposure study called SHIELD.[17] Students were recruited using stratified random sampling, with a total of 153 children participating between two seasons. Home and personal samples were collected and averaged over two continuous days of sampling using passive methods. School measurements took place during school hours only, over the course of 5 days, and outdoor measurements were set up to run continuously outside the school through each week sampled (Monday through Friday). The study reported median, 10th, and 90th percentile concentrations. In personal samples, median benzene concentrations were 1.5 $\mu g/m^3$ in spring and 2.1 $\mu g/m^3$ in winter.[18]

The TEACH exposure study tracked inner-city high school students' exposures in New York, NY and Los Angeles, CA. In the New York City study, 42 students underwent personal, indoor home, and outdoor home air quality monitoring during two seasons.[19] Average winter benzene personal concentrations were 4.70 $\mu g/m^3$, while indoor and outdoor concentrations averaged 5.97 and 2.55 $\mu g/m^3$. Average indoor concentrations exceeding average personal concentrations is unique to the TEACH winter results. Summer values were 3.09, 1.75, and 1.31 $\mu g/m^3$, respectively. The authors noted that VOC concentrations within the city tracked traffic patterns. There was no substantial evidence for indoor sources of benzene.[20] In a subsequent publication, personal exposure concentrations for both cities were reported, averaged across both seasons. New York City average exposure concentrations were 3.82 $\mu g/m^3$, while Los Angeles average exposure concentrations were 4.64 $\mu g/m^3$.[21]

Overall, these studies show that personal and indoor concentrations of benzene and other VOCs are substantially higher than those found outdoors (see Table 3.1-3). In general, these differences are statistically significant. Some of the factors leading to these elevated concentrations are likely a result of motor vehicle impacts such as exhaust and evaporative emissions in attached garages, exposures during on-road commutes and exposures during vehicle re-fueling. These and other factors are discussed in more detail in Section 3.1.3. This suggests that risk reductions from the controls in this proposal will be greater than can currently be estimated using national-scale modeling tools.

3.1.3 Elevated Concentrations and Exposures in Mobile Source-Impacted Areas

Air quality measurements near roads often identify elevated concentrations of air toxic pollutants at these locations. The concentrations of air toxic pollutants near heavily trafficked roads, as well as the pollutant composition and characteristics, differ from those measured distant from heavily trafficked roads. Thus, exposures for populations residing, working, or going to school near major roads are likely different than for other populations. Following is an overview of concentrations of air toxics and exposure to air toxics in areas experiencing elevated pollutant concentrations due to the impacts of mobile source emissions.

Table 3.1-3. Personal Exposure to Benzene from Population-Based Studies[a]

Location	**Year(s)**	**Includes Smokers**	**Personal Average (μg/m^3)**	**"Upper Bound" (μg/m^3)**	**Indoor Average (μg/m^3)**	**Outdoor Average (μg/m^3)**	**Reference**
EPA Region 5	1995-1996	Yes	7.52	13.71[b]	7.21	3.61	Clayton et al. (1999)
Baltimore, MD	2000-2001	No	4.06	7.30[c]	3.70	1.84	Payne-Sturges et al. (2004)
Elizabeth, NJ, Houston, TX, Los Angeles CA	1999-2001	No	3.64	10.7[c], 27.4[g]	3.50	2.15	*Weisel et al. (2005)*
Elizabeth, NJ, Houston, TX, Los Angeles CA	*1999-2001*	*No*	*4.16*	*12.0[c],* *43.6[g]*	*N/R[h]*	*N/R[h]*	*Weisel et al. (2005)*
Minneapolis - St. Paul, MN	*1997*	*Yes[e]*	*4.8*	*9.1*	*3.9*	*3.3*	*Adgate et al. (2004a)*
Minneapolis, MN	*2000*	*Yes[e]*	*2.1 Winter* *1.5 Spring*	*6.5 Winter[b]* *4.2 Spring[b]*	*2.2 Winter* *2.1 Spring*	*1.3 Winter* *1.1 Spring*	*Adgate et al. (2004b)*
New York, NY	*1999-2000*	*No*	*4.7 Winter* *3.1 Summer* *3.8 Total*	*11.4 Winter[d]* *7.0 Summer[d]* *12.3 Total[f]*	*6.0 Winter* *1.8 Summer* *3.6 Total*	*2.5 Winter* *1.3 Summer* *1.8 Total*	*Kinney et al. (2002); Sax et al. (2006)*
Los Angeles, CA	*1999-2000*	*No*	*4.64*	*11.27*	*3.87*	*3.32*	*Sax et al. (2006)*

[a] Children's studies in italics

[b] 90th percentile

[c] 95th percentile

[d] Mean +2 standard deviations

[e] Smoking in homes

[f] Maximum measured value

[g] 99th percentile

[h] Not reported

3.1.3.1 Concentrations Near Major Roadways

3.1.3.1.1 Particulate Matter

Mobile sources influence temporal and spatial patterns of criteria pollutants, air toxics, and PM concentrations within urban areas. Motor vehicle emissions may lead to elevated concentrations of pollutants near major roads. Since motor vehicle emissions generally occur within the breathing zone, near-road populations may be exposed to "fresh" primary emissions as well as combustion pollutants "aged" in the atmosphere. For particulate matter, these fresh versus aged emissions can result in the presence of varying particle sizes near roadways, including ultrafine, fine, and coarse particle modes.

The range of particle sizes of concern is quite broad and is divided into smaller categories. Defining different size categories is useful since particles of different sizes behave differently in the atmosphere and in the human respiratory system. Table 3.1-4 lists the four terms for categorizing particles of different sizes as defined by the US EPA.[22]

Table 3.1-4. Descriptions and Particle Sizes of Each Category of Particles

Description	Particle Size, d_p (μm)
Supercoarse	$d_p > 10$
Coarse (or Thoracic Coarse Mode)	$2.5 < d_p \leq 10$
Fine (or Accumulation Mode)	$0.1 < d_p \leq 2.5$
Ultrafine (or Nuclei Mode)[a]	$d_p \leq 0.1$

[a] Nuclei Mode has also been defined as $d_p \leq 0.05$ μm elsewhere.

Other particle classifications of interest include total suspended particulate matter (TSP). TSP includes a broad range of particle sizes including fine, coarse, and supercoarse particles. PM_{10} is defined as particulate matter with an aerodynamic diameter of less than or equal to 10 μm. PM_{10} is regulated as a specific type of "pollutant" because this size range is considered respirable and can penetrate into the lower respiratory tract. $PM_{2.5}$ is particulate matter with an aerodynamic diameter less than or equal to 2.5 μm. $PM_{2.5}$ settles quite slowly in the atmosphere relative to coarse and supercoarse particles. Normal weather patterns can keep $PM_{2.5}$ airborne for several hours to several days and enable these particles to transport hundreds of miles. $PM_{2.5}$ can cause health problems due to widespread exposures and efficiency at reaching deep into the lungs.

The size distribution of particles can be defined as a function of number, surface area, volume, and mass.[23,24] Typically, on a number basis, emissions from mobile sources are heavily dominated by ultrafine mode particles, which tend to be comprised of volatile carbon. On a surface area basis, the average diameter of particles emitted by mobile sources is 0.1 μm. On a volume and mass basis, the size distribution of particles emitted from mobile sources has an average particle diameter of approximately 0.2 μm.

Evidence of the large number of ultrafine mode particles emitted by motor vehicles can be found in the near-road environment. Roadside and ambient on-road measurements show that ultrafine mode particles dominate the number concentration in close proximity to the roadway, while fine mode dominates farther from the road. Particle size distributions, mass and elemental carbon concentrations have been examined near roads in Los Angeles.[25,26] Researchers observed a four-fold increase in particle number concentrations, when comparing measurements 300 m and 20 m from LA highways. Other studies have similarly shown that ultrafine mode particles show a sharp decrease in particle number concentrations as the distance from major roadways increases.[27,28] Evidence was recently found of increased exposures to ultrafine particles near roads when it was discovered that children living near major roads had elevated levels of particle-containing alveolar macrophages.[29] Additionally, roadside monitoring has shown that particle number varies with vehicle type and vehicle operating conditions. For example, elevated ultrafine mode particle concentrations have been identified when operating speeds on the road increase as well as when the proportion of heavy-duty diesel vehicles increases.[30,31]

An increase in coarse particles near roads could originate from engine deterioration, brake and tire wear, and secondary aerosol formation.[32,33,34,35] Engine deterioration is generally a function of vehicle age and maintenance condition. Brake wear emissions are highly dependent on brake pad materials.[36] Secondary aerosol formation is dependent on fuel composition, emission rates, atmospheric chemistry, and meteorology. Re-entrained road dust, as well as brake and tire wear will also contribute to increased concentrations of coarse PM.

Meteorological factors can affect exposures to motor vehicle emissions near the road. Researchers have noted that particle number concentrations changed significantly with changing wind conditions, such as wind speed, near a road.[37] Studies suggest that ambient temperature variation can also affect particle number gradients near roads substantially.[38] Wind direction also affects traffic-related air pollution mass concentrations inside and outside of schools near motorways.[39,40] Diurnal variations in mixing layer height will also influence both near-road and regional air pollutant concentrations. Decreases in the height of the mixing layer (due to morning inversions, stable atmosphere, etc.) will lead to increased pollutant concentrations at both local and regional scales.

3.1.3.1.2 Gaseous Air Toxics

Concentrations of mobile source air toxics have been estimated by a number of different methods such as the NATA National-Scale Assessment, local-scale modeling assessments, and from air quality monitoring in locations in immediate proximity to busy roadways. Each approach offers a different level of representation of the concentrations of air toxics near roadways.

Air quality monitoring is one way of evaluating pollutant concentrations at locations near sources such as roadways. Ambient VOC concentrations were measured around residences in Elizabeth, NJ, as part of the Relationship among Indoor, Outdoor, and Personal Air (RIOPA) study. Data from that study was analyzed to assess the influence of proximity of known ambient emission sources on residences.[41] The ambient concentrations of benzene, toluene, ethylbenzene, and xylene isomers (BTEX) were found to be inversely associated with: distances from the sampler to interstate highways and major urban roads; distance from the sampler to gasoline stations; atmospheric stability; temperature; and wind speed. The data indicate that

BTEX concentrations around homes within 200 m of roadways and gas stations are 1.5 to 4 times higher than urban background levels. In a subsequent study, proximity to major roadways, meteorology, and photochemistry were all found to be significant determinants of ambient concentration of a range of aldehyde species, including formaldehyde, acetaldehyde, acrolein, and others. For most aldehydes, spring and summer concentrations were significantly higher than those from colder seasons.[42] However, formaldehyde concentrations were significantly lower in summertime, suggesting greater photochemical destruction than production. On colder days, when photochemical activity was lower, concentrations of formaldehyde, acetaldehyde, acrolein, and other aldehydes were significantly higher with increasing proximity to high-traffic roads.

Several other studies have found that concentrations of benzene and other mobile source air toxics are significantly elevated near busy roads compared to "urban background" concentrations measured at a fixed site.[43,44,45,46,47,48] For example, measurements near a tollbooth in Baltimore observed mean benzene concentrations to vary by time of day from 3 to 22.3 μg/m^3 depending on traffic volume, vehicle type, and meteorology.[49] In comparison with ambient levels, Maryland's Department of Environment reported the range of benzene annual averages measured at seven different monitoring sites in 2000 between 0.27-0.71 μg/m^3.[50] Another study measured the average benzene concentration in a relatively high traffic density (~ 16000 automobiles/day) sampling area at 9.6 μg/m^3 and in rural areas with hardly any traffic (< 50 automobiles/day) at 1.3 μg/m^3.[51] The concentration of benzene, along with several other air toxics (toluene and the isomeric xylenes), in the urban area far exceeded those in the rural area.

According to Gaussian dispersion theory, pollutants emitted along roadways will show highest concentrations nearest a road, and concentrations exponentially decrease with increasing distance downwind. These near-road pollutant gradients have been confirmed by measurements of both criteria pollutants and air toxics.[52,53,54,55,56] Researchers have demonstrated exponential reductions in concentrations of CO, as well as PM number, and black carbon (as measured by an aethalometer), with increasing downwind distance from a freeway in Los Angeles.[57,58] These pollutants reached background levels approximately 300 m downwind of the freeway.

3.1.3.2 Exposures Near Major Roadways

The modeling assessments and air quality monitoring studies discussed above have increased our understanding of ambient concentrations of mobile source air toxics and potential population exposures. Results from the following exposure studies reveal that populations spending time near major roadways likely experience elevated personal exposures to motor vehicle related pollutants. In addition, these populations may experience exposures to differing physical and chemical compositions of certain air toxic pollutants depending on the amount of time spent in close proximity to motor vehicle emissions. Following is a detailed discussion on exposed populations near major roadways.

3.1.3.2.1 In Vehicles

Several studies suggest that people may experience significant exposures while driving in vehicles. A recent in-vehicle monitoring study was conducted by EPA and consisted of in-vehicle air sampling throughout work shifts within ten police patrol cars used by the North Carolina State Highway Patrol (smoking not permitted inside the vehicles).[59] Troopers operated their vehicles in typical patterns, including highway and city driving and refueling. In-vehicle benzene concentrations averaged 12.8 $\mu g/m^3$, while concentrations measured at an "ambient" site located outside a nearby state environmental office averaged 0.32 $\mu g/m^3$. The study also found that the benzene concentrations were closely associated with other fuel-related VOCs measured.

The American Petroleum Institute funded a screening study of "high-end" exposure microenvironments as required by section 211(b) of the Clean Air Act.[60] The study included vehicle chase measurements and measurements in several vehicle-related microenvironments in several cities for benzene and other air toxics. In-vehicle microenvironments (average concentrations in parentheses) included the vehicle cabin tested on congested freeways (17.5 $\mu g/m^3$), in parking garages above-ground (155 $\mu g/m^3$) and below-ground (61.7 $\mu g/m^3$), in urban street canyons (7.54 $\mu g/m^3$), and during refueling (46.0 $\mu g/m^3$). It should be noted that sample sizes in this screening study were small, usually with only one to two samples per microenvironment. The final report of this study is expected to be released in 2007.

In 1998, the California Air Resources Board published an extensive study of concentrations of in-vehicle air toxics in Los Angeles and Sacramento, CA.[61] The data set is large and included a variety of sampling conditions. On urban freeways, in-vehicle benzene concentrations ranged from 3 to 15 $\mu g/m^3$ in Sacramento and 10 to 22 $\mu g/m^3$ in Los Angeles. In comparison, ambient benzene concentrations ranged from 1 to 3 $\mu g/m^3$ in Sacramento and 3 to 7 $\mu g/m^3$ in Los Angeles.

Studies have also been conducted in diesel buses, such as the one recently conducted of LA school buses.[62,63] In the study, five conventional diesel buses, one diesel bus equipped with a catalytic particle filter, and one natural gas bus were monitored for benzene, among other pollutants. These buses were driven on a series of real school bus routes in and around Los Angeles, CA. Average benzene concentrations in the buses were 9.5 $\mu g/m^3$, compared with 1.6 $\mu g/m^3$ at a background urban fixed site in west Los Angeles. Type of bus, traffic congestion levels, and encounters with other diesel vehicles contributed to high exposure variability between runs.

The same researchers additionally determined the relative importance of school bus-related microenvironments to children's pollutant exposure.[64] Real-time concentrations of black carbon (BC), particle-bound PAH, nitrogen dioxide (NO_2), particle counts (0.3-0.5 μm size range), and $PM_{2.5}$ mass were measured inside school buses during long commutes, at bus stops along the routes, at bus loading and unloading zones, and at nearby urban background sites. Across all the pollutants, mean concentrations during bus commutes were higher than in any other microenvironment. Mean exposures in bus commutes were 50 to 200 times more than for loading and unloading zones at the school, and 20 to 40 times more than for bus stops along the route, depending on the pollutant. The in-cabin exposures were dominated by the effect of surrounding traffic when windows were open and by the bus' own exhaust when the windows were closed. The mean pollutant concentrations in the three school bus commute-related environments and background air are presented in the Table 3.1-5.

Table 3.1-5. Mean Concentrations of Black Carbon (BC), Particle Bound PAH, NO_2, Particle Count (PC), and $PM_{2.5}$ in Three School Bus Commute Microenvironments and Background Air

	Mean Concentrations			
	Background	(Un)Loading Zone	Bus Stops	Bus Commutes[a]
BC (µg/m^3)	**2 ± 0.1**	**2 ± 0.3**	**4 ± 0.4**	**3-19 (8)**
Particle Bound -PAH (µg/m^3)	**0.027 ± 0.0015**	**0.015 ± 0.0003**	**0.044 ± 0.0045**	**0.064-0.400 (0.134)**
NO_2 (ppb)	**49 ± 1.0**	**35 ± 0.2**	**54 ± 1.9**	**34-110 (73)**
PC (count/cm^3)	**83 ± 3.1**	**Not collected**	**62 ± 1.8**	**77-236 (130)**
$PM_{2.5}$ (µg/m^3)	**20 ± 2.4**	**Not collected**	**25[b]**	**21-62 (43)**

[a] Ranges are associated with different bus types and window positions. Values in parenthesis are the mean for all runs.
[b] Not enough data to establish a confidence interval.

In another recent study of commuter buses, concentrations of benzene and other VOCs were measured in buses on several routes in Detroit, MI.[65] The average in-bus concentration of benzene was 4.5 µg/m^3, while the average concentrations at three fixed sites taken during the study period ranged from 0.9-2.0 µg/m^3. In this study, daily bus/ambient concentration ratios were reported, and ranged from 2.8-3.3 on the three reported study days. The in-bus concentrations were found to be most influenced by local traffic sources. A number of other studies similarly observe that passenger car commuters are exposed to elevated pollutant concentrations while driving on busy roads.[66,67,68,69,70,71]

Older studies that examine in-vehicle concentrations in older model year vehicles are difficult to apply for regulatory analyses, due to the relatively rapid changes in vehicle emission controls over the last 15 years. In general, these studies indicate that concentrations in vehicles are significantly higher than ambient concentrations.[72,73,74] The average benzene measurements of these older in-vehicle studies (Raleigh, NC and CA South Coast Air Basin) are in Table 3.1-6 along with the more recent studies for comparison.

Overall, these studies show that concentrations experienced by commuters and other roadway users are substantially higher than ambient air measured in typical urban air. As a result, the time a person spends in a vehicle will significantly affect their overall exposure.

Table 3.1-6. Benzene Concentrations (μg/m^3) Measured in Vehicles and in Ambient Air

Study	In-Vehicle		Ambient Air	
	Mean	Max	Mean	Max
Raleigh, NC (1989) [a]	11.6	42.8	1.9	8.5
CA South Coast Air Basin (1989) [b]	42.5	267.1	9.3-16.9	--
Boston, MA (1991) [c]	17.0	64.0	--	--
Los Angeles, CA (1998)	10-22	--	3-7	--
Sacramento, CA (1998)	3-15	--	1-3	--
Detroit, MI (2000) [d]	4.5	10.8	0.9-2.0	--
API Gasoline Screening (2002)	17.5	--	--	--
LA, CA School Buses (2003)	9.5	--	1.6	--
NC State Highway Patrol (2003)	12.8	43.1	0.32	1.92

[a] A one-hour measurement was taken for each experimental trip.
[b] The estimated sampling time period was 1.5 hours/round-trip. n=191.
[c] In-vehicle measurement includes both interstate and urban driving, n=40.
[d] Measurements taken from interiors of urban buses.

3.1.3.2.2 In Homes and Schools

The proximity of schools to major roads may result in elevated exposures for children due to potentially increased concentrations indoors and increased exposures during outdoor activities. Here we discuss international studies in addition to the limited number of US studies, because while fleets and fuels outside the U.S. can be much different, the spatial distribution of concentrations is relevant.

There are many sources of indoor air pollution in any home or school. These include indoor sources and outdoor sources, such as vehicle exhaust. Outdoor air enters and leaves a house by infiltration, natural ventilation, and mechanical ventilation. In infiltration, outdoor air flows into the house through openings, joints, and cracks in walls, floors, and ceilings, and around windows and doors. In natural ventilation, air moves through opened windows and doors. Air movement associated with infiltration and natural ventilation is caused by air temperature differences between indoors and outdoors and by wind. Finally, there are a number of mechanical ventilation devices, from outdoor-vented fans that intermittently remove air from a single room, such as bathrooms and kitchen, to air handling systems that use fans and duct work to continuously remove indoor air and distribute filtered and conditioned outdoor air to strategic points throughout the house. The concentrations of outdoor pollutants can therefore influence indoor concentrations. A review of the literature determined that approximately 100% of gaseous compounds, such as benzene, and 80% of diesel PM can penetrate indoors.[75,76]

In the Fresno Asthmatic Children's Environment Study (FACES), traffic-related pollutants were measured on selected days from July 2002 to February 2003 at a central site, and inside and outside of homes and outdoors at schools of asthmatic children.[77] Preliminary data indicate that PAH concentrations are higher at elementary schools located near primary roads than at elementary schools distant from primary roads (or located near primary roads with limited access). PAH concentrations also appear to increase with increase in annual average daily traffic on nearest major collector.

The East Bay Children's Respiratory Health Study studied traffic-related air pollution outside of schools near busy roads in the San Francisco Bay Area in 2001.[78] Concentrations of the traffic pollutants PM_{10}, $PM_{2.5}$, black carbon, total NO_x, and NO_2 were measured at ten school sites in neighborhoods that spanned a busy traffic corridor during the spring and fall seasons. The school sites were selected to represent a range of locations upwind and downwind of major roads. Differences were observed in concentrations between schools nearby (< 300 m) versus those more distant (or upwind) from major roads. Investigators found spatial variability in exposure to black carbon, NOx, NO, and (to a lesser extent) NO_2 associated with roads with heavy traffic within a relatively small geographic area.

A study to assess children's exposure to traffic-related air pollution while attending schools near roadways was performed in the Netherlands.[79] Investigators measured $PM_{2.5}$, NO_2 and benzene inside and outside of 24 schools located within 400 m of roadways. The indoor average benzene concentration was 3.2 $\mu g/m^3$, with a range of 0.6-8.1 $\mu g/m^3$. The outdoor average benzene concentration was 2.2 $\mu g/m^3$, with a range of 0.3-5.0 $\mu g/m^3$. Overall results indicate that indoor pollutant concentrations are significantly correlated with traffic density and composition, percentage of time downwind, and distance from major roadways.

In another study performed in the Netherlands, investigators measured indoor concentrations of black smoke, PM_{10}, and NO_2 in twelve schools between the periods of May and August 1995.[80] The schools were located at varying distances from the motorway (35-645 m). Results indicate that black smoke and NO_2 concentrations inside the schools were significantly correlated with truck and/or car traffic intensity as well as percentage of time downwind from the motorway and distance of the school from the motorway. PM_{10} concentrations measured in classrooms during school hours were highly variable and much higher than those measured outdoors, but they did not correlate with any of the distance or traffic parameters.

In another Dutch study, researchers monitored children's personal exposure concentrations, and home indoor and home outdoor levels of "soot" (particle blackness), NO, and NO_2.[81] Four-month average concentrations were calculated for each pollutant. Personal exposure to "soot" was 35-38% higher in students living within 75 meters of roads with 10,000 average annual daily traffic, a statistically significant result. Nonsignificant elevations in personal exposure to NO, $NO_{2,}$ and NOx were also found.

The TEACH study (Toxic Exposure Assessment – Columbia/Harvard) measured the concentrations of VOCs, $PM_{2.5}$, black carbon, and metals outside the homes of high school students in New York City.[82] The study was conducted during winter and summer of 1999 on 46 students and in their homes. Average winter (and summer) indoor concentrations exceeded outdoor concentrations by a factor of 2.3 (1.3). In addition, spatial and temporal patterns of MTBE concentrations, used as a tracer for motor vehicle pollution, were consistent with traffic patterns.

Average benzene concentrations were determined in a recent evaluation of the exposure of urban inhabitants to atmospheric benzene in Athens, Greece.[83] Home and personal levels of 50 non-smokers in six monitoring campaigns varied between 6.0-13.4 and 13.1-24.6 μg/m^3, respectively. Urban levels varied between 15.4 and 27.9 μg/m^3 with an annual mean of 20.4 μg/m^3. The highest values were observed during the first two sampling periods in fall and winter, when wind speed was low. The low summer values were attributed to decreased vehicle traffic. Among home factors, only proximity to busy roads was determined to be an important influence on indoor benzene levels.

Children are exposed to elevated levels of air toxics not only in their homes, classrooms, and outside on school grounds, but also during their commute to school. See above discussion of in-vehicle (school bus and passenger car) concentrations of air toxics for one method of commuting. The discussion below also presents potential exposures to children from another commuting method.

3.1.3.2.3 Pedestrians and Bicyclists

Researchers have noted that pedestrians and cyclists along major roads experience elevated exposures to motor vehicle related pollutants. Although commuting near roadways leads to higher levels of exposure to traffic pollutants, the general consensus is that exposure levels of those commuting by walking or biking is lower than for those who travel by car or bus, (see discussion on in-vehicle exposure in previous section above). For example, investigators found that personal measurements of exposure to PM_{10} concentrations were 16% higher inside the car than for the walker on the same route, but noted that a walker may have a larger overall exposure due to an increase in journey time.[84] Similarly, researchers found that traffic-related pollutant exposure concentrations of car drivers were higher than for cyclists.[85] Cyclists are typically on the border of the road or on dedicated bike paths and therefore further away from the vehicle emissions and are less delayed by traffic jams. However, after accounting for cyclists' higher ventilation, the uptake of CO, benzene, toluene, and xylenes by cyclists sometimes approached that of car drivers, and for NO_2 it was significantly higher.

In the early 1990's, researchers studied the in-vehicle concentrations of a large number of compounds associated with motor vehicle use and the exposure to VOCs of a pedestrian on an urban sidewalk (50 m from roadways) in Raleigh, NC.[86] The mean concentration of benzene in the six pedestrian sidewalk samples was 6.8 μg/m^3. This concentration was lower than the in-vehicle measurement (11.6 μg/m^3), but higher than the fixed-site measurement (1.9 μg/m^3) on urban roadways 100-300 m from streets.

The same researchers studied the exposure of commuters in Boston to VOCs during car driving, subway travel, walking, and biking.[87] For pedestrians, mean time-weighted concentrations of benzene, toluene, and xylenes of 10.6, 19.8, and 16.7 μg/m^3, respectively, were reported. For cyclists, the time-weighted concentrations were similar to those of pedestrians, at 9.2, 16.3, and 13.0 μg/m^3, respectively. In-vehicle exposure concentrations were higher as discussed above.

Numerous other studies which were conducted in Europe and Asia yield similar results.

A survey of CO concentration was conducted for various transport modes along heavy traffic routes in Athens, Greece.[88] Results showed that mean CO levels for trips of 30 min were 21.4 ppm for private car, 10.4 ppm for bus, and 11.5 ppm for pedestrians. In Northampton, UK during the winter 1999, personal measurements of exposure to PM_{10}, $PM_{2.5}$, and PM_1 were made during walking and in-car journeys on two suburban routes.[89] In-car measurements were highest (43.16, 15.54, and 7.03 $\mu g/m^3$ for PM_{10}, $PM_{2.5}$, and PM1, respectively) followed by walking (38.18, 15.06, and 7.14 $\mu g/m^3$, respectively). Background levels were only available for PM_{10} (26.55 $\mu g/m^3$), but were significantly lower than the walking exposure levels. Researchers found similar results for CO exposure levels of schoolchildren commuters.[90] So although personal exposures are greater for in-vehicle commutes, pedestrians and bicyclists in proximity to heavy traffic are exposed to elevated pollutant levels relative to background.

3.1.3.3 Concentrations and Exposure in Homes with Attached Garages

Residential indoor air quality is a major determinant of personal exposure, with most people spending the majority of their time indoors at home. According to the National Human Activity Pattern Survey, nationally, people spend an average of 16.68 hours per day indoors in a residence.[91] The large fraction of time spent in this microenvironment implies that sources that impact indoor air are likely to have a substantial effect on personal exposure.

Indoor air quality is in large part determined by ventilation of indoor spaces. Natural ventilation occurs as a result of two factors: wind-induced pressure and the “stack effect.” The latter occurs when hot air rises in a home, causing a pressure drop in the lower part of the home, which then creates airflow into the home from higher-pressure locations outside the home. Natural ventilation can also be influenced by opening of windows and doors. Mechanical ventilation employs fans and sometimes ductwork to manage ventilation within a home.

Air can be drawn into a home from either outdoors, or in a home with an attached garage, from the garage. Air from the garage can have higher concentrations of VOCs and other pollutants as a result of the storage of vehicles, other engines and equipment, fuel (gasoline in gas cans), solvents, or cleaning products. As a result, homes with a greater fraction of airflow from the garage are more susceptible to air quality decrements from in-garage emissions.

Several studies have examined homes with attached garages to determine the fraction of residential air intake from the garage. A recent study from Fairbanks, Alaska used perfluorocarbon tracer (PFT) gases to estimate that 12.2% of air entering a mechanically ventilated energy efficient home and 47.4% of the air entering the living spaces of an older passively ventilated home originated in the homes’ attached garages.[92] In an Ann Arbor, Michigan home, researchers used PFT gases to estimate that 16% of the air entering the home entered through the garage.[93] A recent study of a representative sample of homes in Anchorage, Alaska employing PFT estimated that in homes with a forced air furnace in an attached garage, 36.7% of indoor air originated in the garage.[94] In homes that had forced air furnaces indoors or hytronic heat, 17.0% and 18.4% of indoor air originated in the garage, respectively. A study from Minnesota examined homes constructed in 1994, 1998, and 2000.[95] Homes built in 1994 had 17.4% of airflow originating in the garage. Homes built in 1998 and 2000 had 10.5% and 9.4% of airflow from the garage, respectively. In another study conducted in Ottawa, Ontario, an average of 13% of home air intake came from the garage.[96] That study also found that the house-garage interface area was as leaky as the rest of the building envelope. In another study from Washington, D.C., the house-garage interface was found to be 2.5 times as permeable as the rest of the house.[97] This discrepancy may indicate that homes built in colder climates are built more tightly than homes in warmer regions as a result of weather-sealing. However, there is no evidence that in regions with cold weather, colder temperatures lead to elevated indoor concentrations of VOCs.[98]

Several studies have examined the influence of attached garages on indoor air and personal exposure. In the 1980's researchers identified attached garages as a major source of benzene and other VOCs in residences. The Total Exposure Assessment Methodology (TEAM) Study was completed in 1985.[99] The goal of this study was to develop methods to measure individual total exposure (through air, food and water) and resulting body burden to toxic and carcinogenic chemicals, and then to apply these methods with a probability-based sampling framework to estimate the exposures and body burdens of urban populations in several U.S. cities. The study measured personal exposures of 600 people to a number of air toxics. The subjects were selected to represent residents of cities in New Jersey, North Carolina, North Dakota, and California. In the study, a large fraction of an average nonsmoker's benzene exposure originated from sources in attached garages.[100] Work done as part of the TEAM study also identified stored gasoline as an important source of elevated benzene levels indoors.[101] This stored gasoline can be found primarily in gas cans as well as the fuel tanks of lawn and garden equipment, such as lawn mowers and string trimmers. Lawn and garden equipment fuel tank emissions, however, are significantly lower than evaporative emissions from gas cans, because the fuel tanks are much smaller than gas cans, typically 0.3 to 0.4 gallons. Emissions are also higher from gas cans because vents and spouts are left open.

These early studies have highlighted the role of evaporative emissions within the garage as contributors to indoor air pollution. Since then, major changes have affected emissions from vehicles, including additional controls on evaporative emissions, on- board diagnostics, and state inspection and maintenance programs addressing evaporative emission controls. Several researchers have subsequently conducted air measurements in homes and in attached garages to evaluate the effects on indoor air.

Garage concentrations of benzene and other VOCs are generally much higher than either indoor or outdoor air, and constitute one of the highest-concentration microenvironments to which a person might typically be exposed outside the occupational setting. The garage also supplies contaminated air to the home to which it is attached. One recent study from Michigan found average garage benzene concentrations of 36.6 $\mu g/m^3$, with a standard deviation of 38.5 $\mu g/m^3$, compared to mean and standard deviation concentrations of 0.4 $\mu g/m^3$ and 0.12 $\mu g/m^3$ in ambient air.[102] In Alaska, where fuel benzene levels tend to be very high and homes may be built very airtight, garage concentrations have been measured at even higher levels. One study from Anchorage measured average garage benzene concentrations of 103 $\mu g/m^3$, with a standard deviation of 135 $\mu g/m^3$.[103] More recently, a two-home study in Fairbanks found garage benzene average concentrations of 119 $\mu g/m^3$ during summer and 189 $\mu g/m^3$ during winter in one well-ventilated home with an air-to-air heat exchanger.[104] In an older home with passive ventilation summer and winter garage benzene concentrations were 421 and 103 $\mu g/m^3$, respectively.

Other studies have studied the effect of garages or the sources within them on indoor air quality. Most prominently, a group of Canadian investigators conducted source apportionment of indoor non-methane hydrocarbons (NMHC) in 16 Ontario homes in the late 1990's.[105] They also assembled source profiles from hot soak and cold start emissions, which they used to conduct source apportionment of total indoor air NMHC. All emissions samples and house testing were conducted using the same 1993 model year vehicle. Overall, while the vehicle was hot-soaking in the garage over a four hour sampling period, between 9 and 71% of the NMHC inside the house could be attributable to that vehicle's emissions. Similarly, in the two hours following a cold start event, between 13 and 85% of indoor NMHC could be attributed to the vehicle cold start. Prior to the hot soak testing, average indoor benzene concentrations were 3.77 $\mu g/m^3$, while during the hot soak, concentrations averaged 13.4 µg/m3. In the garage, concentrations averaged 121 $\mu g/m^3$ during the cold start. Prior to a cold start, indoor benzene concentrations averaged 6.98 $\mu g/m^3$, while for the two hours following cold start, concentrations averaged 25.9 $\mu g/m^3$. In the garage, concentrations averaged 422 µg/m3 over the two hours following cold start.

The study also conducted real-time monitoring of CO and total hydrocarbons (THC) within the house and garage. Overall, concentrations of CO and THC were relatively constant during hot-soaks, but following a cold start, indoor concentrations of CO and THC tended to rise sharply, and fall over the next two hours. This study provides direct evidence that a high fraction of indoor NMHC (or VOCs) are directly attributable to emission events occurring in the garage.

Other studies have examined the influence of attached garages by comparing homes with and without attached garages. In another study from Alaska, 137 Anchorage homes underwent indoor air quality monitoring for benzene and other VOCs.[106] Homes with attached garages had significantly higher concentrations of indoor benzene compared to homes without attached garages (70.8 µg/m3 vs. 8.6 µg/m3). In addition, elevated benzene indoors was also associated with the presence of a vehicle in the garage, fuel being opened in the garage, and the use of forced-air heaters.

In another Alaska study, concentrations of benzene and toluene in indoor air were found to be not significantly associated with their urinary biomarkers, but indoor concentrations were associated with the number of gasoline-powered engines stored in the garage.[107] In a recent follow-up to the study, ventilation patterns in two homes were evaluated using perfluorocarbon tracers and a multi-zone indoor air quality model.[108] In the study, average garage concentrations were consistently elevated relative to the home. Furthermore, the study calculated the "virtual" source strengths for benzene and toluene within the garage, and the garage was the only major source of benzene within the home. Median garage source strengths for benzene ranged from 14-126 mg/h.

Several population-based surveys have also found evidence of the influence of attached garages. The National Human Exposure Assessment Survey (NHEXAS) Phase I pilot study in Arizona was a representative exposure survey of the population. It found that in non-smoking homes with attached garages, distribution of toluene concentrations indoors was shifted significantly higher in homes with attached garages.[109] Homes with attached garages had median toluene levels of 24 μg/m^3, while homes without garages had median concentrations of 5 μg/m^3. The NHEXAS study in EPA Region 5 states was of similar design, but covering the states of the upper Midwest. Using multivariate statistics, investigators found that VOCs including benzene were associated with the storage of gasoline-powered equipment in an attached garage.[110]

In one study from New Jersey, investigators evaluated the indoor air effects of a vehicle fueled with "M85" – an 85% methanol, 15% gasoline blend – parking in the garage of a single home.[111] Testing was undertaken with both normally-functioning and malfunctioning evaporative emissions controls, as well as with the HVAC system on and off. Garage benzene concentrations exceeded indoor concentration by approximately 10-fold. Furthermore, the room adjacent to the garage had substantially higher concentrations than a room on the opposite side of the house. This study provides evidence that the garage is a major source of benzene inside the house.

Appendix 3A presents an EPA analysis of the effect of attached garages on indoor air under various scenarios. This study was undertaken to evaluate the magnitude of exposure underestimation using the national-scale exposure modeling techniques discussed above. Using a mass balance model, steady-state concentrations of benzene were calculated as a function of the concentration of air in the garage, the concentration of outdoor air, and the fraction of house air intake from a garage. Data were obtained from studies discussed above. Because it is unclear how well the homes studied to date represent the housing nationally, it is not currently feasible to provide a highly precise estimate of the effect of attached garages on benzene exposure nationally. Depending on how the available data are summarized, overall modeled exposure concentrations would be expected to increase between 1.2 and 6.6 μg/m^3 above average inhalation exposure concentrations to benzene from ambient sources (1.4 μg/m^3, as discussed in Section 3.2). It should be noted that there is considerable uncertainty associated with this estimated range, as discussed in Appendix 3A.

Proposed reductions in fuel benzene content, new standards for cold temperature exhaust emissions during vehicle starts, and reduced emissions from gas cans are all expected to significantly reduce this major source of exposure.

3.1.3.4 Concentrations and Exposure in Parking Garages

Relatively limited air quality data for parking garages is available in the literature. The following are results of air quality studies performed in parking garages, all of which indicate that air toxics and criteria pollutants measured in these environments are substantially higher than found in outdoor air. Because of the limited amount of data, we include results from some non-U.S. studies, although differences in fuels and control technology limited their applicability to the U.S.

In November 1990, a study of microenvironments, partially funded by the US EPA, evaluated the potential range in concentrations of selected air toxics.[112] Ten parking garages, along with gasoline stations and office buildings, were randomly chosen for sampling since they were among the least studied of the potentially important exposure microenvironments. The principal air contaminants monitored were benzene, formaldehyde, and CO. Additional compounds included toluene, xylenes, 1,2-dichloroethane, chloroform, carbon tetrachloride, perchloroethylene, 1,1,1-trichloroethane, 1,3-butadiene, and trichloroethylene. The majority of the compounds measured were significantly higher inside the garage compared to the ambient sample. For example, the median 5-minute concentration of benzene was 67.1 $\mu g/m^3$ in the parking garage and 12.8 $\mu g/m^3$ in ambient air. CO was 11000 ppb in the parking garage and 2000 ppb in ambient air. The researchers identified elevated levels of selected air toxics in parking garages and pointed out the potential contribution from cold starts at the end of the work day.

A more recent 2002 study was funded by The American Petroleum Institute to screen "high-end" exposure microenvironments as required by section 211(b) of the Clean Air Act.[113] An interim report is available. The study included measurements at underground parking garages and surface parking lots in several cities. Air toxics quantified included hydrocarbons (HCs), carbonyl compounds, BTEX, total VOC, and CO. When sampling at parking lot exits, spikes in pollutant concentrations were observed when vehicles accelerated out of the parking lot, while presumably prior to full catalyst warm-up. In underground garages, the levels of BTEX and other compounds of interest varied with traffic level and reached concentrations that were significantly higher than ambient levels outside the garage. The final report of the 211(b) is expected in 2007.

A comparative study of indoor air quality in Hong Kong showed that the levels of CO, NOx, and nonmethane hydrocarbons (NMHC) detected in a local park garage were the highest among 13 other indoor sampling locations.[114] The study did not specify the type or size of the chosen parking garage, but indicated that it was located in an urban commercial area. High indoor/outdoor ratios indicated that the air quality was mainly affected by indoor sources, namely the vehicle exhaust. They also concluded that the pollution generated might cause health hazards to the users and workers using such an environment.

Another assessment of the air quality in indoor park garages was performed in Hong Kong in August through December 2000.[115] Air samples were collected in two different garages (an enclosed and semi-enclosed parking garage) as well as outdoors (within 10 m of each parking garage) and analyzed for one hundred different C3-C12 VOCs. Other compounds measured included CO, CO_2, PM_{10}, and $PM_{2.5}$. The CO levels in the enclosed garage were more than in the semi-enclosed garage, and double the levels of the outdoor air. The PM_{10} and $PM_{2.5}$ concentrations were also found to be higher in the parking garage environments than outdoors. High mass fractions of aliphatic and aromatic compounds detected in the enclosed garage showed that fuel evaporation and motor vehicular exhaust were the major contributors to the VOCs. The total concentrations of NMHC in the enclosed and semi-enclosed garages ranged from 580 to 4610 $\mu g/m^3$ and 43.1 to 175 $\mu g/m^3$, respectively. The mean concentration of NMHC measured in the enclosed garage (1910 $\mu g/m^3$) was about 17 times higher than in the semi-enclosed garage (94.6 $\mu g/m^3$), and 3 times higher than measured at the outdoor sites. Not only was the level of VOCs higher in the enclosed garage, but also the abundance of species identified. The most abundant species in similar ranking order for both garages was toluene, 2-methylbutane, *m/p*-xylenes, *n*-pentane, 2-methylpentane, *n*-hexane, and *n*-butane. Other major gasoline components such as benzene, xylenes, and C4-C7 saturated HCs were also very high in the enclosed garage. The difference between the two sites could be associated with the ventilation and location, since the occupancy rates and fleet mixes were similar. The authors also noted that the absence of sunlight in the enclosed garage would result in a slower or negligible photochemical depletion rate of unsaturated hydrocarbons, and consequently an increased abundance of the species observed.

In another study of multi-level parking garages in an Athens urban area, CO levels were characterized in autumn 1999.[116] Samples were collected at the exit sites (ramp where the flow of vehicles was concentrated), the indoor site (first underground level where the majority of cars parked), and immediately outside of each garage. Results indicate that CO levels varied significantly over site, time, and day of measurement. The peak 1-hour value at the indoor sites ranged from 22.9 to 109.3 ppm. At the indoor site, levels showed little variation and remained high over time. The peak 1-hour value at the exit sites ranged from 8.9 to 57.3 ppm. At the exit sites, 15-minute maximum concentrations were 5-15 times higher than the maximum recorded CO level immediately outside the garage. CO levels on Saturday were much lower than a typical weekday due to the reduced traffic, and weekday values were highest during the afternoon sampling times (12:00-16:00 hour) corresponding with peak traffic volumes.

In Mumbai, India, ambient levels of benzene were determined during different seasons at several different locations, including two parking areas.[117] Parameters of the parking areas were not specified, but 24-hour geometric means of benzene measured 117.4 and 74.2 $\mu g/m^3$ during the summer, 94.5 and 75.4 $\mu g/m^3$ during the monsoon, and 148.0 and 703.0 $\mu g/m^3$ during the winter seasons, respectively. These values were considerably higher in comparison to less heavily trafficked residential locations. The mean benzene concentrations of four different residential locations ranged from 4.7 to 32.9 $\mu g/m^3$, 1.9 to 33.5 $\mu g/m^3$, and 4.7 to 18.8 $\mu g/m^3$, respectively, for the summer, monsoon, and winter seasons. The high concentrations in parking areas were attributed to cold start-up emissions of engines.

A study in the UK of twelve underground parking garages identified high pollutant levels of NOx, CO, CO2, BTEX, and PM.[118] The parking garages selected covered a cross-section of sizes (1 to 8 decks), ventilation system (natural and mechanical), designs (50 to 690 spaces), and usages (business, shopping, and/or residential). Monitoring sites were located inside and at the exit of the parking garage. The highest 15-minute average CO levels were measured at the exit of parking garages, but a number of the parking garages had CO levels consistently higher inside than at their exit. The NO_2 measurements showed similar trends. Weekday benzene concentration measurements averaged over one hour inside the parking garage and at the exit ranged from 60 to 870 $\mu g/m^3$ and 10 to 350 $\mu g/m^3$, respectively.

In Madrid, Spain, atmospheric pollution produced by vehicles in parking garages was studied.[119] Two parking garages of different design were chosen for measurements of PM_{10}, lead, 12 PAHs, and CO. In both garages, CO, NO, TSP, and lead concentrations directly correlated with vehicle traffic flow into and out of the garage. Also, higher values were observed on the weekdays than during the weekend, for CO, NO, PAHs, and TSP in both garages. For example, in one garage, the average daily TSP concentrations were 78-122 $\mu g/m^3$ on the weekdays versus 39 $\mu g/m^3$ on the weekend, which was similar to outdoor city average measurement (50 $\mu g/m^3$). The researchers conclude that maximum concentrations for NO were observed during maximum parking garage exits and therefore due to vehicle cold-starts. They also conclude that the mechanical ventilation used in both garages was not sufficient to disperse the pollutants emitted by the vehicles.

3.1.3.5 Concentrations and Exposure at Service Stations

Although there is relatively limited air quality data for service stations available currently in the literature, the general consensus is that exposures to air toxics at service stations significantly exceed ambient background levels. The studies below measure personal exposures and concentrations during refueling either inside or outside of vehicles throughout the United States. Several studies conducted outside of the United States chronicle similar results but are not presented here due to differences in fuels and control technologies.

The TEAM study from the 1980's, described above, pumping gas and exposure to auto exhaust were significantly associated with elevated benzene exposure. People who filled their tanks with gasoline had twice as much benzene in their breath as people who did not. Estimated concentrations at the breathing zone could exceed 1000 μg/m^3 (100 times the ambient level), based on the median breath benzene value measured (n=67) for those who had worked at or been in a service station during the past 24 hours. Since this study, implementation of fuel controls, onboard vapor recovery, and Stage II vapor recovery have changed emission and concentration levels as discussed in Section 3.1.1.

In March 1990, another study randomly sampled 100 self-service filling stations throughout Southern California along with samples at 10 parking garages and 10 offices nearby those garages.[120] The study took five-minute samples of 13 motor vehicle air pollutants (CO, formaldehyde, and VOCs) in each microenvironment and in the ambient environment. The median benzene concentration measured at the service stations was 28.8 μg/m^3 with the maximum reported value of 323 μg/m^3. The median benzene concentration in ambient air was significantly lower at 12.8 μg/m^3.

A 1993 National Institute for Occupational Safety and Health (NIOSH) study assessed benzene and MTBE concentrations and service station attendant exposures at service stations with and without Stage II vapor recovery in Cincinnati, Phoenix, and Los Angeles.[121] The mean (and maximum) benzene exposure measurements were 96 (927), 160 (1662), and 192 (607) μg/m^3, respectively. The study found that Stage II vapor recovery did not significantly reduce exposure to benzene during refueling. However, the efficiency of Stage II vapor recovery has improved over the years. Northeast States for Coordinated Air Use Management (NESCAUM) has suggested that Stage II vapor recovery systems are greater than 90% effective at capturing MTBE and benzene vapors during refueling.[122] These systems would therefore be expected to reduce exposure beyond that shown in the NIOSH exposure assessment.

In March 1996 to July 1997, concentrations of MTBE, benzene, and toluene were determined inside automobile cabins during fueling.[123] Air samples were collected at service stations in New Jersey, and the mean benzene in-cabin concentration was 54.3 μg/m^3 (n=46). The background concentration at the pump island measured 9.6 μg/m^3 (n=36). The highest in-cabin concentrations for all three pollutants occurred in a car that had a malfunctioning vapor recovery system and in a series of cars sampled on an unusually warm, calm winter day when the fuel volatility was high, the evaporation maximal, and the wind dispersion minimal. The in-cabin concentrations were also typically higher when the car window was opened during the entire fueling process.

In a study conducted between summer 1998 and spring 1999, self-service gas station customers took part in a study to measure personal and breath concentrations of benzene at gas stations in New Jersey.[124] Benzene exposure concentrations during refueling (with a median duration of three minutes) averaged 2.9 mg/m^3 (SD = 5.8 mg/m^3). Breath concentrations averaged 160 µg/m^3 (SD = 260 µg/m^3). Breath benzene concentrations were significantly correlated with refueling exposure concentrations, which was itself significantly associated with refueling duration, time of year, and fuel octane grade.

Most recently, as discussed in the section on in-vehicle and parking garage exposure and concentrations, a screening study of "high-end" exposure microenvironments was performed by the American Petroleum Institute.[60] The study included several vehicle-related microenvironments in Houston and Atlanta during summer 2002. Among the various microenvironments examined, the highest short-term concentrations occurred during refueling. The in-vehicle average concentration of benzene measured during refueling was 46.0 µg/m^3.

3.1.3.6 Occupational Exposure

Occupational settings can be considered a microenvironment in which exposure to benzene and other air toxics can occur. Occupational exposures to benzene from mobile sources or fuels can be several orders of magnitude greater than typical exposures in the non-occupationally exposed population. Several key occupational groups are discussed below.

Occupations that involve fuel distribution, storage, and tank remediation lead to elevated exposure to mobile-source related air toxics. Researchers published a review of benzene and total hydrocarbon exposures in the downstream petroleum industry, including exposure data from the past two decades among workers in the following categories: refinery, pipeline, marine, rail, bulk terminals, tank truck drivers, service stations, underground storage tanks, tank cleaning, and site remediation.[125] The studies reviewed indicate that benzene exposure can range from <1 to more than 10 mg/m^3, which is approximately three orders of magnitude higher than typical non-occupational exposures (although there are occurrences of high benzene exposures in non-occupational settings as well). This review is relevant because of the potential for fuel benzene reductions to reduce their exposures as well. This statement is echoed by researchers in the occupational literature.[126] Occupational exposures in this range have been associated with increased risk of certain leukemias in occupational epidemiology studies (Section 1.3.1).

Handheld and non-handheld equipment operators may also be exposed to elevated concentrations of air toxics. As discussed below, several studies were conducted in work categories employing small engine equipment, such as lawn and garden workers, workers in construction/demolition, and others. Many of these occupations require the use of personal protective equipment to prevent high exposures to carbon monoxide or other species. At present, there are no representative samples of exposures among these categories. Non-occupational exposures from these equipment types may also be important contributors to overall exposure.

EPA recently conducted a study of occupational exposures among lawn and garden workers using riding tractors, walk-behind lawn mowers, string trimmers, and chainsaws.[127] Results demonstrated that equipment operators can experience highly variable exposures, with short-term personal concentrations of CO and $PM_{2.5}$ ranging over two orders of magnitude. The study also reported operator breathing-zone concentrations of formaldehyde and acetaldehyde that were higher than background levels in all tests. This study illustrated the role of operator's activity in affecting exposure levels to fuel-related air toxics.

Another study provides some insight into the possible range of benzene exposures in workers who operate gasoline-powered engines, particularly those with 2-stroke engine cycles.[128] A study of snowmobile rider exposures in Sweden found benzene concentrations ranging from under 10 $\mu g/m^3$ to 2.5 mg/m^3, a range of at least two orders of magnitude. Exposures measured on riders on the back of the vehicle ranged from 0.7-0.8 mg/m^3. These measurements illustrate the potential for relatively high exposures when operating 2-stroke equipment, as used in this study. Yellowstone National Park commissioned a study in 2002 to examine occupational exposures of park employees to benzene, other VOCs, PM_{10}, and CO.[129] Work shift benzene concentrations at a snowmobile entry gate 176.7 $\mu g/m^3$, while snowmobile-bound mobile patrol officers' exposure concentrations averaged 137.20 $\mu g/m^3$. The highest observed work shift concentration in the study was 514.1 $\mu g/m^3$. At major sites of tourist interest where snowmobiles parked, such as the Old Faithful geyser, concentrations averaged 41.3 to 48.8 $\mu g/m^3$. 15-minute "peak" samples of workers' personal air ranged from 46.8 $\mu g/m^3$ to 842.8 $\mu g/m^3$. This study provides an indication of the variability of occupational benzene exposure concentrations with time, and highlights the potential for elevated work shift exposures over several hours.

A preliminary report published by the Northeast States for Coordinated Air Use Management further illustrates the occupational impact of nonroad heavy-duty diesel equipment.[130] In-cabin and work site perimeter measurements were collected for diesel equipment emissions from the agricultural, construction (building and roadway), and lumber industries in the Northeast. Initial results indicate that $PM_{2.5}$ concentrations were 1-16 times greater than the average ambient concentrations in each monitoring area. In-cabin exposures to $PM_{2.5}$ for operators ranged from 2 $\mu g/m^3$ to over 660 $\mu g/m^3$. Additionally, measured concentrations of acetaldehyde, benzene, and formaldehyde were found to be significantly elevated, although concentrations were not presented.

In one recently-published study of diesel exhaust exposures in a representative sample of trucking terminals nationally, investigators applied structural equation modeling to data on personal exposure to diesel exhaust (as elemental carbon).[131] The study found that worker exposure to elemental carbon depended on work area concentrations and worker tobacco use. Work area concentrations depended on the size and type of the trucking terminal, whether the work site was a mechanical shop, work site ventilation, and terminal yard concentrations. Terminal yard concentrations in turn were related to local meteorology, the proximity of interstate highways, surrounding industrial land uses, and region of the country. This study is valuable in showing how personal occupational exposures are a complicated function of many factors. Sophisticated statistical methods are needed to properly estimate models with highly complex covariance structures.

In addition, some occupations require that workers spend considerable time in vehicles, which increases the time they spend in a higher-concentration microenvironment. In-vehicle concentrations are discussed in Section 3.1.3.2.1 above.

3.1.4 Uncertainties in Air Toxics Measurements

A number of uncertainties limit our ability to fully describe the impacts of motor vehicle emissions. As described above, most people in the U.S. experience some level of exposure to emissions from motor vehicles. Thus, proper characterization of the level of these exposures is critical. However, the exposure assessment techniques used may not adequately represent the populations' true exposures to motor vehicle emissions.

Air quality and exposure measurements are expensive and therefore are limited. The high costs of measurement techniques affect the quantity of samples that can be collected and quantity of compounds that can be identified. As a result, measurements may only occur at central monitoring sites, rather than in microenvironments impacted by motor vehicle emissions or in personal breathing zones. Air quality monitoring at these central sites often do not represent actual exposures, especially for populations living near roads or with substantial occupational exposure.

Monitoring samples are often integrated and therefore lack time resolution. This can result in difficulty in determining source contributions. Additionally, some compounds are hard to measure accurately. For example, 1,3-butadiene is very reactive in the ambient atmosphere and has a short atmospheric lifetime, estimated to be only two hours.[132] Thus, this compound can easily break down before samples are analyzed. Also, a vapor pressure of 3.3 atm at 25°C makes it a very volatile compound. Secondary reactions are a confounding factor in air quality measurements and can add additional uncertainty to measured ambient concentrations.

Personal exposure monitoring provides greater realism in describing a person's actual exposure to air toxics. However, given the limitations on size of equipment, detection limits in personal exposure monitoring studies are sometimes greater than those found in studies using other techniques.

3.2 Modeled Air Quality, Exposures, and Risks for Air Toxics

3.2.1 National-Scale Modeled Air Quality, Exposure, and Risk for Air Toxics

EPA assesses human health impacts from outdoor, inhalation, chronic exposures to air toxics in the National-Scale Air Toxics Assessment (NATA). It assesses lifetime risks assuming continuous exposure to levels of air toxics estimated for a particular point in time. The most recent NATA was done for the year 1999.[133] It had four steps:

1) Compiled a national emissions inventory of air toxics emissions from outdoor sources. The 1999 National Emissions Inventory is the underlying basis for the emissions information in the 1999 assessment.

2) Estimated ambient concentrations based on emissions as input to an air dispersion model (the Assessment System for Population Exposure Nationwide, or ASPEN model).[134]
3) Estimated population exposures based on a screening-level inhalation exposure model (Hazardous Air Pollutant Exposure Model, version 5, or HAPEM5) and the estimated ambient concentrations (from the ASPEN model) as input to the exposure model.[135]
4) Characterized 1999 potential public health risks due to inhalation of air toxics. This included cancer and noncancer effects, using available information on air toxics health effects, current EPA risk assessment and risk characterization guidelines, and estimated population exposures.[136]

For this final rule, we have conducted air quality, exposure and risk modeling for the years 1999, 2015, 2020, and 2030, using the same general approach as the 1999 NATA. We modeled all the pollutants in Table 2.2-1 for both the reference case, which includes all control programs currently planned by EPA in regulations, and the control case, which includes the cumulative impacts of the standards proposed in this rule. These pollutants

- Are on EPA's list of hazardous air pollutants in Section 112 of the Clean Air Act
- Are emitted by mobile sources
- Are included in the National Emissions Inventory
- Are included in the 1999 NATA

Note that the modeling did not include diesel PM and diesel exhaust organic gases. EPA has previously done future-year projections of the mobile source contribution to air toxics concentrations, exposure, and risk for selected air toxics,[137, 138, 139, 140] but prior to the proposal for this rule, had never done a comprehensive assessment that includes projections for all mobile source air toxics, as well as the stationary source contribution for those pollutants. It should be noted that the reference case assessment results developed for the proposal have been published in a peer reviewed journal article.[141]

As discussed in Chapter 2, a number of major revisions to inventory methodology have been made relative to what was done for both the 1999 NATA, and air quality exposure and risk modeling for the proposal. These include revisions to cold start emissions, use of NMIM2005 for nonroad equipment, addition of portable fuel container emissions, and changes to gasoline distribution inventories. Also, this final rule modeling for 1999 does not include data submitted by States for the 1999 NEI. In addition, the modeling for the final rule relied on an updated version of the HAPEM model, HAPEM6.[142] HAPEM6 improves on HAPEM5 by accounting for the spatial variability of outdoor concentrations of air toxics within a census tract due to higher outdoor concentrations at locations near major roadways. Other improvements to HAPEM are discussed in section 3.2.1.2.1. This modeling work is discussed in more detail in an EPA technical report, "National Scale Modeling of Air Toxics for the Final Mobile Source Air Toxics Rule; Technical Support Document," Report Number EPA-454/R-07-002. It should be noted that the control case modeling accounted only for the 0.62 percent standard, but not the 1.3 vol% maximum average. Thus, the emission reductions from highway vehicles and other sources attributable to the fuel benzene standard are underestimated in many areas of the country, particularly in areas where fuel benzene levels were highest without control, such as the Northwest.

The NATA modeling framework has a number of limitations which prevent its use as the sole basis for setting regulatory standards. 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.

Among the significant limitations of the framework is that it cannot be used to identify ambient "hot spots," as mobile sources are not represented explicitly as roads or other locations of mobile source activity. In addition, this kind of modeling assessment cannot address the kinds of questions an epidemiology study might allow, such as the relationship between asthma or cancer risk, and proximity of residences to point sources, roadways and other sources of air toxics emissions. The framework also does not account for risk from potentially significant sources of air toxics originating indoors, such as stoves or out-gassing from building materials or evaporative benzene emissions from cars in attached garages. The ASPEN model performs well for some pollutants, but has also been shown to systematically underestimate pollutant concentrations relative to measured levels for certain pollutants such as metals and some reactive compounds. The cancer unit risk estimates for most pollutants are "upper bound," meaning they probably lead to overestimates of risk. It should be noted, however, that the unit risk estimate for benzene is a maximum likelihood estimate, which is a best scientific estimate. The above limitations are discussed in detail in Section 3.2.1.4.

Although we do not use it in this modeling, another tool that EPA uses to assess distributions of concentrations of air toxics at the national scale is the Community Multiscale Air Quality (CMAQ) modeling system.[143] CMAQ can account for photochemical destruction and production, deposition and regional transport of toxic air pollutants, and thus can be used to predict the concentrations of HAPs with significant atmospheric production. In general, predicted concentrations of air toxics from CMAQ were within a factor of 2 of measured values, with a tendency to underpredict measured ambient concentrations.[144] CMAQ underpredicts monitored benzene levels more than ASPEN, because ASPEN values contain a large, added-on concentration based on monitored values of benzene. CMAQ has sophisticated photochemistry, but does not yet have the spatial resolution of dispersion models such as ASPEN, and thus accounts for less of the total variability in levels of air toxics with localized concentration gradients, such as benzene.[145] Finally, CMAQ is requires more computational resources, which makes it more difficult to use for evaluating trends in a large number of air toxics over many years or impacts of control scenarios.

Details of the methods used and presentation of key results are discussed in the following sections. Results do not account for other potentially significant sources of inhalation exposure, such as benzene emissions from sources in attached garages (such as vehicles, snowblowers, lawnmowers and gas cans).

3.2.1.1 Air Quality Modeling

3.2.1.1.1 Methods

Prior to performing air quality modeling of the projected emissions, the emissions from the stationary and mobile inventories (discussed in Chapter 2) are processed in the Emissions Modeling System for Hazardous Air Pollutants (EMS-HAP) Version 3 to create the emissions input files used by ASPEN to calculate air quality concentrations.[146] In addition to projecting stationary and area source emissions to future years for some source categories, EMS-HAP spatially allocates emissions inventoried at the county level to the census tract level, and temporally allocates them to eight three-hour time periods throughout the day. Once the emissions are processed, they are input into ASPEN to calculate air quality concentrations. In addition to the emissions, ASPEN uses meteorological parameters and census tract centroid locations for concentration calculations. ASPEN estimates do not account for day-of-week or seasonal variations in emissions. The ASPEN model takes into account important determinants of pollutant concentrations, such as: rate of release, location of release, the height from which the pollutants are released, wind speeds and directions from the meteorological stations nearest to the release, breakdown of the pollutants in the atmosphere after being released (i.e., reactive decay), settling of pollutants out of the atmosphere (i.e., deposition), and transformation of one pollutant into another. The model first estimates concentrations at receptors arranged in rings around emission sources up to 50 kilometers away. The model then interpolates concentrations to census tract centroids. For 1999, meteorological conditions in 1999 and 2000 census tract data were used.

In using ASPEN to estimate projected concentrations in 2015, 2020, and 2030 for this final rule, the same meteorology and census tract locations were used as for the 1999 NATA. Details of how ASPEN processed emissions data are provided in the technical document, "National-Scale Modeling of Mobile Source Air Toxic Emissions, Air Quality, Exposure and Risk for the Mobile Source Air Toxics Final Rule." ASPEN only accounts for sources within a 50-kilometer radius of each source when calculating ambient concentrations. Thus, the contribution to ambient levels of air toxics from sources further away than 50-kilometers, as well as the contribution of uninventoried sources, is addressed through the addition of a "background" term.[147] Mobile source pollutants which include a background component are 1,3-butadiene, acetaldehyde, benzene, formaldehyde, and xylenes. Each of the three projection years used the same 1999-based background. However, background levels are likely to change with emissions. Thus, for the proposal, a sensitivity analysis was done to evaluate the potential impact of not changing the background concentration (see Section 3.2.1.4).

It should be noted that in the control case scenarios, we have modeled the cumulative impacts on air quality, exposure, and risk for all of the programs finalized today, not the impacts of individual programs. Were we to model each program individually, we anticipate that changes in air quality, exposure, and risk would track the patterns of emission changes closely.

Also, for the final rule, we estimated the contribution of secondary formation to ambient concentrations of MSATs by applying ratios of secondary to primary concentrations from 1999 NATA to the modeled primary concentrations for this rule. This is different from the approach used in the proposal where we projected precursor emissions and then modeled secondary formation. When we applied the ratio approach to the proposal's primary concentrations, the results were very similar to the full modeling approach (see Section 3.2.1.3). The comparisons are discussed in the technical document cited above.

We estimated the contributions to ambient concentrations for the following source sectors: major, area and other, onroad, nonroad, and background.[b]

3.2.1.1.2 Air Quality Trends for Air Toxics: Reference Case

Table 3.2-1 summarizes nationwide mean census tract ambient concentrations, without the controls being finalized in this rule, of mobile source air toxics in 1999 and projection years for the following source sectors: major sources, area and other sources, highway vehicles, nonroad sources, and background. The behavior of benzene is typical of the projected trends. Over 90% of the mobile source contribution to ambient benzene levels is attributable to gasoline vehicles and engines. Figure 3.2-1 depicts the trend in nationwide average census tract concentrations of benzene over this time period. The mobile source contribution to ambient benzene concentrations is projected to decrease over 40% by 2015, with a decrease in ambient benzene concentration from all sources of about 25%. Subsequently, increases in vehicle miles traveled (VMT) are projected to produce increasing concentrations. Summary tables providing data by State, and for reformulated and non-reformulated (i.e., conventional) gasoline areas, can be found in the docket for this rule. Due to greater population and vehicle activity, the average ambient benzene concentration in 1999 is much higher for counties in reformulated gasoline areas than non-reformulated gasoline areas – about 1.9 $\mu g/m^3$ versus 1.2 $\mu g/m^3$. However the percent reduction in average 2015 ambient concentration is similar regardless of fuel type – 22% for non-reformulated gasoline counties versus 29% for reformulated gasoline counties.

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[b] Major and "area and other" are stationary source emission sectors. Major sources, as defined by the Clean Air Act, are those stationary facilities that emit or have the potential to emit 10 tons of any one toxic air pollutant or 25 tons of more than one toxic air pollutant per year. Area and other sources include sources that generally have smaller emissions on an individual basis than "major sources" and are often too small or ubiquitous in nature to be inventoried as individual sources. "Area sources" include facilities that have air toxics emissions below the major source threshold as defined in the air toxics sections of the Clean Air Act and thus emit less than 10 tons of a single toxic air pollutant or less than 25 tons of multiple toxic air pollutants in any one year. Area sources include smaller facilities, such as dry cleaners. "Other sources" include sources such as wildfires and prescribed burnings that may be more appropriately addressed by other programs rather than through regulations developed under certain air toxics provisions (section 112 or 129) in the Clean Air Act. For example, wildfires and prescribed burning are being addressed through the burning policy agreed to by the Interim Federal Wildland Policy. "Background" includes emissions from transport and uninventoried sources.

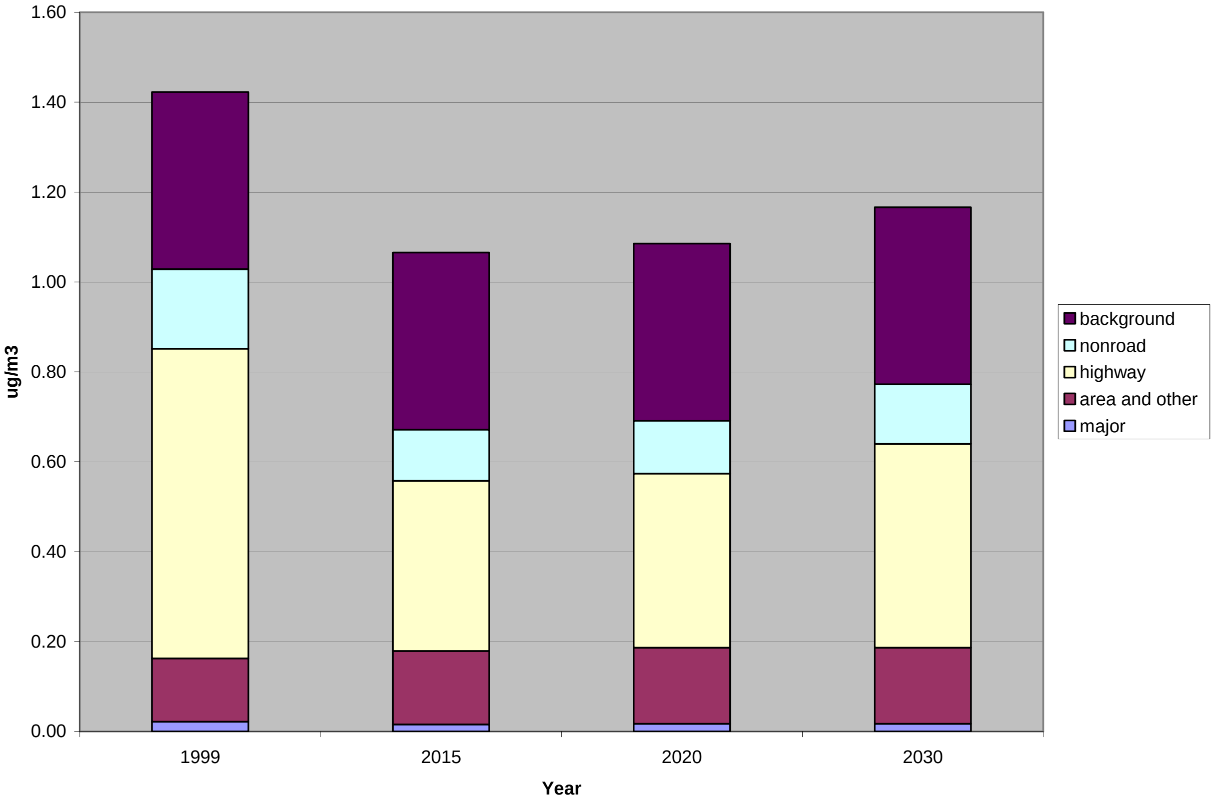
Table 3.2-1. Mean Ambient Concentrations of Mobile Source Air Toxics in 1999, 2015, 2020, and 2030, Without Controls in this Rule.

		1999 average concentrations ($\mu g\ m^{-3}$)					2015 annual average concentrations ($\mu g\ m^{-3}$)				
Pollutant	**background ($\mu g\ m^{-3}$)**	**major**	**area & other**	**onroad**	**nonroad**	**total (including background)**	**major**	**area & other**	**onroad**	**nonroad**	**total (including background)**
1,3-Butadiene	5.10E-02	1.97E-03	2.05E-02	5.20E-02	1.81E-02	1.44E-01	2.17E-03	2.05E-02	2.28E-02	1.08E-02	1.07E-01
2,2,4-Trimethylpentane	0.00E+00	2.16E-02	2.32E-02	7.29E-01	1.96E-01	9.70E-01	1.09E-02	2.69E-02	3.66E-01	1.15E-01	5.19E-01
Acetaldehyde	5.17E-01	2.94E-02	5.49E-02	6.78E-01	1.47E-01	1.43E+00	2.97E-02	5.71E-02	3.86E-01	1.10E-01	1.10E+00
Acrolein	0.00E+00	3.21E-03	2.93E-02	5.63E-02	2.27E-02	1.11E-01	3.53E-03	2.62E-02	2.42E-02	1.81E-02	7.20E-02
Benzene	3.94E-01	2.20E-02	1.40E-01	6.89E-01	1.77E-01	1.42E+00	1.55E-02	1.63E-01	3.79E-01	1.14E-01	1.07E+00
Chromium III	0.00E+00	8.22E-04	4.53E-04	3.22E-05	5.53E-05	1.36E-03	1.04E-03	6.16E-04	4.40E-05	5.85E-05	1.76E-03
Chromium VI	0.00E+00	1.07E-04	1.98E-04	2.15E-05	1.25E-05	3.39E-04	1.36E-04	2.72E-04	2.94E-05	1.32E-05	4.50E-04
Ethyl Benzene	0.00E+00	1.84E-02	9.00E-02	2.73E-01	9.73E-02	4.79E-01	1.24E-02	1.19E-01	1.35E-01	5.66E-02	3.24E-01
Formaldehyde	7.62E-01	3.99E-02	8.77E-02	4.65E-01	2.21E-01	1.58E+00	4.98E-02	9.82E-02	1.92E-01	1.63E-01	1.27E+00
Hexane	0.00E+00	6.68E-02	4.30E-01	2.34E-01	8.56E-02	8.17E-01	5.94E-02	5.21E-01	1.16E-01	5.93E-02	7.56E-01
MTBE	0.00E+00	1.30E-02	6.04E-02	4.00E-01	4.04E-01	8.77E-01	1.38E-02	6.52E-02	1.05E-01	1.08E-01	2.93E-01
Manganese	0.00E+00	2.71E-03	2.22E-03	1.73E-05	5.46E-06	4.95E-03	3.23E-03	2.92E-03	2.36E-05	6.46E-06	6.17E-03
Naphthalene	0.00E+00	4.56E-03	4.11E-02	1.46E-02	4.36E-03	6.46E-02	3.97E-03	5.01E-02	7.90E-03	4.49E-03	6.65E-02
Nickel	0.00E+00	7.76E-04	1.42E-03	3.96E-05	9.98E-05	2.33E-03	8.87E-04	1.62E-03	5.43E-05	1.15E-04	2.67E-03
POM	0.00E+00	4.93E-03	1.61E-02	1.73E-03	8.60E-04	2.37E-02	3.79E-03	1.86E-02	9.13E-04	7.66E-04	2.40E-02
Propionaldehyde	0.00E+00	1.01E-02	2.33E-02	1.68E-01	4.27E-02	2.45E-01	9.31E-03	2.39E-02	8.24E-02	2.83E-02	1.44E-01
Styrene	0.00E+00	2.52E-02	1.40E-02	2.98E-02	3.65E-03	7.27E-02	3.00E-02	1.89E-02	1.50E-02	2.18E-03	6.61E-02
Toluene	0.00E+00	2.03E-01	8.05E-01	1.81E+00	4.18E-01	3.24E+00	1.43E-01	1.06E+00	9.00E-01	2.50E-01	2.35E+00
Xylenes	1.70E-01	9.98E-02	5.59E-01	1.01E+00	3.99E-01	2.23E+00	8.22E-02	7.60E-01	4.98E-01	2.18E-01	1.73E+00

Table 3.2-1 (cont'd). Mean Ambient Concentrations of Mobile Source Air Toxics in 1999, 2015, 2020, and 2030, Without Controls in this Rule.

		2020 annual average concentrations (μg m^{-3})					2030 annual average concentrations (μg m^{-3})				
Pollutant	background (μg m^{-3})	major	area & other	onroad	nonroad	total (including background)	major	area & other	onroad	nonroad	total (including background)
1,3-Butadiene	5.10E-02	2.34E-03	2.05E-02	2.37E-02	1.14E-02	1.09E-01	2.34E-03	2.05E-02	2.78E-02	1.30E-02	1.15E-01
2,2,4-Trimethylpentane	0.00E+00	1.17E-02	2.84E-02	3.66E-01	1.14E-01	5.20E-01	1.17E-02	2.84E-02	4.24E-01	1.24E-01	5.88E-01
Acetaldehyde	5.17E-01	3.10E-02	5.83E-02	3.98E-01	1.09E-01	1.11E+00	3.10E-02	5.83E-02	4.69E-01	1.18E-01	1.19E+00
Acrolein	0.00E+00	3.96E-03	2.54E-02	2.50E-02	1.91E-02	7.34E-02	3.96E-03	2.54E-02	2.94E-02	2.18E-02	8.05E-02
Benzene	3.94E-01	1.70E-02	1.69E-01	3.88E-01	1.18E-01	1.09E+00	1.70E-02	1.69E-01	4.54E-01	1.32E-01	1.17E+00
Chromium III	0.00E+00	1.17E-03	6.96E-04	4.84E-05	5.90E-05	1.97E-03	1.17E-03	6.96E-04	5.94E-05	6.04E-05	1.98E-03
Chromium VI	0.00E+00	1.54E-04	3.07E-04	3.23E-05	1.34E-05	5.07E-04	1.54E-04	3.07E-04	3.96E-05	1.37E-05	5.15E-04
Ethyl Benzene	0.00E+00	1.39E-02	1.31E-01	1.35E-01	5.78E-02	3.38E-01	1.39E-02	1.31E-01	1.57E-01	6.45E-02	3.66E-01
Formaldehyde	7.62E-01	5.65E-02	1.03E-01	1.97E-01	1.64E-01	1.28E+00	5.65E-02	1.03E-01	2.31E-01	1.80E-01	1.33E+00
Hexane	0.00E+00	6.53E-02	5.62E-01	1.07E-01	6.13E-02	7.96E-01	6.53E-02	5.62E-01	1.18E-01	6.87E-02	8.14E-01
MTBE	0.00E+00	1.55E-02	6.67E-02	8.48E-02	1.12E-01	2.79E-01	1.55E-02	6.67E-02	8.42E-02	1.25E-01	2.92E-01
Manganese	0.00E+00	3.59E-03	3.21E-03	2.60E-05	6.83E-06	6.83E-03	3.59E-03	3.21E-03	3.19E-05	7.59E-06	6.84E-03
Naphthalene	0.00E+00	4.46E-03	5.32E-02	7.86E-03	4.80E-03	7.03E-02	4.46E-03	5.32E-02	9.11E-03	5.51E-03	7.23E-02
Nickel	0.00E+00	9.61E-04	1.78E-03	5.97E-05	1.20E-04	2.92E-03	9.61E-04	1.78E-03	7.34E-05	1.31E-04	2.95E-03
POM	0.00E+00	4.21E-03	1.90E-02	9.47E-04	7.71E-04	2.49E-02	4.21E-03	1.90E-02	1.12E-03	8.57E-04	2.52E-02
Propionaldehyde	0.00E+00	9.35E-03	2.45E-02	8.45E-02	2.78E-02	1.46E-01	9.35E-03	2.45E-02	9.84E-02	2.99E-02	1.62E-01
Styrene	0.00E+00	3.44E-02	2.09E-02	1.57E-02	2.21E-03	7.32E-02	3.44E-02	2.09E-02	1.85E-02	2.47E-03	7.63E-02
Toluene	0.00E+00	1.60E-01	1.16E+00	9.11E-01	2.50E-01	2.48E+00	1.60E-01	1.16E+00	1.06E+00	2.75E-01	2.65E+00
Xylenes	1.70E-01	9.29E-02	8.38E-01	5.04E-01	2.18E-01	1.82E+00	9.29E-02	8.38E-01	5.86E-01	2.40E-01	1.93E+00

Figure 3.2-1. Nationwide Average Benzene Concentration, 1999-2030, Without Controls in this Rule.



3.2.1.1.3 Distributions of Air Toxic Concentrations across the U. S.: Reference Case

Table 3.2-2 gives the distribution of census tract concentrations, summed across all source sectors and background, for mobile source air toxics across the nation in 2020, absent the controls being finalized in this rule. Distributions for other years are similar. Summary tables providing distributions for other years, as well as distributions by State and for reformulated and non-reformulated gasoline areas, can be found in the docket for this rule. From this table, it can be seen that 95th percentiles of average census tract concentrations for mobile-source dominated pollutants such as benzene and 1,3-butadiene are typically two to five times higher than the median of census tract concentrations, even though mobile source emissions are widely dispersed. For pollutants with large major source contributions (e.g., manganese), the 95th percentile of census tract averages can be much higher than the median. In addition, average census tract concentrations can span one to several orders of magnitude. Thus, there is considerable variation in average concentrations across the U.S.

Figure 3.2-2 depicts the geographic distribution of county median concentrations of benzene in 2020. Relatively high levels are seen in the Northeast, Southern California, Florida, parts of Texas, and the Great Lakes Region, where there is high population density and thus high vehicle and nonroad equipment activity. Relatively high levels are also seen in the Pacific Northwest, parts of Alaska, and the upper Great Lakes region. Analysis of fuel survey data

Table 3.2-2. National Distribution of Census Tract Concentrations for Mobile Source Air Toxics in 2020, Without Controls in this Rule.

	2020 concentration ($\mu g\ m^{-3}$) distribution						
Pollutant	**5th percentile**	**10th percentile**	**25th percentile**	**Median**	**75th percentile**	**90th percentile**	**95th percentile**
1,3-Butadiene	3.03E-03	5.60E-03	3.12E-02	8.36E-02	1.30E-01	1.98E-01	3.28E-01
2,2,4-Trimethylpentane	3.83E-02	7.00E-02	1.74E-01	3.79E-01	6.80E-01	1.12E+00	1.50E+00
Acetaldehyde	5.45E-01	5.82E-01	6.99E-01	9.41E-01	1.29E+00	1.84E+00	2.49E+00
Acrolein	6.04E-03	9.78E-03	2.09E-02	4.41E-02	8.64E-02	1.71E-01	2.71E-01
Benzene	3.42E-01	4.15E-01	6.33E-01	9.37E-01	1.32E+00	1.90E+00	2.36E+00
Chromium III	5.73E-06	1.52E-05	6.40E-05	2.41E-04	7.31E-04	2.34E-03	4.89E-03
Chromium VI	3.52E-06	8.79E-06	3.56E-05	1.22E-04	3.32E-04	9.08E-04	1.55E-03
Ethyl Benzene	2.04E-02	3.79E-02	1.01E-01	2.30E-01	4.06E-01	6.70E-01	9.60E-01
Formaldehyde	4.08E-01	5.29E-01	8.08E-01	1.16E+00	1.52E+00	2.12E+00	2.67E+00
Hexane	3.27E-02	6.16E-02	1.90E-01	4.76E-01	8.93E-01	1.70E+00	2.81E+00
MTBE	3.34E-03	7.88E-03	2.39E-02	7.22E-02	2.44E-01	8.80E-01	1.30E+00
Manganese	1.33E-05	4.35E-05	2.04E-04	8.68E-04	3.53E-03	1.42E-02	2.10E-02
Naphthalene	2.88E-03	5.91E-03	1.86E-02	4.48E-02	8.82E-02	1.67E-01	2.37E-01
Nickel	1.38E-05	3.80E-05	1.67E-04	6.65E-04	2.01E-03	4.78E-03	8.17E-03
POM	1.72E-03	2.94E-03	5.73E-03	1.19E-02	2.08E-02	3.62E-02	5.78E-02
Propionaldehyde	1.24E-02	2.13E-02	4.81E-02	1.07E-01	1.93E-01	3.26E-01	4.33E-01
Styrene	2.52E-03	4.88E-03	1.23E-02	2.70E-02	5.39E-02	1.06E-01	1.75E-01
Toluene	1.54E-01	2.83E-01	7.34E-01	1.64E+00	2.96E+00	5.31E+00	7.43E+00
Xylenes	2.66E-01	3.43E-01	6.35E-01	1.22E+00	2.06E+00	3.61E+00	5.38E+00

indicate higher than average fuel benzene levels in these areas. These areas also have higher benzene emissions in winter due to cold starts. Higher benzene levels in Idaho are not due to fuel benzene levels, but are primarily due to wildfire emission estimates, which were determined to be an error in the 1999 National Emissions Inventory and the subsequent projections.

Similar benzene median county concentration maps for 1999, 2015, and 2030 can be found in the docket for this rule, along with maps for other mobile source air toxics and tables of concentration distributions.

3.2.1.1.4 Impacts of Controls on Ambient Concentrations

The standards being finalized in this rule will substantially reduce ambient concentrations of air toxics across the United States. As noted above, these results reflect the cumulative effects of all of the programs finalized in today's rule, not the individual programs. Table 3.2-3 shows the reduction in nationwide average census tract concentrations of MSATs from all sources in 2015, 2020 and 2030. Table 3.2-4 shows the reduction in the highway vehicle contribution to nationwide average census tract concentrations of MSATs. Table 3.2-5 shows that in 2030, the highway vehicle portion of ambient benzene concentrations will be reduced almost 45% across the U.S., the nonroad equipment contribution will be reduced about 10%, and

Figure 3.2-2. Geographic Distribution of County Median Concentrations (µg/m^3) of Benzene in 2020 Without Controls in this Rule.

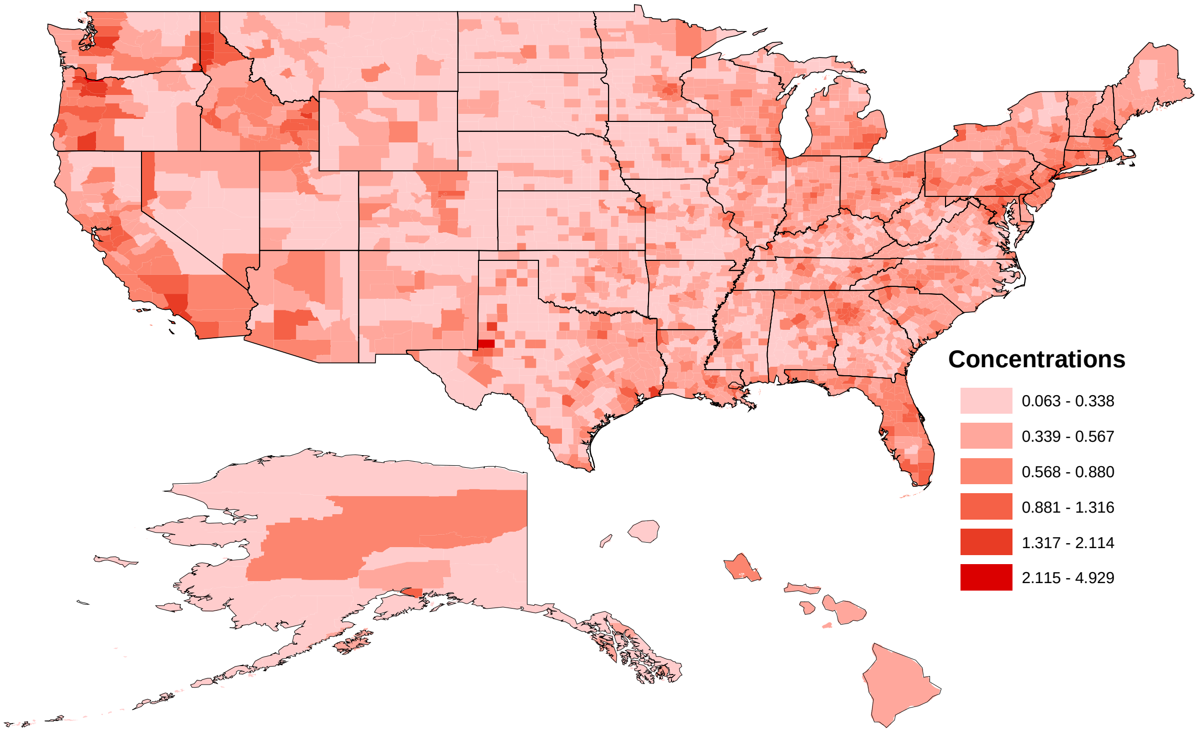


Table 3.2-3. Nationwide Average Census Tract Concentrations of MSATs, With and Without Controls in this Rule, 2015, 2020, and 2030.

	2015			2020			2030		
	Reference	Control	% Reduction	Reference	Control	% Reduction	Reference	Control	% Reduction
1,3-Butadiene	1.07E-01	1.03E-01	3.6	1.09E-01	1.03E-01	5.7	1.15E-01	1.04E-01	9.0
2,2,4-Trimethylpentane	5.19E-01	4.53E-01	12.7	5.20E-01	4.19E-01	19.5	5.88E-01	4.26E-01	27.6
Acetaldehyde	1.10E+00	1.04E+00	5.8	1.11E+00	1.01E+00	9.1	1.19E+00	1.03E+00	13.7
Acrolein	7.20E-02	6.79E-02	5.7	7.34E-02	6.69E-02	8.9	8.05E-02	6.97E-02	13.4
Benzene	1.07E+00	9.56E-01	10.3	1.09E+00	9.38E-01	13.6	1.17E+00	9.50E-01	18.5
Chromium III	1.76E-03	1.76E-03	0.0	1.97E-03	1.97E-03	0.0	1.98E-03	1.98E-03	0.0
Chromium VI	4.50E-04	4.50E-04	0.0	5.07E-04	5.07E-04	0.0	5.15E-04	5.15E-04	0.0
Ethyl Benzene	3.24E-01	2.99E-01	7.5	3.38E-01	3.01E-01	11.1	3.66E-01	3.07E-01	16.3
Formaldehyde	1.27E+00	1.24E+00	2.3	1.28E+00	1.24E+00	3.6	1.33E+00	1.26E+00	5.6
Hexane	7.56E-01	7.37E-01	2.5	7.96E-01	7.70E-01	3.2	8.14E-01	7.76E-01	4.7
MTBE	2.93E-01	2.82E-01	3.5	2.79E-01	2.66E-01	4.6	2.92E-01	2.74E-01	6.0
Manganese	6.17E-03	6.17E-03	0.0	6.83E-03	6.83E-03	0.0	6.84E-03	6.84E-03	0.0
Naphthalene	6.65E-02	6.65E-02	0.0	7.03E-02	7.03E-02	0.0	7.23E-02	7.23E-02	0.0
Nickel	2.67E-03	2.67E-03	0.0	2.92E-03	2.92E-03	0.0	2.95E-03	2.95E-03	0.0
POM	2.40E-02	2.40E-02	0.0	2.49E-02	2.49E-02	0.0	2.52E-02	2.52E-02	0.0
Propionaldehyde	1.44E-01	1.33E-01	7.8	1.46E-01	1.28E-01	12.2	1.62E-01	1.33E-01	18.0
Styrene	6.61E-02	6.33E-02	4.3	7.32E-02	6.87E-02	6.2	7.63E-02	6.89E-02	9.7
Toluene	2.35E+00	2.18E+00	7.1	2.48E+00	2.22E+00	10.4	2.65E+00	2.24E+00	15.7
Xylenes	1.73E+00	1.64E+00	5.3	1.82E+00	1.68E+00	7.8	1.93E+00	1.70E+00	11.8

Table 3.2-4. Nationwide Highway Vehicle Contribution to Average Census Tract Concentrations of MSATs, With and Without Controls in this Rule, 2015, 2020, and 2030.

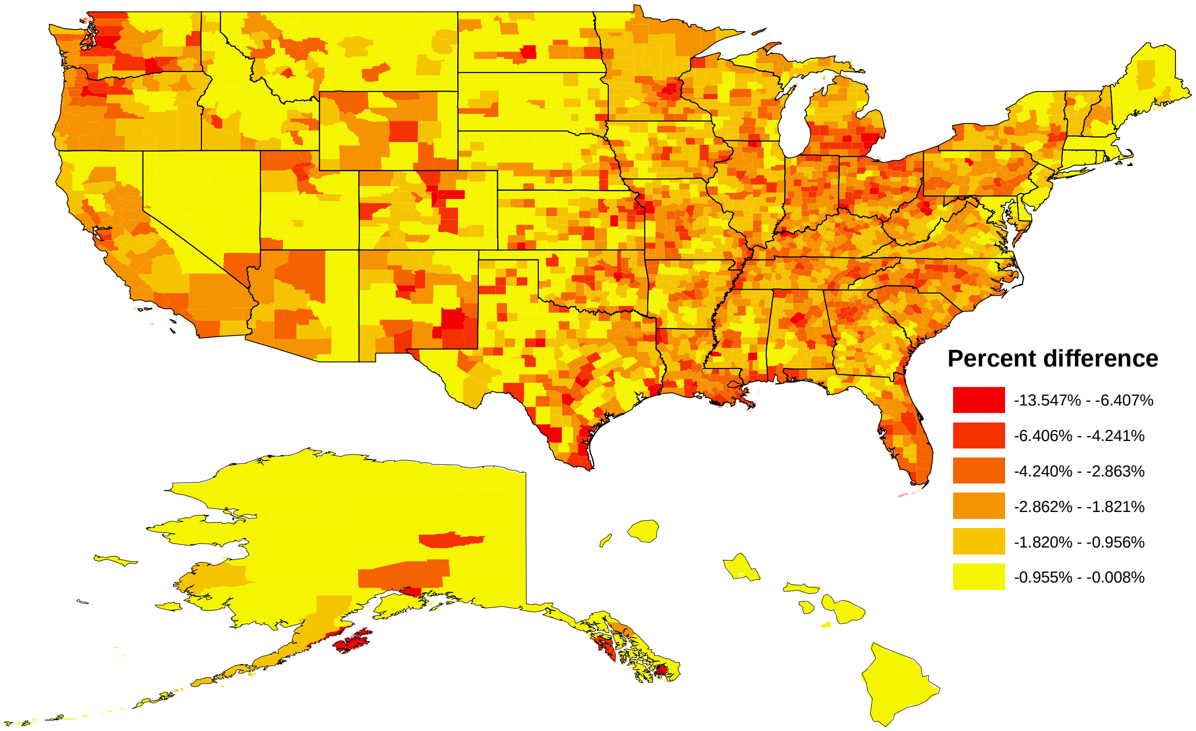
	2015			2020			2030		
	Reference	Control	% Reduction	Reference	Control	% Reduction	Reference	Control	% Reduction
1,3-Butadiene	2.28E-02	1.89E-02	17.0	2.37E-02	1.74E-02	26.3	2.78E-02	1.75E-02	37.0
2,2,4-Trimethylpentane	3.66E-01	3.06E-01	16.3	3.66E-01	2.71E-01	25.9	4.24E-01	2.70E-01	36.4
Acetaldehyde	3.86E-01	3.22E-01	16.5	3.98E-01	2.97E-01	25.4	4.69E-01	3.06E-01	34.8
Acrolein	2.42E-02	2.01E-02	17.0	2.50E-02	1.85E-02	26.2	2.94E-02	1.87E-02	36.6
Benzene	3.79E-01	2.83E-01	25.3	3.88E-01	2.55E-01	34.2	4.54E-01	2.54E-01	44.0
Chromium III	4.40E-05	4.40E-05	0.0	4.84E-05	4.84E-05	0.0	5.94E-05	5.94E-05	0.0
Chromium VI	2.94E-05	2.94E-05	0.0	3.23E-05	3.23E-05	0.0	3.96E-05	3.96E-05	0.0
Ethyl Benzene	1.35E-01	1.14E-01	16.0	1.35E-01	1.01E-01	25.6	1.57E-01	1.00E-01	36.1
Formaldehyde	1.92E-01	1.62E-01	15.3	1.97E-01	1.50E-01	23.6	2.31E-01	1.56E-01	32.4
Hexane	1.16E-01	1.05E-01	9.8	1.07E-01	8.89E-02	16.9	1.18E-01	8.84E-02	25.0
MTBE	1.05E-01	1.01E-01	4.3	8.48E-02	7.77E-02	8.3	8.42E-02	7.30E-02	13.4
Manganese	2.36E-05	2.36E-05	0.0	2.60E-05	2.60E-05	0.0	3.19E-05	3.19E-05	0.0
Naphthalene	7.90E-03	7.90E-03	0.0	7.86E-03	7.86E-03	0.0	9.11E-03	9.11E-03	0.0
Nickel	5.43E-05	5.43E-05	0.0	5.97E-05	5.97E-05	0.0	7.34E-05	7.34E-05	0.0
POM	9.13E-04	9.13E-04	0.0	9.47E-04	9.47E-04	0.0	1.12E-03	1.12E-03	0.0
Propionaldehyde	8.24E-02	7.12E-02	13.6	8.45E-02	6.66E-02	21.1	9.84E-02	6.92E-02	29.6
Styrene	1.50E-02	1.22E-02	18.8	1.57E-02	1.12E-02	28.8	1.85E-02	1.11E-02	39.8
Toluene	9.00E-01	7.47E-01	17.1	9.11E-01	6.66E-01	26.9	1.06E+00	6.62E-01	37.7
Xylenes	4.98E-01	4.14E-01	16.9	5.04E-01	3.69E-01	26.7	5.86E-01	3.67E-01	37.5

Table 3.2-5. Contributions of Source Sectors to Nationwide Average Census Tract Concentrations of Benzene, With and Without Controls in this Rule, 2015, 2020, and 2030.

	2015 annual average concentrations (μg m^{-3})					2020 annual average concentrations (μg m^{-3})					2030 annual average concentrations (μg m^{-3})				
	major	area & other	highway vehicles	nonroad	total (including background)	major	area & other	highway vehicles	nonroad	total (including background)	major	area & other	highway vehicles	nonroad	total (including background)
Reference	1.55E-02	1.63E-01	3.79E-01	1.14E-01	1.07E+00	1.70E-02	1.69E-01	3.88E-01	1.18E-01	1.09E+00	1.70E-02	1.69E-01	4.54E-01	1.32E-01	1.17E+00
Control	1.54E-02	1.61E-01	2.83E-01	1.02E-01	9.56E-01	1.69E-02	1.67E-01	2.55E-01	1.05E-01	9.38E-01	1.69E-02	1.67E-01	2.54E-01	1.18E-01	9.50E-01
% Difference	0	-1	-25	-10	-10	0	-1	-34	-10	-14	0	-1	-44	-10	-19
Average Nationwide Difference in Ambient Benzene Concentration -- Non RFG Areas															
Reference	1.08E-02	1.43E-01	2.96E-01	8.15E-02	8.93E-01	1.20E-02	1.48E-01	3.06E-01	8.34E-02	9.11E-01	1.20E-02	1.48E-01	3.57E-01	9.29E-02	9.71E-01
Control	1.08E-02	1.41E-01	2.17E-01	6.82E-02	7.99E-01	1.20E-02	1.46E-01	2.00E-01	6.95E-02	7.89E-01	1.20E-02	1.46E-01	1.97E-01	7.72E-02	7.94E-01
% Difference	0	-2	-27	-16	-11	0	-2	-35	-17	-13	0	-2	-45	-17	-18
Average Nationwide Difference in Ambient Benzene Concentration -- RFG Areas															
Reference	2.39E-02	1.99E-01	5.29E-01	1.72E-01	1.38E+00	2.58E-02	2.08E-01	5.34E-01	1.79E-01	1.40E+00	2.58E-02	2.08E-01	6.29E-01	2.03E-01	1.52E+00
Control	2.38E-02	1.97E-01	4.02E-01	1.63E-01	1.24E+00	2.58E-02	2.05E-01	3.54E-01	1.70E-01	1.21E+00	2.58E-02	2.05E-01	3.57E-01	1.92E-01	1.23E+00
% Difference	0	-1	-24	-5	-10	0	-1	-34	-5	-14	0	-1	-43	-5	-19

the area source contribution will be reduced about 1 to 2%. The reduction for area sources is due to the impacts of fuel benzene control on gasoline distribution emissions, and reductions in portable fuel container (PFC) emissions from PFC and fuel benzene controls. Reductions in non-reformulated gasoline areas are even larger. It should be noted that the estimated total reductions in ambient concentrations from all sources are probably significantly underestimated, since we could not account for the impacts of controls on background levels, which includes transport of emissions from these sources. Figure 3.2-3 presents the distribution of percent reductions in median ambient benzene concentrations for U.S. counties with the controls being finalized in 2030. Again, since the 1.3% maximum average fuel benzene standard is not included in the modeling, reductions in some parts of the country, including the Pacific Northwest, are underestimated. Summary tables providing data by State, as well as maps of MSAT concentrations with controls and percent reductions with controls, can be found in the docket for the rule.

Figure 3.2-3. Distribution of Percent Reductions in Median Ambient Benzene Concentrations, 2030, for U. S. Counties with the Controls in this Rule.



3.2.1.2 Exposure and Risk Modeling

3.2.1.2.1 Methods

The HAPEM6 exposure model used in this assessment is the most recent version in a series of models that the EPA has used to model population exposures and risks at the urban and national scale in a number of assessments.[148, 149, 150] HAPEM6 is designed to assess average long-term inhalation exposures of the general population, or a specific sub-population, over spatial scales ranging from urban to national. HAPEM6 uses the general approach of tracking representatives of 6 specified age groups as they move among indoor and outdoor microenvironments and among geographic locations (a total of 14, HAPEM5 had 37). The estimated pollutant concentrations in each microenvironment visited are combined into a time-weighted average concentration, which is assigned to members of the demographic group. HAPEM calculates 30 replicates with different exposures for each demographic group. These data can be used to develop a distribution of exposures for the entire U. S. population.

HAPEM6 uses five primary sources of information: year 2000 population data from the U.S. Census, population activity data, air quality data, roadway locations, and microenvironmental data. The population data used are obtained from the U.S. Census. Two kinds of activity data are used: activity pattern data and commuting pattern data. The activity pattern data quantify the amount of time individuals spend in a variety of microenvironments and come from EPA's Consolidated Human Activity Database (CHAD).[151] The commuting data contained in the HAPEM6 default file were derived from the year 2000 U.S. Census, and includes the number of residents of each tract that work in that tract and every other U.S. Census tract, as well as data on commuting times and distances. The air quality data come from ASPEN (after background has been added). The road locations are determined from geographic information system files from the U.S. Census. The microenvironmental data consist of factors that estimate air toxic concentrations in specific microenvironments, based on penetration of outdoor air into the microenvironment, proximity of the microenvironment to the emission source, and emission sources within the microenvironment. These factors vary among pollutants.[152]

New to HAPEM6 are algorithms which account for the gradient in concentrations of primary (directly emitted) mobile source air toxics within 200 meters of major roadways.[153] HAPEM6 adjusts ambient concentrations generated by ASPEN for each census tract using concentration gradients developed with the CALPUFF dispersion model.[154] For locations within 75 meters and from 75 to 200 meters from major roads, ambient concentrations are adjusted upward, while locations further from major roadways are adjusted downward. These adjustments are consistent with results from prior modeling studies that explicitly accounted for concentration gradients around major roads within census tracts.[155] These adjusted concentrations are then employed in microenvironmental concentration calculations.

HAPEM6 has a number of other technical improvements over the previous version of HAPEM. These improvements, along with other details of the model, are described in the HAPEM6 User's Guide.[156] In short, HAPEM6 reduces the number of demographic groups to 6 age-based groups from 10 age-gender groups in HAPEM5, and reduces the number of microenvironments modeled, from 37 to 14. This reduces modeling run time significantly with little impact on results. HAPEM6 also accounts for commuting time better, basing commute times and travel modes for each census tract on distributions reported in the 2000 Census. The HAPEM runs used year 2000 census data. Average lifetime exposure for an individual in a census tract was calculated from data for individual demographic groups using a post-processing routine. We estimated the contributions to ambient concentrations for the following source sectors: major, area and other, onroad, nonroad, and background.

Once HAPEM runs were completed, cancer risk and noncancer risk were calculated for each of the mobile source air toxic pollutants, based on population exposure distributions. In the HAPEM6 output, for each source category, there are 30 replicate exposure concentrations for each of the six demographic groups (180 concentrations per census tract for each source category). For each source category and each of the 30 replicates, a lifetime exposure concentration was calculated. A risk estimate was then calculated for each of the 30 replicates. The resulting data were used to develop distributions of population risks at various summary levels (census tract, county, state, national). More detail is provided in the technical support document. Table 3.2-6 lists the pollutants with their respective unit risk estimates (UREs) for cancer calculations and reference concentrations (RfCs) for noncancer calculations. These are the same values used in the 1999 NATA, and more detailed information on how dose-response values were selected is provided at the website for that assessment. Also listed are the cancer weight of evidence classifications and target organ system(s) for noncancer calculations.

Table 3.2-6. Dose-Response Values Use in Risk Modeling (Concentrations in μg/m^3)

HAP	Carcinogen Class	URE (per μg/m$^{3)}$	Source	Organ Systems	RfC (mg/ m$^{3)}$	Source
1,3-Butadiene	A	$3.0x10^{-5}$	IRIS	Reproductive	$2.0x10^{-3}$	
2,2,4-Trimethylpentane	N/A	N/A		N/A	N/A	
Acetaldehyde	B2	$2.2x10^{-6}$	IRIS	Respiratory	$9.0x10^{-3}$	IRIS
Acrolein		0		Respiratory	$2.0x10^{-5}$	IRIS
Benzene	A	$7.8x10^{-6}$*	IRIS	Immune	$3.0x10^{-2}$	IRIS
Chromium III	N/A	N/A		N/A	N/A	
Chromium VI	A	$1.2x10^{-2}$	IRIS	Respiratory	$1.0x10^{-4}$	IRIS
Ethyl Benzene		0		Developmental	1.0	IRIS
Formaldehyde	B	$5.5x10^{-9}$	CIIT	Respiratory	$9.8x10^{-3}$	ATSDR
Hexane		N/A		Respiratory, Neurological	$2.0x10^{-1}$	IRIS
Manganese		N/A		Neurological	$5.0x10^{-5}$	IRIS
MTBE		N/A		Liver, Kidney, Ocular	3.0	IRIS
Naphthalene	C	$3.4x10^{-5}$	CAL	Respiratory	$3.0x10^{-3}$	IRIS
Nickel	A	$1.6x10^{-4}$	EPA/ OAQPS	Respiratory, Immune	$6.5x10^{-5}$	CAL
POM1	B2	$5.5x10^{-5}$	OAQPS		N/A	
POM2	B2	$5.5x10^{-5}$	OAQPS		N/A	
POM3	B2	$1.0x10^{-1}$	OAQPS		N/A	
POM4	B2	$1.0x10^{-2}$	OAQPS		N/A	
POM5	B2	$1.0x10^{-3}$	OAQPS		N/A	
POM6	B2	$1.0x10^{-4}$	OAQPS		N/A	
POM7	B2	$1.0x10^{-5}$	OAQPS		N/A	
POM8	B2	$2.0x10^{-4}$	OAQPS		N/A	
Styrene		N/A		Neurological	1.0	IRIS
Toluene		N/A		Respiratory, Neurological	$4.0x10^{-1}$	IRIS
Xylenes		N/A		Neurological	$1.0x10^{-1}$	IRIS

*represents upper end of a range of MLE values

The weight of evidence classifications provided in this table were developed under EPA's 1986 risk assessment guidelines where:
A = Known human carcinogen
B1 = Probable human carcinogen, based on incomplete human data
B2 = Probable human carcinogen, based on adequate animal data
C = Possible human carcinogen

Dose-response values were selected using the following hierarchy:

1) EPA IRIS assessments.
2) Agency for Toxic Substances and Disease Registry (ATSDR) minimum risk levels (MRLs) for noncancer effects – used as RfC.
3) California Office of Environmental Health Hazard Assessment (OEHHA) values.

There are a number of exceptions to this hierarchy:

1) Formaldehyde -- EPA no longer considers the formaldehyde URE reported in IRIS, which is based on a 1987 study, to represent the best available science in the peer-reviewed literature. Accordingly, the 1999 risk estimates for formaldehyde are based on a dose-response value developed by the CIIT Centers for Health Research (formerly the Chemical Industry Institute of Toxicology) and published in 1999. This issue is discussed in Chapter 1 of the RIA.
2) Nickel -- The IRIS URE for nickel inhalation shown in Table 3.2.-6 was derived from evidence of the carcinogenic effects of insoluble nickel compounds in crystalline form. Soluble nickel species, and insoluble species in amorphous form, do not appear to produce genotoxic effects by the same toxic mode of action as insoluble crystalline nickel. Nickel speciation information for some of the largest nickel-emitting sources (including oil combustion, coal combustion, and others) suggests that at least 35% of total nickel emissions may be soluble compounds. The remaining insoluble nickel emissions are not well-characterized, however. Consistent with this limited information, this analysis has conservatively assumed that 65% of emitted nickel is insoluble, and that all insoluble nickel is crystalline. On this basis, the nickel URE (based on nickel subsulfide, and representative of pure insoluble crystalline nickel) was adjusted to reflect an assumption that 65% of the total mass of nickel may be carcinogenic. The ATSDR MRL in Table 3.2.-6 was not adjusted, however, because the noncancer effects of nickel are not thought to be limited to the crystalline, insoluble form.
3) POM -- POM was divided into eight toxicity categories to cover the range of unit risks of the individual POM species and POM groups contained in the 1999 NEI. The unit risks for those eight categories were based on the midpoint of the range of unit risks defining the toxicity category. More details on the development of these unit risks can be found on the website for the 1999 NATA and in Appendix H of the 2001 EPA draft report to the Science Advisory Board on the 1996 National-Scale Assessment.[157]

Individual cancer risk estimates (the product of unit risk estimates and exposure levels) for various pollutants were assumed to be additive, since there was no evidence of non-additive interactions for any of the pollutants. Most of the estimates are based on the statistical upper confidence limit (UCL) of the fitted dose-response curve, but the estimates for hexavalent chromium, nickel, and benzene are based on the statistical best fit ("maximum likelihood estimate," or MLE). Except for benzene and chromium, where risks are based on maximum likelihood dose-response values, risks from mobile source air toxics should all be considered upper-bound values. True risks could be greater, but are likely to be lower, and could be zero.

To express chronic noncancer hazards, we used the RfC as part of a calculation called the hazard quotient (HQ), which is the ratio between the concentration to which a person is exposed and the RfC. A value of the HQ less than one indicates that the exposure is lower than the RfC and that no adverse health effects would be expected. A value of the HQ greater than one indicates that the exposure is higher than the RfC. However, because many RfCs incorporate protective assumptions in the face of uncertainty, an HQ greater than one does not necessarily suggest a likelihood of adverse effects. Furthermore, the HQ cannot be translated to a probability that adverse effects will occur and is not likely to be proportional to risk. A HQ greater than one can best be described as indicating that a potential exists for adverse health effects. However one should evaluate the weight of evidence supporting the RfC value for a particular chemical before determining potential risks. Following the approach used in the 1999 NATA, combined noncancer hazards were calculated using the hazard index (HI), defined as the sum of hazard quotients for individual air toxics compounds that affect the same organ or organ system. The HI is only an approximation of the combined effect, because some of the substances may affect the target organs in different (i.e., non-additive) ways. As with the HQ, a value of the HI below 1.0 will likely not result in adverse effects over a lifetime of exposure. However, a value of the HI greater than 1.0 does not necessarily suggest a likelihood of adverse effects. Furthermore, the HI cannot be translated to a probability that adverse effects will occur and is not likely to be proportional to risk. An HI greater than one can be best described as indicating that a potential may exist for adverse health effects.

3.2.1.2.2 Exposure and Risk Trends for Air Toxics: Reference Case

Tables 3.2-7 and 3.2-8 summarize nationwide averages of median and 90th percentile census tract exposure concentrations of mobile source air toxics in 1999, 2015, 2020, and 2030, without the controls being finalized in this rule. It should be noted that all the other non-inventoried sources, as well as the contribution from transport, contribute to background levels. Overall, exposure to ambient concentrations tends to be less than ambient concentrations because penetration rates to indoor microenvironments are typically less than one.[c] However, highway vehicles make a larger contribution to overall average population exposures than they do to ambient levels. This is largely because of elevated exposures experienced inside vehicles.

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[c] In the exposure monitoring studies discussed in section 3.1.2, average measured personal exposure concentrations are greater than those in both indoor and outdoor air. These differences may be attributable to several factors. First, HAPEM6 does not include pollution sources within indoor microenvironments, such as attached garages, environmental tobacco smoke, and solvent storage. Second, measured personal breathing zone concentrations are integrated measurements that account for time-weighted average (TWA) concentrations that incorporate every source, activity, and location with which a monitor comes into contact. Microenvironmental models like HAPEM6 simplify individual time budgets so they fit within the microenvironments modeled or monitored.

Table 3.2-9 summarizes national average population cancer risk across census tracts for these years by pollutant, as well as total cancer risk across pollutants. The total cancer risk from mobile source air toxics (including the stationary source contribution) was about 25 in a million in 1999.

In all projection years, benzene emissions are by far the largest contributor to cancer risk from mobile sources (see Figure 3.2-4). Other significant contributors to cancer risk from mobile source air toxics include 1,3-butadiene, acetaldehyde, naphthalene, and hexavalent chromium. It should be noted, however, that we have no actual measurements of hexavalent chromium emissions from mobile sources, and that the risk estimate for this pollutant is based on an assumption that forty percent of the chromium from highway vehicles and eighteen percent of the chromium from nonroad sources was assumed to be the highly toxic hexavalent form. The estimate for highway vehicles is based on data from utility boilers,[158] and the estimate for nonroad equipment is, based on combustion data from stationary combustion turbines that burn diesel fuel.[159] Thus there is a great deal of uncertainty in estimates for this pollutant.

Despite significant reductions in risk from mobile source air toxics, average inhalation cancer risks for these pollutants in 2030, accounting for both mobile and stationary source contributions, remain well above 20 in 1,000,000 (Figure 3.2-5). In addition, average risk from exposure to benzene remains above 9 in 1,000,000.

Table 3.2-7. National Means of Census Tract Median Population Exposure Concentrations of Mobile Source Air Toxics in 1999, 2015, 2020, and 2030, Without Controls in this Rule.

		1999 annual average concentrations (μg m^{-3})					2015 annual average concentrations (μg m^{-3})				
Pollutant	**background (μg m^{-3})**	**major**	**area & other**	**onroad**	**nonroad**	**total (including background)**	**major**	**area & other**	**onroad**	**nonroad**	**total (including background)**
1,3-Butadiene	3.96E-02	1.54E-03	1.66E-02	6.39E-02	1.64E-02	1.38E-01	1.72E-03	1.69E-02	2.88E-02	1.01E-02	9.71E-02
2,2,4-Trimethylpentane	0.00E+00	1.70E-02	1.86E-02	8.23E-01	1.57E-01	1.02E+00	8.68E-03	2.18E-02	4.16E-01	9.26E-02	5.39E-01
Acetaldehyde	4.00E-01	2.34E-02	4.33E-02	8.08E-01	1.18E-01	1.39E+00	2.41E-02	4.60E-02	4.70E-01	9.07E-02	1.03E+00
Acrolein	0.00E+00	2.56E-03	2.35E-02	6.62E-02	1.83E-02	1.10E-01	2.91E-03	2.14E-02	2.90E-02	1.49E-02	6.83E-02
Benzene	3.05E-01	1.76E-02	1.16E-01	8.08E-01	1.51E-01	1.40E+00	1.25E-02	1.37E-01	4.53E-01	9.87E-02	1.01E+00
Chromium III	0.00E+00	3.23E-04	1.79E-04	1.93E-05	2.21E-05	5.43E-04	4.11E-04	2.43E-04	2.64E-05	2.34E-05	7.03E-04
Chromium VI	0.00E+00	4.25E-05	7.94E-05	1.30E-05	5.06E-06	1.40E-04	5.40E-05	1.09E-04	1.78E-05	5.38E-06	1.86E-04
Ethyl Benzene	0.00E+00	1.45E-02	7.49E-02	3.22E-01	8.02E-02	4.91E-01	9.92E-03	1.00E-01	1.62E-01	4.69E-02	3.19E-01
Formaldehyde	6.12E-01	3.29E-02	7.20E-02	5.78E-01	1.88E-01	1.48E+00	4.15E-02	8.26E-02	2.46E-01	1.38E-01	1.12E+00
Hexane	0.00E+00	5.50E-02	3.60E-01	2.85E-01	7.13E-02	7.71E-01	4.94E-02	4.41E-01	1.44E-01	4.98E-02	6.85E-01
MTBE	0.00E+00	1.05E-02	4.84E-02	4.61E-01	3.40E-01	8.59E-01	1.26E-03	1.17E-03	1.48E-05	2.84E-06	2.45E-03
Manganese	0.00E+00	1.05E-03	8.93E-04	1.08E-05	2.40E-06	1.96E-03	1.13E-02	5.35E-02	1.24E-01	8.90E-02	2.78E-01
Naphthalene	0.00E+00	3.82E-03	3.37E-02	1.79E-02	3.85E-03	5.92E-02	3.37E-03	4.18E-02	9.89E-03	4.02E-03	5.91E-02
Nickel	0.00E+00	3.02E-04	5.78E-04	2.38E-05	4.17E-05	9.46E-04	3.47E-04	6.50E-04	3.29E-05	4.80E-05	1.08E-03
POM	0.00E+00	2.87E-03	1.00E-02	1.56E-03	5.48E-04	1.50E-02	2.26E-03	1.16E-02	8.33E-04	4.97E-04	1.52E-02
Propionaldehyde	0.00E+00	7.73E-03	1.80E-02	1.93E-01	3.35E-02	2.52E-01	7.24E-03	1.89E-02	9.56E-02	2.28E-02	1.45E-01
Styrene	0.00E+00	2.04E-02	1.14E-02	3.40E-02	3.03E-03	6.88E-02	2.40E-02	1.56E-02	1.73E-02	1.83E-03	5.86E-02
Toluene	0.00E+00	1.61E-01	6.57E-01	2.14E+00	3.42E-01	3.30E+00	1.16E-01	8.80E-01	1.09E+00	2.06E-01	2.29E+00
Xylenes	1.28E-01	8.08E-02	4.66E-01	1.21E+00	3.33E-01	2.22E+00	6.79E-02	6.43E-01	6.11E-01	1.85E-01	1.63E+00

Table 3.2-7 (cont'd). National Means of Census Tract Median Population Exposure Concentrations of Mobile Source Air Toxics in 1999, 2015, 2020, and 2030, Without Controls in this Rule.

		2020 annual average concentrations (μg m^{-3})					2030 annual average concentrations (μg m^{-3})				
Pollutant	**background (μg m^{-3})**	**major**	**area & other**	**onroad**	**nonroad**	**total (including background)**	**major**	**area & other**	**onroad**	**nonroad**	**total (including background)**
1,3-Butadiene	3.96E-02	1.86E-03	1.69E-02	2.98E-02	1.07E-02	9.88E-02	1.86E-03	1.69E-02	3.49E-02	1.21E-02	1.05E-01
2,2,4-Trimethylpentane	0.00E+00	9.37E-03	2.31E-02	4.16E-01	9.21E-02	5.41E-01	9.37E-03	2.31E-02	4.81E-01	1.00E-01	6.14E-01
Acetaldehyde	4.00E-01	2.52E-02	4.70E-02	4.85E-01	9.01E-02	1.05E+00	2.52E-02	4.70E-02	5.68E-01	9.78E-02	1.14E+00
Acrolein	0.00E+00	3.27E-03	2.07E-02	2.99E-02	1.58E-02	6.97E-02	3.27E-03	2.07E-02	3.51E-02	1.79E-02	7.70E-02
Benzene	3.05E-01	1.37E-02	1.42E-01	4.64E-01	1.02E-01	1.03E+00	1.37E-02	1.42E-01	5.40E-01	1.15E-01	1.12E+00
Chromium III	0.00E+00	4.59E-04	2.74E-04	2.90E-05	2.37E-05	7.86E-04	4.59E-04	2.74E-04	3.56E-05	2.43E-05	7.93E-04
Chromium VI	0.00E+00	6.14E-05	1.23E-04	1.96E-05	5.45E-06	2.09E-04	6.14E-05	1.23E-04	2.40E-05	5.62E-06	2.14E-04
Ethyl Benzene	0.00E+00	1.11E-02	1.10E-01	1.62E-01	4.83E-02	3.32E-01	1.11E-02	1.10E-01	1.87E-01	5.41E-02	3.62E-01
Formaldehyde	6.12E-01	4.71E-02	8.68E-02	2.52E-01	1.38E-01	1.14E+00	4.71E-02	8.68E-02	2.94E-01	1.51E-01	1.19E+00
Hexane	0.00E+00	5.44E-02	4.77E-01	1.33E-01	5.19E-02	7.17E-01	5.44E-02	4.77E-01	1.46E-01	5.83E-02	7.36E-01
MTBE	0.00E+00	1.27E-02	5.48E-02	1.01E-01	9.25E-02	2.61E-01	1.27E-02	5.48E-02	1.00E-01	1.04E-01	2.72E-01
Manganese	0.00E+00	1.40E-03	1.29E-03	1.62E-05	3.00E-06	2.71E-03	1.40E-03	1.29E-03	1.99E-05	3.35E-06	2.71E-03
Naphthalene	0.00E+00	3.78E-03	4.44E-02	9.84E-03	4.31E-03	6.23E-02	3.78E-03	4.44E-02	1.14E-02	4.94E-03	6.45E-02
Nickel	0.00E+00	3.77E-04	7.15E-04	3.62E-05	5.02E-05	1.18E-03	3.77E-04	7.15E-04	4.45E-05	5.47E-05	1.19E-03
POM	0.00E+00	2.51E-03	1.18E-02	8.63E-04	5.01E-04	1.57E-02	2.51E-03	1.18E-02	1.02E-03	5.58E-04	1.59E-02
Propionaldehyde	0.00E+00	7.27E-03	1.94E-02	9.81E-02	2.25E-02	1.47E-01	7.27E-03	1.94E-02	1.14E-01	2.42E-02	1.65E-01
Styrene	0.00E+00	2.74E-02	1.72E-02	1.80E-02	1.87E-03	6.45E-02	2.74E-02	1.72E-02	2.13E-02	2.10E-03	6.80E-02
Toluene	0.00E+00	1.30E-01	9.68E-01	1.10E+00	2.09E-01	2.41E+00	1.30E-01	9.68E-01	1.28E+00	2.30E-01	2.61E+00
Xylenes	1.28E-01	7.68E-02	7.10E-01	6.18E-01	1.87E-01	1.72E+00	7.68E-02	7.10E-01	7.17E-01	2.06E-01	1.84E+00

Table 3.2-8. National Means of Census Tract 90th Percentile Population Exposure Concentrations of Mobile Source Air Toxics in 1999, 2015, 2020, and 2030, Without Controls in this Rule.

		1999 annual average concentrations (μg m^{-3})					2015 annual average concentrations (μg m^{-3})				
Pollutant	**background (μg m^{-3})**	**major**	**area & other**	**onroad**	**nonroad**	**total (including background)**	**major**	**area & other**	**onroad**	**nonroad**	**total (including background)**
1,3-Butadiene	5.88E-02	2.03E-03	2.23E-02	1.00E-01	2.49E-02	2.08E-01	2.15E-03	2.16E-02	4.11E-02	1.39E-02	1.38E-01
2,2,4-Trimethylpentane	0.00E+00	2.65E-02	3.12E-02	1.42E+00	2.65E-01	1.75E+00	1.30E-02	3.56E-02	7.08E-01	1.54E-01	9.10E-01
Acetaldehyde	5.82E-01	3.48E-02	6.34E-02	1.27E+00	1.80E-01	2.13E+00	3.32E-02	6.27E-02	6.89E-01	1.28E-01	1.49E+00
Acrolein	0.00E+00	3.68E-03	3.36E-02	1.07E-01	2.82E-02	1.72E-01	3.72E-03	2.79E-02	4.36E-02	2.11E-02	9.64E-02
Benzene	4.50E-01	2.57E-02	1.71E-01	1.24E+00	2.28E-01	2.12E+00	1.70E-02	1.91E-01	6.52E-01	1.39E-01	1.45E+00
Chromium III	0.00E+00	4.55E-04	2.59E-04	2.88E-05	3.15E-05	7.74E-04	5.81E-04	3.51E-04	3.97E-05	3.35E-05	1.01E-03
Chromium VI	0.00E+00	6.16E-05	1.15E-04	1.92E-05	7.20E-06	2.03E-04	7.88E-05	1.57E-04	2.63E-05	7.67E-06	2.70E-04
Ethyl Benzene	0.00E+00	2.33E-02	1.19E-01	5.49E-01	1.35E-01	8.27E-01	1.51E-02	1.51E-01	2.63E-01	7.53E-02	5.04E-01
Formaldehyde	8.03E-01	4.21E-02	9.22E-02	7.89E-01	2.52E-01	1.98E+00	4.93E-02	9.74E-02	3.03E-01	1.67E-01	1.42E+00
Hexane	0.00E+00	7.54E-02	5.11E-01	4.32E-01	1.07E-01	1.13E+00	6.51E-02	5.95E-01	2.04E-01	7.06E-02	9.34E-01
MTBE	0.00E+00	1.46E-02	7.13E-02	7.22E-01	5.16E-01	1.32E+00	1.45E-02	7.24E-02	1.92E-01	1.34E-01	4.13E-01
Manganese	0.00E+00	1.44E-03	1.18E-03	1.47E-05	3.25E-06	2.64E-03	1.72E-03	1.55E-03	2.01E-05	3.85E-06	3.30E-03
Naphthalene	0.00E+00	4.81E-03	4.39E-02	2.44E-02	5.09E-03	7.83E-02	4.07E-03	5.13E-02	1.25E-02	4.99E-03	7.29E-02
Nickel	0.00E+00	4.25E-04	8.25E-04	3.52E-05	6.04E-05	1.35E-03	4.94E-04	9.09E-04	4.77E-05	6.89E-05	1.52E-03
POM	0.00E+00	3.68E-03	1.21E-02	2.04E-03	7.05E-04	1.85E-02	2.89E-03	1.38E-02	1.04E-03	6.14E-04	1.84E-02
Propionaldehyde	0.00E+00	1.30E-02	2.79E-02	3.36E-01	5.58E-02	4.33E-01	1.15E-02	2.72E-02	1.60E-01	3.57E-02	2.34E-01
Styrene	0.00E+00	2.87E-02	1.78E-02	5.90E-02	5.23E-03	1.11E-01	3.31E-02	2.31E-02	2.87E-02	3.01E-03	8.79E-02
Toluene	0.00E+00	2.52E-01	1.05E+00	3.61E+00	5.66E-01	5.48E+00	1.70E-01	1.32E+00	1.71E+00	3.21E-01	3.52E+00
Xylenes	2.04E-01	1.23E-01	7.05E-01	1.95E+00	5.25E-01	3.50E+00	9.59E-02	9.14E-01	9.13E-01	2.72E-01	2.40E+00

Table 3.2-8 (cont'd). National Means of Census Tract 90th Percentile Population Exposure Concentrations of Mobile Source Air Toxics in 1999, 2015, 2020, and 2030, Without Controls in this Rule.

		2020 annual average concentrations ($\mu g\ m^{-3}$)					2030 annual average concentrations ($\mu g\ m^{-3}$)				
Pollutant	**background ($\mu g\ m^{-3}$)**	**major**	**area & other**	**onroad**	**nonroad**	**total (including background)**	**major**	**area & other**	**onroad**	**nonroad**	**total (including background)**
1,3-Butadiene	5.88E-02	2.32E-03	2.16E-02	4.28E-02	1.48E-02	1.40E-01	2.32E-03	2.16E-02	5.11E-02	1.72E-02	1.51E-01
2,2,4-Trimethylpentane	0.00E+00	1.40E-02	3.75E-02	7.09E-01	1.54E-01	9.14E-01	1.40E-02	3.75E-02	8.25E-01	1.69E-01	1.05E+00
Acetaldehyde	5.82E-01	3.47E-02	6.42E-02	7.14E-01	1.28E-01	1.52E+00	3.47E-02	6.42E-02	8.55E-01	1.41E-01	1.68E+00
Acrolein	0.00E+00	4.15E-03	2.70E-02	4.53E-02	2.23E-02	9.87E-02	4.15E-03	2.70E-02	5.37E-02	2.56E-02	1.10E-01
Benzene	4.50E-01	1.86E-02	1.99E-01	6.68E-01	1.44E-01	1.48E+00	1.86E-02	1.99E-01	7.93E-01	1.65E-01	1.63E+00
Chromium III	0.00E+00	6.51E-04	3.97E-04	4.37E-05	3.39E-05	1.13E-03	6.51E-04	3.97E-04	5.40E-05	3.48E-05	1.14E-03
Chromium VI	0.00E+00	8.98E-05	1.77E-04	2.90E-05	7.78E-06	3.04E-04	8.98E-05	1.77E-04	3.58E-05	8.04E-06	3.11E-04
Ethyl Benzene	0.00E+00	1.68E-02	1.65E-01	2.62E-01	7.71E-02	5.21E-01	1.68E-02	1.65E-01	3.06E-01	8.71E-02	5.75E-01
Formaldehyde	8.03E-01	5.60E-02	1.02E-01	3.11E-01	1.67E-01	1.44E+00	5.60E-02	1.02E-01	3.70E-01	1.86E-01	1.52E+00
Hexane	0.00E+00	7.12E-02	6.39E-01	1.86E-01	7.27E-02	9.69E-01	7.12E-02	6.39E-01	2.06E-01	8.21E-02	9.98E-01
MTBE	0.00E+00	1.61E-02	7.34E-02	1.52E-01	1.37E-01	3.78E-01	1.61E-02	7.34E-02	1.50E-01	1.53E-01	3.93E-01
Manganese	0.00E+00	1.92E-03	1.71E-03	2.21E-05	4.07E-06	3.65E-03	1.92E-03	1.71E-03	2.72E-05	4.54E-06	3.66E-03
Naphthalene	0.00E+00	4.55E-03	5.44E-02	1.24E-02	5.33E-03	7.66E-02	4.55E-03	5.44E-02	1.45E-02	6.16E-03	7.96E-02
Nickel	0.00E+00	5.39E-04	1.00E-03	5.25E-05	7.19E-05	1.66E-03	5.39E-04	1.00E-03	6.45E-05	7.86E-05	1.68E-03
POM	0.00E+00	3.21E-03	1.42E-02	1.08E-03	6.21E-04	1.91E-02	3.21E-03	1.42E-02	1.29E-03	6.97E-04	1.94E-02
Propionaldehyde	0.00E+00	1.16E-02	2.78E-02	1.65E-01	3.52E-02	2.39E-01	1.16E-02	2.78E-02	1.94E-01	3.83E-02	2.72E-01
Styrene	0.00E+00	3.78E-02	2.55E-02	2.99E-02	3.07E-03	9.64E-02	3.78E-02	2.55E-02	3.57E-02	3.47E-03	1.03E-01
Toluene	0.00E+00	1.88E-01	1.44E+00	1.73E+00	3.23E-01	3.68E+00	1.88E-01	1.44E+00	2.04E+00	3.61E-01	4.03E+00
Xylenes	2.04E-01	1.08E-01	1.01E+00	9.22E-01	2.74E-01	2.51E+00	1.08E-01	1.01E+00	1.09E+00	3.07E-01	2.71E+00

Table 3.2-9. National Average Cancer Risk Across Census Tracts for 1999, 2015, 2020, and 2030 by Pollutant, Without Controls in this Rule.

	1999 average individual risk					2015 annual average individual risk				
Pollutant	**major**	**area & other**	**onroad**	**nonroad**	**total (including background)**	**major**	**area & other**	**onroad**	**nonroad**	**total (including background)**
1,3-Butadiene	4.36E-08	4.85E-07	2.06E-06	5.39E-07	4.43E-06	4.62E-08	4.50E-07	8.69E-07	3.20E-07	2.97E-06
Acetaldehyde	5.65E-08	1.10E-07	1.96E-06	2.89E-07	3.39E-06	5.59E-08	1.16E-07	1.08E-06	2.12E-07	2.43E-06
Benzene	1.49E-07	9.82E-07	6.79E-06	1.30E-06	1.18E-05	1.00E-07	1.13E-06	3.66E-06	8.25E-07	8.33E-06
Chromium VI	5.32E-07	9.43E-07	1.69E-07	7.18E-08	1.72E-06	6.67E-07	1.25E-06	2.29E-07	8.11E-08	2.23E-06
Formaldehyde	1.81E-10	4.51E-10	3.36E-09	1.11E-09	8.69E-09	2.10E-10	5.18E-10	1.35E-09	7.69E-10	6.43E-09
Naphthalene	1.21E-07	1.22E-06	6.38E-07	1.37E-07	2.11E-06	1.01E-07	1.46E-06	3.43E-07	1.39E-07	2.04E-06
Nickel	4.81E-08	9.79E-08	4.17E-09	6.20E-09	1.56E-07	5.53E-08	1.07E-07	5.65E-09	6.87E-09	1.75E-07
POM	1.77E-07	1.06E-06	1.05E-07	3.62E-08	1.38E-06	1.46E-07	1.25E-06	5.39E-08	3.25E-08	1.48E-06

	2020 annual average individual risk					2030 annual average individual risk				
Pollutant	**major**	**area & other**	**onroad**	**nonroad**	**total (including background)**	**major**	**area & other**	**onroad**	**nonroad**	**total (including background)**
1,3-Butadiene	4.95E-08	4.38E-07	8.92E-07	3.39E-07	3.00E-06	4.82E-08	4.19E-07	1.03E-06	3.86E-07	3.16E-06
Acetaldehyde	5.80E-08	1.19E-07	1.10E-06	2.08E-07	2.46E-06	5.75E-08	1.19E-07	1.28E-06	2.23E-07	2.65E-06
Benzene	1.09E-07	1.17E-06	3.71E-06	8.54E-07	8.45E-06	1.08E-07	1.16E-06	4.29E-06	9.59E-07	9.13E-06
Chromium VI	7.53E-07	1.40E-06	2.50E-07	8.34E-08	2.49E-06	7.48E-07	1.38E-06	3.05E-07	8.78E-08	2.52E-06
Formaldehyde	2.34E-10	5.47E-10	1.38E-09	7.63E-10	6.49E-09	2.28E-10	5.54E-10	1.59E-09	8.22E-10	6.76E-09
Naphthalene	1.12E-07	1.54E-06	3.39E-07	1.48E-07	2.14E-06	1.09E-07	1.52E-06	3.91E-07	1.69E-07	2.19E-06
Nickel	6.02E-08	1.16E-07	6.19E-09	7.10E-09	1.90E-07	6.01E-08	1.15E-07	7.55E-09	7.60E-09	1.90E-07
POM	1.61E-07	1.30E-06	5.54E-08	3.27E-08	1.55E-06	1.61E-07	1.31E-06	6.52E-08	3.59E-08	1.57E-06

Figure 3.2-4. Contributions to Average Inhalation Cancer Risk from Air Toxics Emitted by Mobile Sources, 2020 (Not Including Diesel PM and Diesel Exhaust Organic Gases), Without Controls in this Rule.

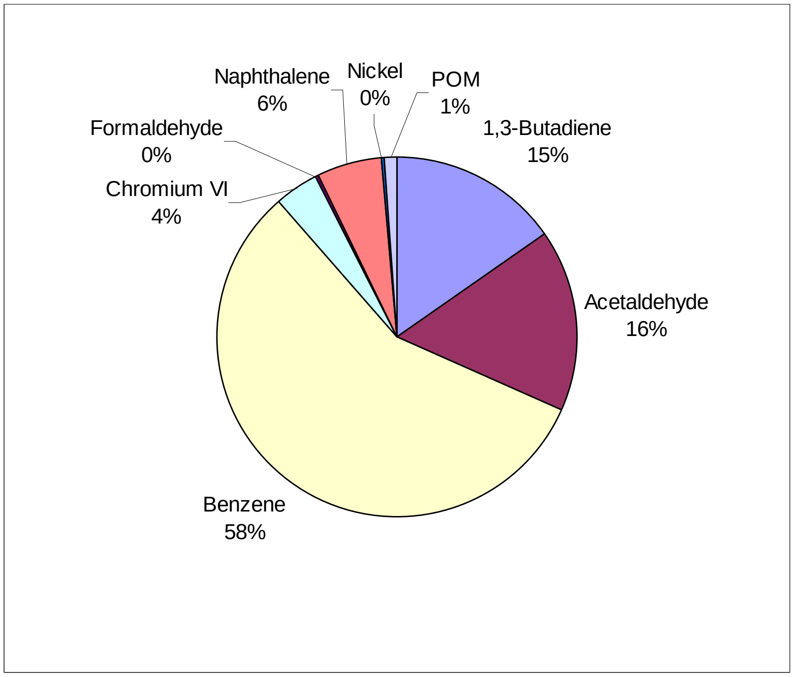
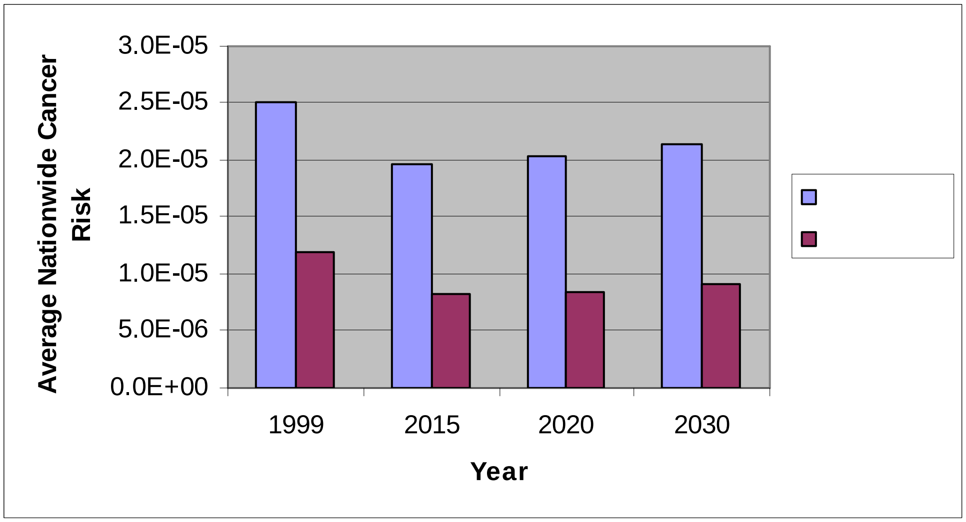
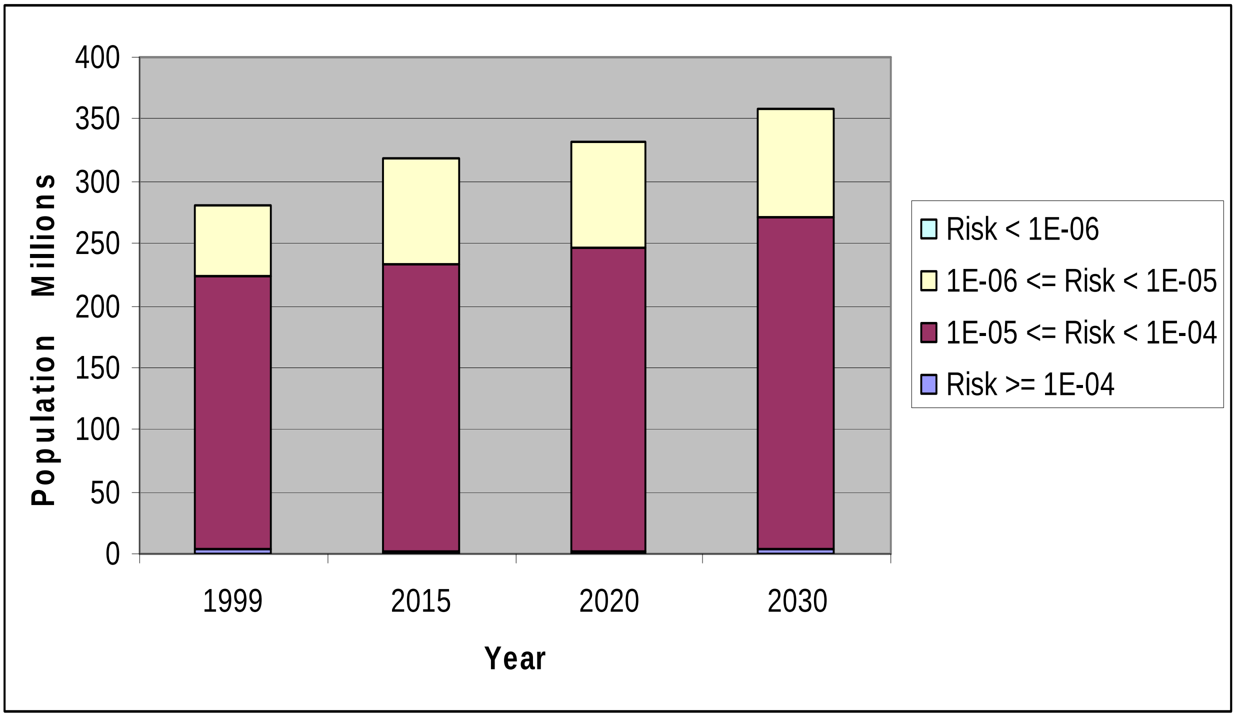


Figure 3.2-5. Average Nationwide Cancer Risk from Emissions of Mobile Source Air Toxics from both Mobile and Stationary Sources across Census Tracts, 1999 to 2030 (Not Including Diesel PM and Diesel Exhaust Organic Gases), Without Controls in this Rule.



It should also be noted that because of population growth projected to occur in the United States, the number of Americans above cancer risk benchmarks will increase. Figure 3.2-6 depicts the U. S. population at various risk benchmarks for mobile source air toxics in 1999, 2015, 2020, and 2030, using population projections from EPA's BenMAP model, a tool the EPA uses to estimate benefits of air pollution control strategies, and average census tract exposures. (BenMAP was recently used for EPA's Clean Air Interstate Air Quality Rule (CAIR),[160] and is also discussed in Chapter 12 of the RIA). These statistics do not include populations in Alaska and Hawaii; thus populations in these States were assumed to remain at year 2000 levels. More details on the methodology used to project the U. S. population above various cancer risk benchmarks are provided in the technical support document "National-Scale Modeling of Mobile Source Air Toxic Emissions, Air Quality, Exposure and Risk for the Final Mobile Source Air Toxics Rule." From Figure 3.2-6 it can be seen that, based on average census tract risks, the vast majority of the population experiences risks between one in a million ($1x10^{-6}$) and one in ten thousand ($1x10^{-4}$). However, the number of people experiencing risks above one in a hundred thousand ($1x10^{-5}$) increases from 223 million in 1999 to 272 million in 2030.

Figure 3.2-6. U. S. Population at Various Cancer Risk Benchmarks due to Exposure to Mobile Source Air Toxics, 1999 – 2030, Without Controls in this Rule.



Tables 3.2-10 and 3.2-11 summarize national average population hazard quotients for chronic non-cancer effects across census tracts for these years by pollutant, as well as the respiratory hazard index across pollutants. The respiratory system is the only target organ system where the hazard index exceeds one. Although the average respiratory hazard index for mobile source air toxics decreases by almost 33% between 1999 and 2030 (Figure 3.2-7), it is still over 4 in 2030, indicating a potential for adverse health effects. The reduction in hazard index occurs despite large increases in activity for highway and nonroad sources. In addition,

about 90% of this non-cancer risk is attributable to acrolein in all projection years. It should be noted that the confidence in the RfC for acrolein is medium. About 25% of primary acrolein emissions are from mobile sources, and about 70% of ambient concentrations of acrolein (and about 75% of exposure) are attributable to mobile sources. The mobile source contribution to concentrations and exposure is largely attributable to the contribution from mobile source 1,3-butadiene, which is transformed to acrolein in the atmosphere. Moreover, projected growth in the U. S. population and increasing vehicle miles traveled will increase the number of Americans with a respiratory hazard index for mobile source air toxics above one, from 258 million in 1999 to 307 million in 2030 (Figure 3.2-8).

Detailed summary tables presenting cancer risk, hazard quotients and hazard indices by State, and for reformulated and non-reformulated (i.e., conventional) gasoline areas, can be found in the docket for this rule, along with statistics on number of individuals above various cancer and non-cancer benchmarks, by source sector.

3.2.1.2.3 Distributions of Air Toxics Risk across the U. S.: Reference Case

Table 3.2-12 gives the distribution of nationwide individual cancer risks for mobile source air toxics in 2020, absent the controls being finalized in this rule. Summary tables providing distributions for other years, as well as distributions by State and for reformulated and non-reformulated gasoline areas, can be found in the docket for this rule. Risk distributions are broader than the distributions of ambient concentrations in Table 3.2-2. For instance, while the 95th percentile benzene concentration is about twice the median value, the 95th percentile cancer risk is roughly three times the median risk. A key reason for this is the variability in activity patterns, concentrations among microenvironments, and commuting patterns. Figures 3.2-9 through 3.2-12 depict the geographic distributions of median county cancer risks in 2020 for all mobile source air toxics, and separately for benzene, acetaldehyde and 1,3-butadiene. These geographic distributions closely track distributions of ambient concentrations, with the highest risks in major population centers of the country where mobile source activity is the greatest. Relatively high benzene risks are also seen in areas of the country where fuel benzene levels are higher, such as the Pacific Northwest, parts of Alaska, and the upper Great Lakes region, since higher fuel benzene levels lead to higher benzene emissions and higher exposures. Higher risks are also seen in States with colder winters, due to elevated cold start emissions.

Previously discussed changes to the HAPEM exposure model, to account for near road impacts, can impact distributions of risk. In order to evaluate the effect of switching to HAPEM6 from HAPEM5 on individual risks nationally, we conducted model runs using identical input data. Figure 3.2-13 depicts the national distribution of individual cancer risks from benzene, comparing HAPEM6 and HAPEM5. Note that the graph is on a logarithmic scale. As the graph illustrates, when HAPEM6 is used, there are fewer individuals with lower benzene cancer risk levels (e.g. $<1\text{x}10^{-6}$) in 1999. The population with higher benzene risk levels (e.g. $>1\text{x}10^{-4}$) is higher with HAPEM6 than HAPEM5. In general, the distribution of cancer risks shifts slightly higher when comparing HAPEM6 to HAPEM5, but the largest effects are observed in the populations with the highest and lowest risk levels, which are generally small fractions of the total population.

Table 3.2-13 gives the distribution of nationwide individual hazard quotients for acrolein, and hazard indices for the respiratory target system in 2020. Patterns for other years are similar. The average respiratory hazard index at the 95th percentile is over 20 times that at the 5th percentile, and about 4 times the median. Thus, some populations are experiencing much higher hazard indices than others. Figure 3.2-14 depicts the geographic distribution of median county respiratory hazard indices in 2020. The high hazard indices in Idaho are the result of high inventory estimates for wildfires and reflect a known error in the Idaho inventory for this source. This error was discovered at too late a date to produce and update emissions inventories for use in the analyses undertaken for this rule. The errors are not expected to affect the analyses of the impacts of controls undertaken for this rule.

Table 3.2-10. National Average Population Hazard Quotient for Chronic Noncancer Effects Across Census Tracts, 1999 – 2030, Without Controls in this Rule.

		1999 average Hazard Quotient					2015 average Hazard Quotient				
Pollutant	**Target System**	**major**	**area & other**	**onroad**	**nonroad**	**total (including background)**	**major**	**area & other**	**onroad**	**nonroad**	**total (including background)**
1,3-Butadiene	Reproductive	7.27E-04	8.08E-03	3.43E-02	8.98E-03	7.39E-02	7.69E-04	7.49E-03	1.45E-02	5.34E-03	4.96E-02
Acetaldehyde	Respiratory	2.86E-03	5.54E-03	9.92E-02	1.46E-02	1.71E-01	2.82E-03	5.84E-03	5.46E-02	1.07E-02	1.23E-01
Acrolein	Respiratory	1.44E-01	1.28E+00	3.70E+00	1.03E+00	6.16E+00	1.58E-01	1.13E+00	1.54E+00	8.10E-01	3.63E+00
Benzene	Immunological	6.35E-04	4.20E-03	2.90E-02	5.55E-03	5.06E-02	4.29E-04	4.83E-03	1.56E-02	3.53E-03	3.56E-02
Chromium VI	Respiratory	4.43E-04	7.86E-04	1.41E-04	5.98E-05	1.43E-03	5.56E-04	1.04E-03	1.90E-04	6.76E-05	1.86E-03
Ethyl Benzene	Developmental	1.60E-05	8.09E-05	3.60E-04	9.17E-05	5.48E-04	1.05E-05	1.05E-04	1.74E-04	5.30E-05	3.42E-04
Formaldehyde	Respiratory	3.36E-03	8.37E-03	6.23E-02	2.05E-02	1.61E-01	3.90E-03	9.62E-03	2.51E-02	1.43E-02	1.19E-01
Hexane	Neurological, Respiratory	2.76E-04	1.89E-03	1.55E-03	3.95E-04	4.11E-03	2.43E-04	2.21E-03	7.58E-04	2.71E-04	3.48E-03
MTBE	Liver, Kidney, Ocular	3.86E-06	1.76E-05	1.72E-04	1.28E-04	3.21E-04	3.94E-06	1.88E-05	4.43E-05	3.20E-05	9.90E-05
Manganese	Neurological	2.04E-02	1.93E-02	2.27E-04	4.59E-05	3.99E-02	2.65E-02	2.56E-02	3.07E-04	5.32E-05	5.24E-02
Naphthalene	Respiratory	1.19E-03	1.19E-02	6.25E-03	1.35E-03	2.07E-02	9.88E-04	1.43E-02	3.36E-03	1.36E-03	2.00E-02
Nickel	Respiratory, Immunological	4.62E-03	9.42E-03	4.01E-04	5.96E-04	1.50E-02	5.32E-03	1.03E-02	5.43E-04	6.61E-04	1.68E-02
Styrene	Neurological	2.38E-05	1.28E-05	3.77E-05	3.46E-06	7.78E-05	2.85E-05	1.76E-05	1.84E-05	2.05E-06	6.66E-05
Toluene	Respiratory, Neurological	4.55E-04	1.82E-03	5.96E-03	9.69E-04	9.20E-03	3.12E-04	2.39E-03	2.88E-03	5.72E-04	6.16E-03
Xylenes	Neurological	8.47E-04	5.00E-03	1.32E-02	3.72E-03	2.43E-02	6.85E-04	6.69E-03	6.38E-03	2.02E-03	1.72E-02

Table 3.2-10 (cont'd). National Average Population Hazard Quotient for Chronic Noncancer Effects Across Census Tracts, Without Controls in this Rule.

		2020 average Hazard Quotient					2030 average Hazard Quotient				
Pollutant	**Target System**	**major**	**area & other**	**onroad**	**nonroad**	**total (including background)**	**major**	**area & other**	**onroad**	**nonroad**	**total (including background)**
1,3-Butadiene	Reproductive	8.25E-04	7.30E-03	1.49E-02	5.64E-03	5.00E-02	8.03E-04	6.98E-03	1.72E-02	6.43E-03	5.26E-02
Acetaldehyde	Respiratory	2.93E-03	5.99E-03	5.58E-02	1.05E-02	1.24E-01	2.90E-03	6.02E-03	6.47E-02	1.13E-02	1.34E-01
Acrolein	Respiratory	1.78E-01	1.09E+00	1.57E+00	8.52E-01	3.69E+00	1.78E-01	1.08E+00	1.82E+00	9.62E-01	4.04E+00
Benzene	Immunological	4.67E-04	4.99E-03	1.58E-02	3.65E-03	3.61E-02	4.63E-04	4.96E-03	1.83E-02	4.10E-03	3.90E-02
Chromium VI	Respiratory	6.28E-04	1.17E-03	2.09E-04	6.95E-05	2.07E-03	6.23E-04	1.15E-03	2.54E-04	7.32E-05	2.10E-03
Ethyl Benzene	Developmental	1.17E-05	1.14E-04	1.72E-04	5.44E-05	3.52E-04	1.15E-05	1.12E-04	1.96E-04	6.09E-05	3.81E-04
Formaldehyde	Respiratory	4.34E-03	1.02E-02	2.55E-02	1.42E-02	1.20E-01	4.23E-03	1.03E-02	2.95E-02	1.53E-02	1.25E-01
Hexane	Neurological, Respiratory	2.66E-04	2.37E-03	6.92E-04	2.82E-04	3.61E-03	2.65E-04	2.32E-03	7.53E-04	3.17E-04	3.66E-03
MTBE	Liver, Kidney, Ocular	4.36E-06	1.91E-05	3.53E-05	3.28E-05	9.16E-05	4.26E-06	1.90E-05	3.44E-05	3.62E-05	9.38E-05
Manganese	Neurological	2.99E-02	2.80E-02	3.37E-04	5.59E-05	5.83E-02	3.08E-02	2.81E-02	4.11E-04	6.15E-05	5.94E-02
Naphthalene	Respiratory	1.09E-03	1.51E-02	3.33E-03	1.45E-03	2.10E-02	1.07E-03	1.49E-02	3.83E-03	1.65E-03	2.14E-02
Nickel	Respiratory, Immunological	5.78E-03	1.12E-02	5.95E-04	6.83E-04	1.83E-02	5.78E-03	1.10E-02	7.26E-04	7.30E-04	1.83E-02
Styrene	Neurological	3.29E-05	1.96E-05	1.90E-05	2.09E-06	7.36E-05	3.32E-05	1.97E-05	2.22E-05	2.32E-06	7.74E-05
Toluene	Respiratory, Neurological	3.47E-04	2.63E-03	2.89E-03	5.78E-04	6.45E-03	3.44E-04	2.63E-03	3.32E-03	6.37E-04	6.93E-03
Xylenes	Neurological	7.69E-04	7.35E-03	6.39E-03	2.04E-03	1.80E-02	7.59E-04	7.26E-03	7.33E-03	2.25E-03	1.90E-02

Table 3.2-11. National Respiratory Hazard Index for Chronic Noncancer Effects across Census Tracts, Without Controls in this Rule.

Respiratory System Average Hazard Index						
Year	background	major	area & other	onroad	nonroad	total (including background)
1999	0.12	0.16	1.32	3.88	1.07	6.54
2015	0.12	0.17	1.17	1.63	0.84	3.92
2020	0.12	0.19	1.14	1.66	0.88	3.99
2030	0.11	0.19	1.13	1.92	0.99	4.35

Figure 3.2-7. Average Respiratory Hazard Index for U.S. Population (Aggregate of Hazard Quotients for Individual Pollutants), Without Controls in this Rule.

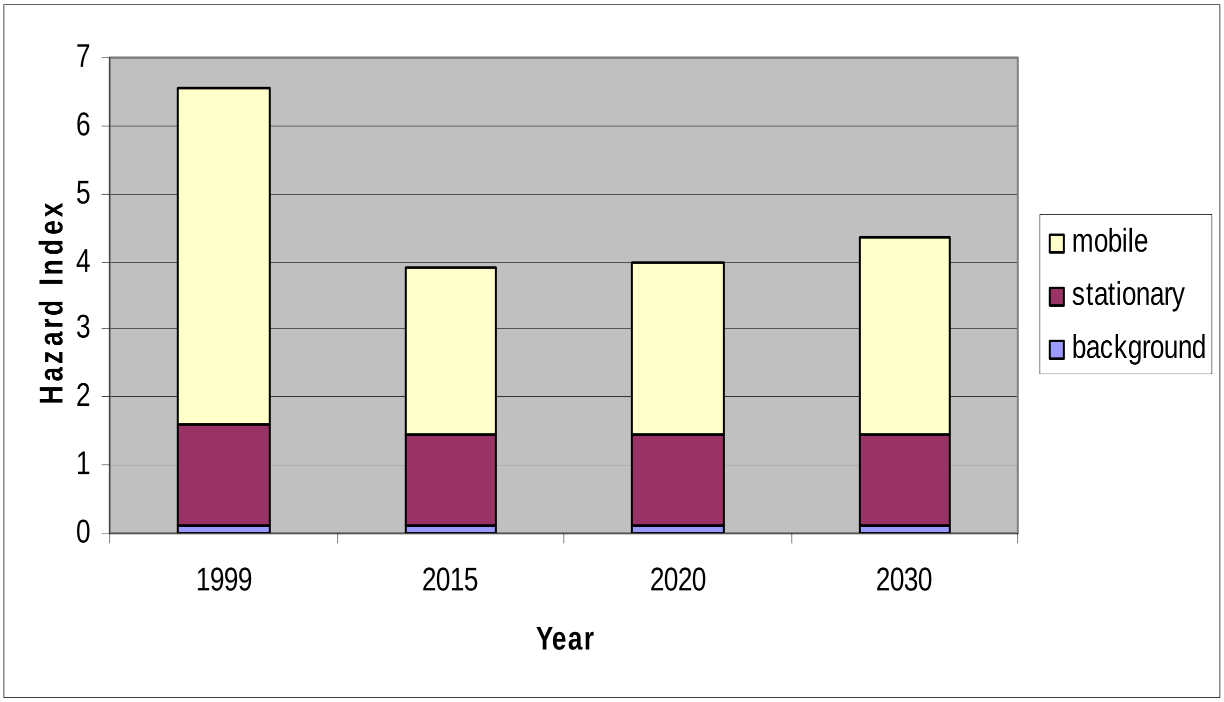


Figure 3.2-8. U. S. Population at Various Non-Cancer Hazard Benchmarks due to Exposure to Mobile Source Air Toxics, 1999 – 2030, Without Controls in this Rule.

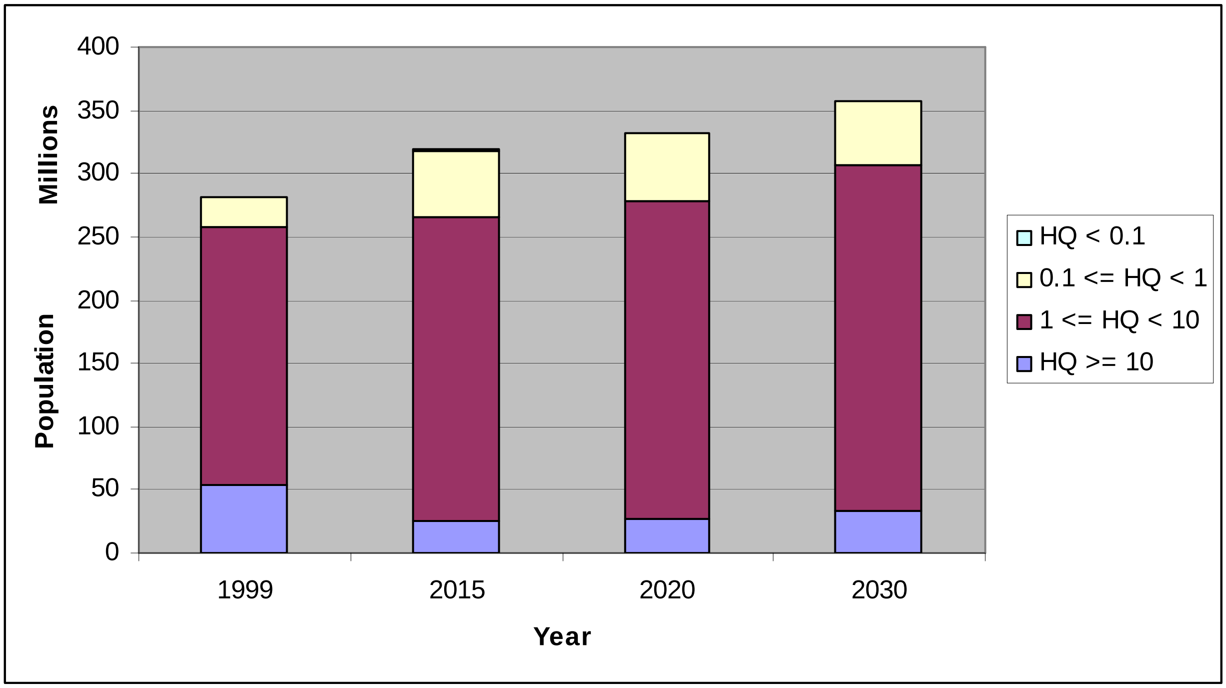


Table 3.2-12. Distribution of Individual Cancer Risks for Mobile Source Air Toxics in 2020, Without Controls in this Rule.

	2020 risk distribution						
Pollutant	5th percentile	10th percentile	25th percentile	Median	75th percentile		95th percentile
Total Risk: All HAPs	4.71E-06	6.08E-06	9.78E-06	1.53E-05	2.37E-05	3.79E-05	4.93E-05
1,3-Butadiene	1.52E-07	2.96E-07	1.06E-06	2.30E-06	3.60E-06	5.47E-06	7.70E-06
Acetaldehyde	1.09E-06	1.19E-06	1.46E-06	1.96E-06	2.81E-06	4.20E-06	5.35E-06
Benzene	2.72E-06	3.36E-06	4.84E-06	6.93E-06	1.00E-05	1.48E-05	1.86E-05
Chromium VI	3.85E-08	7.93E-08	2.38E-07	7.01E-07	1.81E-06	4.54E-06	7.29E-06
Formaldehyde	2.29E-09	2.89E-09	4.12E-09	5.75E-09	7.67E-09	1.05E-08	1.29E-08
Naphthalene	1.59E-07	2.80E-07	6.72E-07	1.39E-06	2.61E-06	4.73E-06	6.68E-06
Nickel	1.84E-09	4.09E-09	1.39E-08	4.60E-08	1.31E-07	3.04E-07	5.06E-07
POM	1.26E-07	1.90E-07	3.48E-07	6.78E-07	1.19E-06	1.99E-06	3.07E-06

Figure 3.2-9. 2020 County Median Cancer Risk for All Mobile Source Air Toxics, Without Controls in this Rule.

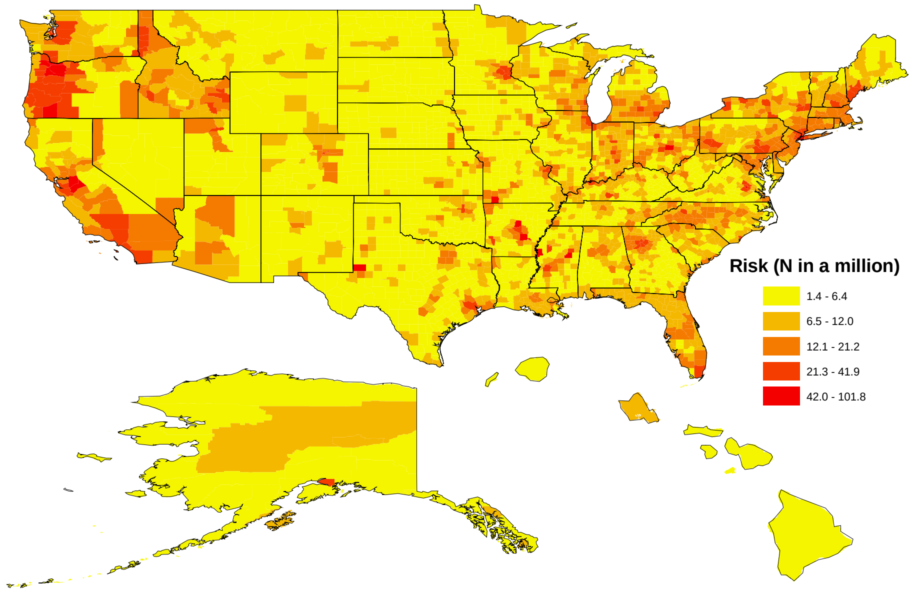


Figure 3.2-10. 2020 County Median Cancer Risk for Benzene, Without Controls in this Rule.

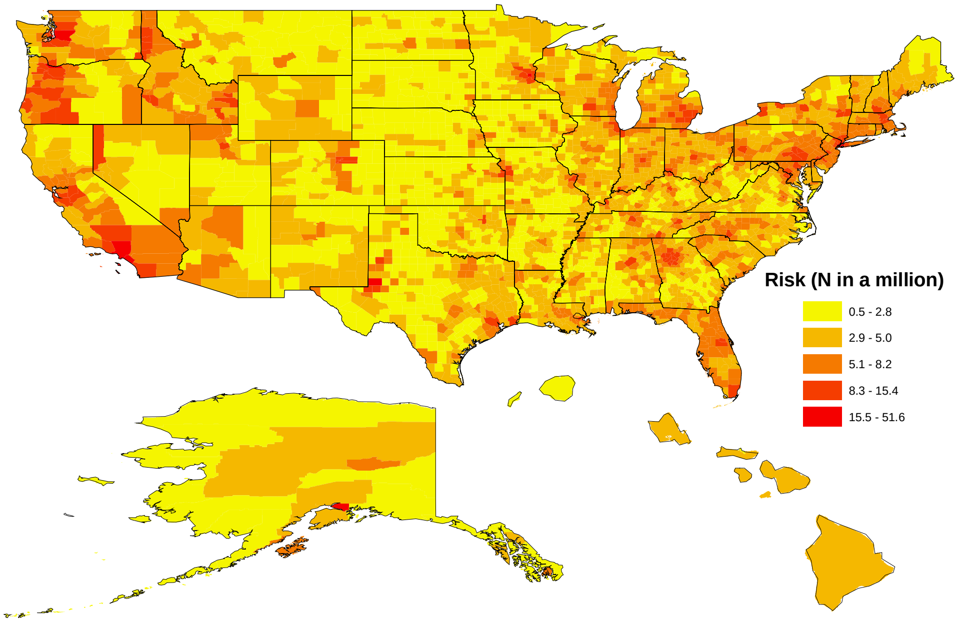


Figure 3.2-11. 2020 County Median Cancer Risk for Acetaldehyde, Without Controls in this Rule.

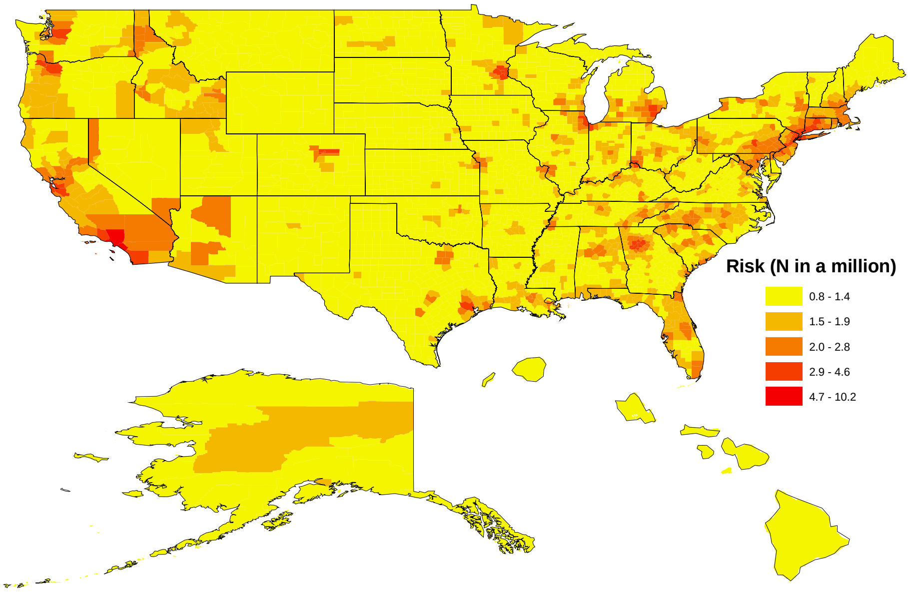


Figure 3.2-12. 2020 County Median Cancer Risk for 1,3-Butadiene, Without Controls in this Rule.

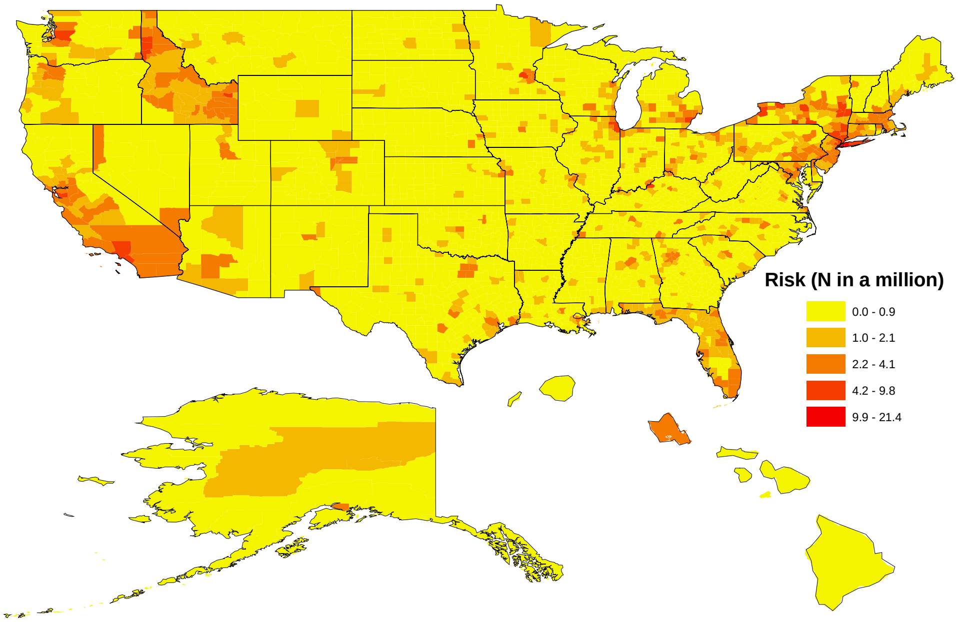


Figure 3.2-13. 1999 Comparison Between HAPEM6 and HAPEM5 Nationwide Individual Benzene Cancer Risk, Without Controls in this Rule.

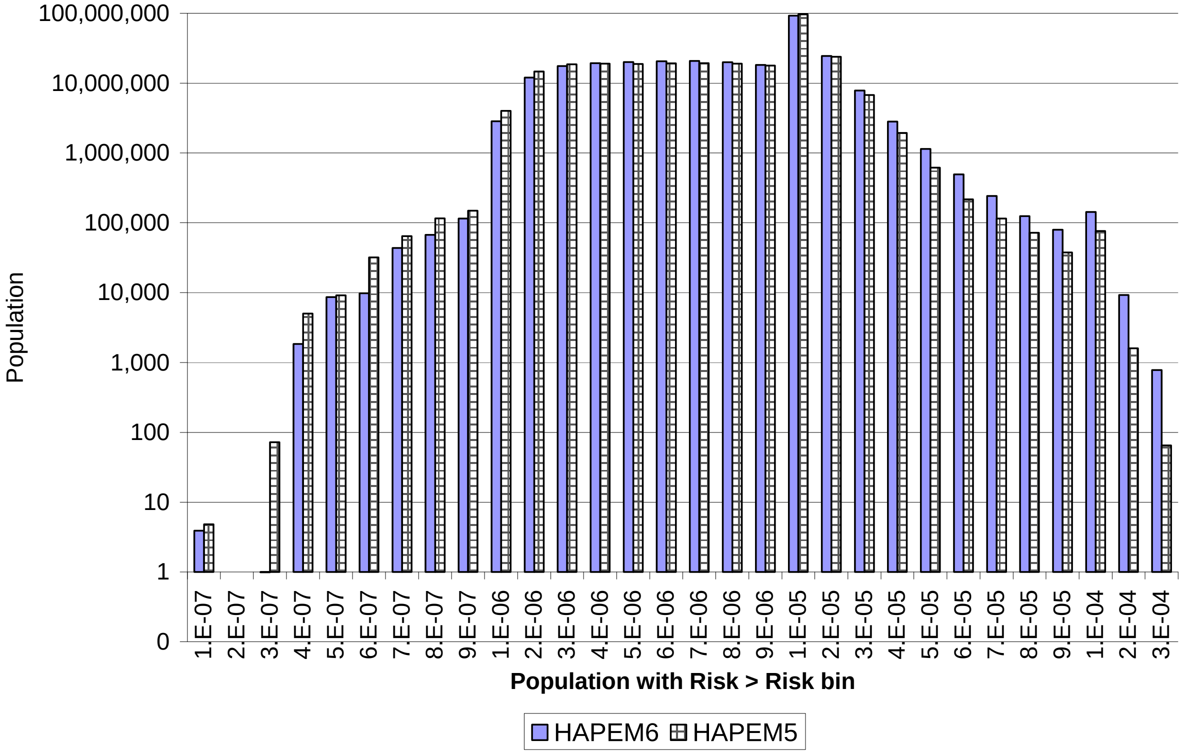
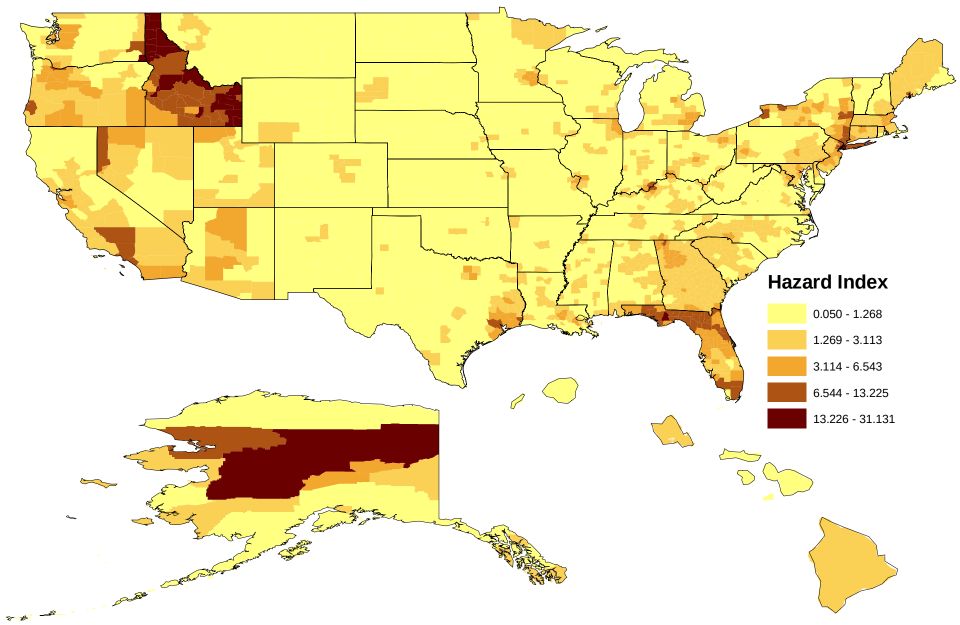


Table 3.2-13. Distribution of Individual Hazard Quotients/Hazard Indices for Mobile Source Air Toxics (from both Mobile and Stationary Sources) in 2020, Without Controls in this Rule.

	2020 average Hazard Quotient or Hazard Index						
Pollutant	5th percentile	10th percentile	25th percentile	Median	75th percentile	90th percentile	95th percentile
Acrolein	0.41	0.61	1.18	2.31	4.47	8.05	11.3
Respiratory System	0.53	0.75	1.36	2.57	4.83	8.54	11.9

Figure 3.2-14. 2020 County Median Non-Cancer Hazard Index Respiratory Mobile Source Air Toxics, Without Controls in this Rule.



3.2.1.2.4 Impacts of Controls on Average Inhalation Cancer Risks and Noncancer Hazards

The standards being finalized in this rule will substantially reduce inhalation cancer and noncancer risk from exposure to air toxics emitted by mobile sources across the United States. Table 3.2-14 shows that in 2030, the highway vehicle contribution to MSAT cancer risk will be reduced on average 36% across the U.S., and the nonroad equipment contribution will be reduced about 6%. In 2030, the highway vehicle contribution to benzene cancer risk will be reduced on average by 43% across the U.S., and the nonroad contribution will be reduced by 11%. Table 3.2-15 summarizes the change in median and 95th percentile inhalation cancer risks from benzene and all MSATs attributable to all outdoor sources in 2015, 2020, and 2030, with the controls being finalized in this rule. Reductions are significantly larger for individuals in the 95th percentile than in the 50th percentile. Thus, this rule is providing bigger benefits to individuals experiencing the highest levels of risk. In states with high fuel benzene levels and high cold start emissions, the cancer risk reduction from total MSATs is about 40% or higher (Table 3.2-16).[d] Figure 3.2-15 depicts the impact on the mobile source contribution to nationwide average population cancer risk from all MSATs and benzene in 2030. Nationwide, the cancer risk attributable to total MSATs would be reduced by 30%, and the risk from mobile source benzene would be reduced by 37%. Figures 3.2-16 and 3.2.-17 present the distribution of percent reductions in average MSAT and benzene cancer risk, respectively, from all sources in 2030 with the controls being finalized in 2030. Table 3.2-17 shows reductions in hazard quotients and hazard indices for acrolein and respiratory effects, respectively. Nationwide, the mobile source contribution to the acrolein hazard quotient and respiratory hazard index would both be reduced about 23%, and the highway vehicle contribution will be reduced about 35%. Summary tables providing exposure and risk data by State, as well as maps of cancer risks and noncancer hazards with controls and percent reductions with controls, can be found in the docket for the rule.

It should be noted that the estimated total relative reductions are significant underestimates, since we could not account for further reductions in emissions from transport, i.e., background sources. In Section 3.2.1.4, we provide a quantitative estimate of the expected reductions in background concentrations in future years. Again, as noted previously, since this modeling did not include the 1.3 vol% maximum average fuel benzene level, reductions in risk for some parts of the country, such as the Pacific Northwest, are underestimated.

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[d] Reductions are likely to be higher than estimated by this modeling, due to the 1.3% maximum average fuel benzene level.

Table 3.2-14. Contributions of Source Sectors to Nationwide Average Cumulative MSAT Cancer Risk, With and Without Controls, 2015, 2020, and 2030

	2015 Average Risks					2020 Average Risks					2030 Average Risks				
	major	area & other	total onroad	total nonroad	total (including background)	major	area & other	total onroad	total nonroad	total (including background)	major	area & other	total onroad	total nonroad	total (including background)
Total MSATs															
Reference	1.17E-06	5.76E-06	6.24E-06	1.62E-06	1.97E-05	1.30E-06	6.08E-06	6.35E-06	1.67E-06	2.03E-05	1.29E-06	6.02E-06	7.37E-06	1.87E-06	2.14E-05
Control	1.17E-06	5.74E-06	4.98E-06	1.53E-06	1.83E-05	1.30E-06	6.06E-06	4.58E-06	1.58E-06	1.84E-05	1.29E-06	6.01E-06	4.69E-06	1.77E-06	1.86E-05
% Difference	0.0	0.3	20.2	5.3	6.9	0.0	0.3	27.9	5.5	9.3	0.0	0.3	36.3	5.6	13.1
Benzene															
Reference	1.00E-07	1.13E-06	3.66E-06	8.25E-07	8.33E-06	1.09E-07	1.17E-06	3.71E-06	8.54E-07	8.45E-06	1.08E-07	1.16E-06	4.29E-06	9.59E-07	9.13E-06
Control	1.00E-07	1.12E-06	2.73E-06	7.38E-07	7.30E-06	1.09E-07	1.15E-06	2.45E-06	7.62E-07	7.09E-06	1.08E-07	1.15E-06	2.43E-06	8.54E-07	7.15E-06
% Difference	0.3	1.3	25.4	10.5	12.3	0.3	1.3	34.0	10.8	16.2	0.3	1.3	43.4	10.9	21.7

Table 3.2-15. Change in Median and 95th Percentile Inhalation Cancer Risk from Benzene and all MSATs Attributable to Outdoor Sources in 2015, 2020, and 2030 with the Controls Being Finalized in this Rule.

	2015		2020		2030	
	median	95th	median	95th	median	95th
All MSATs						
Without Controls	$1.50\text{x}10^{-5}$	$4.75\text{x}10^{-5}$	$1.53\text{x}10^{-5}$	$4.93\text{x}10^{-5}$	$1.61\text{x}10^{-5}$	$5.28\text{x}10^{-5}$
With Controls	$1.41\text{x}10^{-5}$	$4.37\text{x}10^{-5}$	$1.40\text{x}10^{-5}$	$4.40\text{x}10^{-5}$	$1.42\text{x}10^{-5}$	$4.49\text{x}10^{-5}$
Percent Change	6	8	8	11	12	15
Benzene						
Without Controls	$6.86\text{x}10^{-6}$	$1.82\text{x}10^{-5}$	$6.93\text{x}10^{-6}$	$1.86\text{x}10^{-5}$	$7.37\text{x}10^{-6}$	$2.06\text{x}10^{-5}$
With Controls	$6.17\text{x}10^{-6}$	$1.53\text{x}10^{-5}$	$6.02\text{x}10^{-6}$	$1.47\text{x}10^{-5}$	$6.06\text{x}10^{-6}$	$1.49\text{x}10^{-5}$
Percent Change	10	16	13	21	18	28

Table 3.2-16. States with Highest Reductions in Average Benzene Cancer Risk Resulting from Mobile Source Emissions, 2030.

State	Average Risk – Reference Case	Average Risk – Control Case	Percent Difference
Alaska	$1.01\text{x}10^{-5}$	$4.23\text{x}10^{-6}$	-58%
North Dakota	$2.92\text{x}10^{-6}$	$1.68\text{x}10^{-6}$	-42
Washington	$1.39\text{x}10^{-5}$	$8.10\text{x}10^{-6}$	-42
Minnesota	$1.21\text{x}10^{-5}$	$7.08\text{x}10^{-6}$	-42
Wyoming	$2.38\text{x}10^{-6}$	$1.39\text{x}10^{-6}$	-41
Montana	$3.12\text{x}10^{-6}$	$1.87\text{x}10^{-6}$	-40
Idaho	$5.03\text{x}10^{-6}$	$3.02\text{x}10^{-6}$	-40
Michigan	$1.09\text{x}10^{-5}$	$6.55\text{x}10^{-6}$	-40
South Dakota	$2.73\text{x}10^{-6}$	$1.66\text{x}10^{-6}$	-39
Oregon	$1.01\text{x}10^{-5}$	$6.17\text{x}10^{-6}$	-39

Figure 3.2-15. Contribution to Nationwide Average Population Cancer Risk from Mobile Source MSATs and Benzene Emitted by Mobile Sources in 2030, Without and With Controls in this Rule.

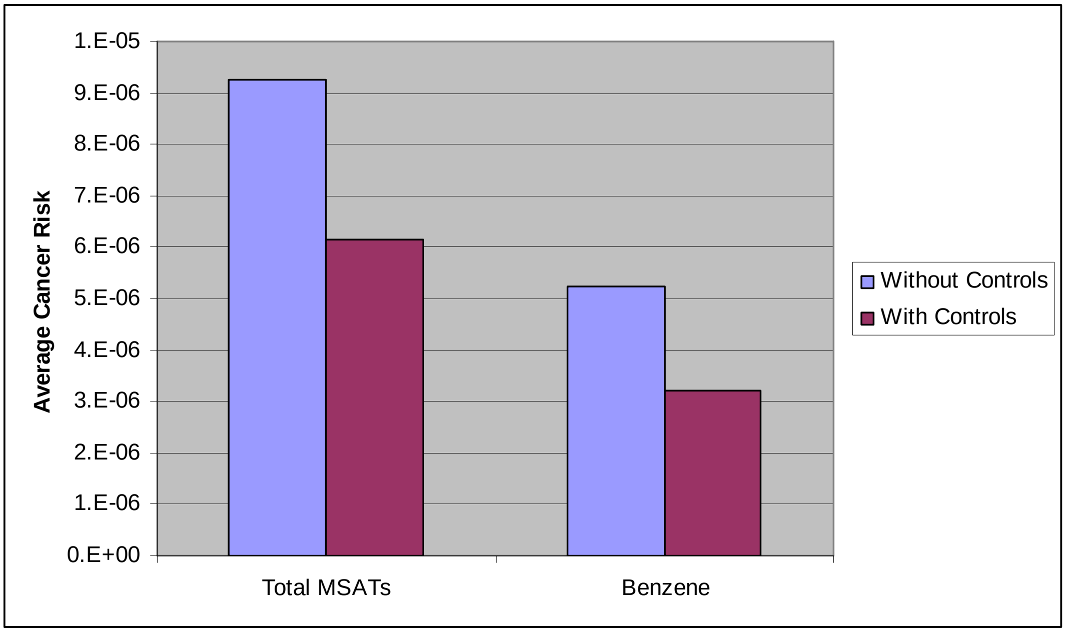


Figure 3.2-16. Distribution of Percent Reductions in Median MSAT Cancer Risk, 2030, for U.S. Counties with Controls in this Rule.

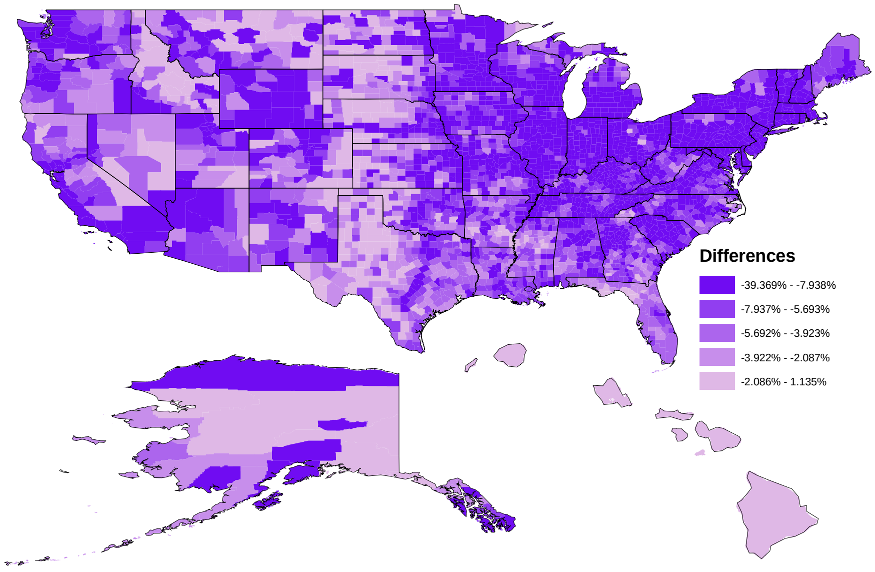
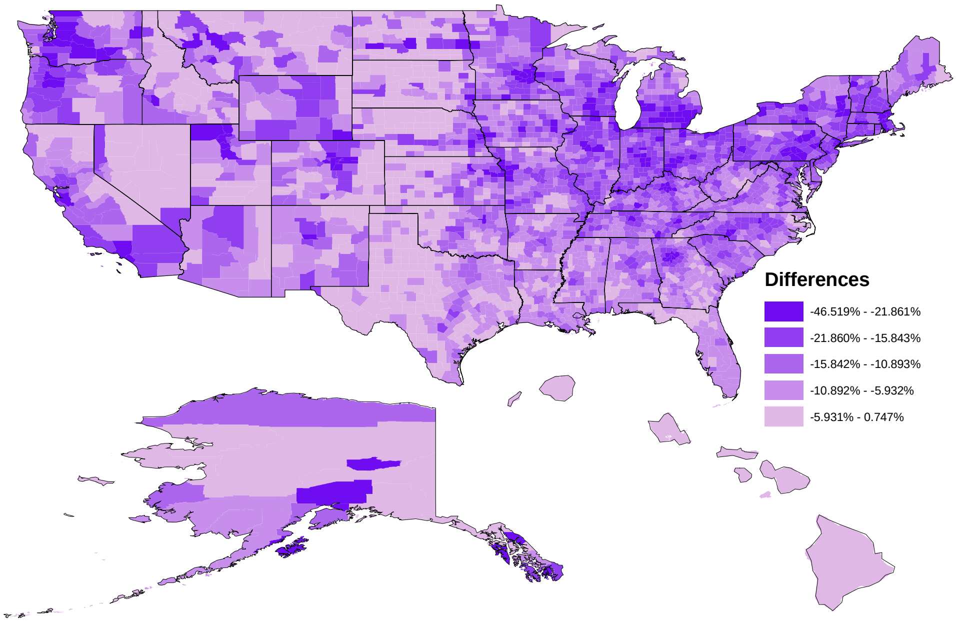


Figure 3.2-17. Distribution of Percent Reductions in Median Benzene Cancer Risk, 2030, for U.S. Counties With Controls in this Rule.



As a result of the controls being finalized in this rule, the number of people above the 1 in 100,000 cancer risk level due to exposure to all mobile source air toxics from all sources will decrease by over 11 million in 2020 and by about 17 million in 2030. The number of people above the 1 in 100,000 increased cancer risk level from exposure to benzene from all sources decreases by about 30 million in 2020 and 46 million in 2030 (Table 3.2-18).

Table 3.2.-17. Reductions in Hazard Quotients and Hazard Indices for Acrolein and Respiratory Effects Due to MSAT Controls.

2015 Average Hazard Index/Quotient				2020 Average Hazard Index/Quotient					2030 Average Hazard Index/Quotient				
area & other	total onroad	total nonroad	total (including background)	major	area & other	total onroad	total nonroad	total (including background)	major	area & other	total onroad	total nonroad	total (including background)
1.17	1.63	0.84	3.92	0.19	1.14	1.66	0.88	3.99	0.19	1.13	1.92	0.99	4.35
1.17	1.35	0.84	3.65	0.19	1.14	1.24	0.88	3.56	0.19	1.13	1.24	0.99	3.67
0.0	16.7	0.0	6.9	0.0	0.0	25.6	0.0	10.7	0.0	0.0	35.4	0.0	15.6
1.13	1.54	0.81	3.63	0.18	1.09	1.57	0.85	3.69	0.18	1.08	1.82	0.96	4.04

Table 3.2-18. Decrease in Number of People with Inhalation Exposure above the 1 in 100,000 Cancer Risk Level due to Inhalation Exposure from Ambient Sources, With Controls in this Rule.

Year	Benzene	All Mobile Source Air Toxics
2015	21,697,000	8,149,000
2020	30,031,000	11,257,000
2030	46,360,000	16,737,000

The standards being finalized will also impact on the number of people above various respiratory hazard index levels (Table 3.2-19).

Table 3.2-19. Decrease in Number of People with Inhalation Exposure above a Respiratory Hazard Index of One due to Inhalation Exposure from Ambient Sources, With Controls in this Rule.

Year	Decrease in Population with Respiratory HI > 1
2015	5,639,000
2020	10,227,000
2030	16,919,000

3.2.1.3 Strengths and Limitations

Air quality, exposure, and risk were assessed using the best available suite of tools for national-scale analysis of air toxics. The same general suite of tools was used in 1996 and 1999 NATA. The 1996 NATA was reviewed by EPA's Science Advisory Board, and the analyses done for 1999 incorporate several changes in response to comments made in this peer review. Among the improvements were:

- Improved emission inventory with detailed characterization of source categories within the onroad and nonroad source sectors and more speciated data for some pollutant groups (POM) within particular source categories.
- Speciation of chromium to hexavalent form based on emission sources rather than a single number applied across all sources
- Improved surrogates for spatial allocation in EMS-HAP.
- Improved estimation of "background" concentrations for many pollutants. These background levels were previously uniform across the country. Now, for many pollutants, background levels are based on recent monitor data and spatially vary depending on county population density.[161]
- Improved version of HAPEM, which includes more recent census data, commuting algorithms and better characterization of exposure distributions through improvements in modeling long-term activity patterns and variability in concentration levels in microenvironments.

In addition to the improvements for the 1999 NATA, improvements were made in analyses for this rule, including inventory improvements and updates to HAPEM discussed earlier.

The SAB expressed their belief that due to the limitations inherent in the analysis, the 1996 NATA should not be used to support regulatory action. However, the use of the improved analyses in this rule does provide useful insight on the nature of the mobile source air toxics problem and the possible public health improvements associated with this rule.

In addition to the strengths listed above, there are limitations due to uncertainty. The inventory uncertainties are discussed in Chapter 2. There are a number of additional significant uncertainties associated with the air quality, exposure and risk modeling. These uncertainties result from a number of parameters including: development of county-level estimates from broader geographic data (i.e., state, regional or national), surrogates used to allocate emissions to census tracts, parameters used to characterize photochemical processes, long range transport, terrain effects, deposition rates, human activity pattern parameters, assumptions about relationships between ambient levels in different microenvironments, and dose-response parameters. Uncertainties in dose-response parameters are discussed in Chapter 1 of the RIA. The modeling also has certain key limitations: results are most accurate for large geographic areas, exposure modeling does not fully reflect variation among individuals, non-inhalation exposure pathways and indoor sources are not accounted for; and for some pollutants, the ASPEN dispersion model may underestimate concentrations. Also, the 1999 NATA does not include default adjustments for early life exposures recently recommended in the Supplemental Guidance for Assessing Susceptibility from Early-Life Exposure to Carcinogens.[162] If warranted, incorporation of such adjustments would lead to higher estimates of lifetime risk. EPA will determine as part of the IRIS assessment process which substances meet the criteria for making adjustments, and future assessments will reflect them.

As part of the 1999 NATA, EPA compared ASPEN-modeled concentrations with available, but geographically limited, ambient air quality monitoring data for 1999. For each monitor-pollutant combination, EPA compared the annual average concentration estimated by the ASPEN model at the exact geographical coordinates of the monitor location with the annual average monitored value to get a point-to-point comparison between the model and monitor concentrations. The agreement between model and monitor values for benzene was very good, with a median model to monitor ratio of 0.95, and 74% of sites within a factor of 2. Agreement for acetaldehyde was almost as good as benzene, but data suggest that ASPEN could be underpredicting for other mobile source air toxics (see Table 3.2-20).

More detailed discussion of modeling limitations and uncertainties can be found on the 1999 NATA website.

Table 3.2-20. Agreement of 1999 Model and Monitors by Pollutant on a Point-to-Point Basis Pollutants listed were Monitored in at least 30 Sites and in a Broad Geographical Area (Several States)

Pollutant	No. of Sites	Median of Ratios	Within Factor of 2	Within 30%	Underestimated
Acetaldehyde	68	0.92	74%	44%	56%
Benzene	115	0.95	72%	43%	52%
Formaldehyde	68	0.64	60%	28%	76%
Chromium	42	0.29	26%	5%	95%
Manganese	34	0.4	44%	15%	91%
Nickel	40	0.53	48%	18%	75%

In addition to the limitations and uncertainties associated with modeling the 1999 base year, there are additional ones in the projection year modeling. For instance, the modeling is not accounting for impacts of demographic shifts that are likely to occur in the future. Assumptions about future-year meteorology introduce additional uncertainty in ambient concentrations and resulting exposures. Another limitation is the use of 1999 “background” levels to account for mid-range to long-range transport. However, since background is related to emissions far away from receptors, these levels should decrease as those emissions decrease. For the proposed rule we performed a sensitivity analysis for benzene, formaldehyde, acetaldehyde and 1,3-butadiene to evaluate the potential bias introduced by this assumption. We used background estimates scaled by the change in the proposed rule inventory for a future year relative to 1999. The scaling factors applied to the background level for an individual county were based on emissions for counties within 300 kilometers of that county’s centroid. Our analysis indicated that using a scaled background reduced benzene concentrations about 15% on average across the U. S in 2015, 2020, and 2030. Table 3.2-21 compares national average total concentrations from the proposed rule using 1999 versus scaled backgrounds. More details are provided in the technical support document for the proposed rule.[163]

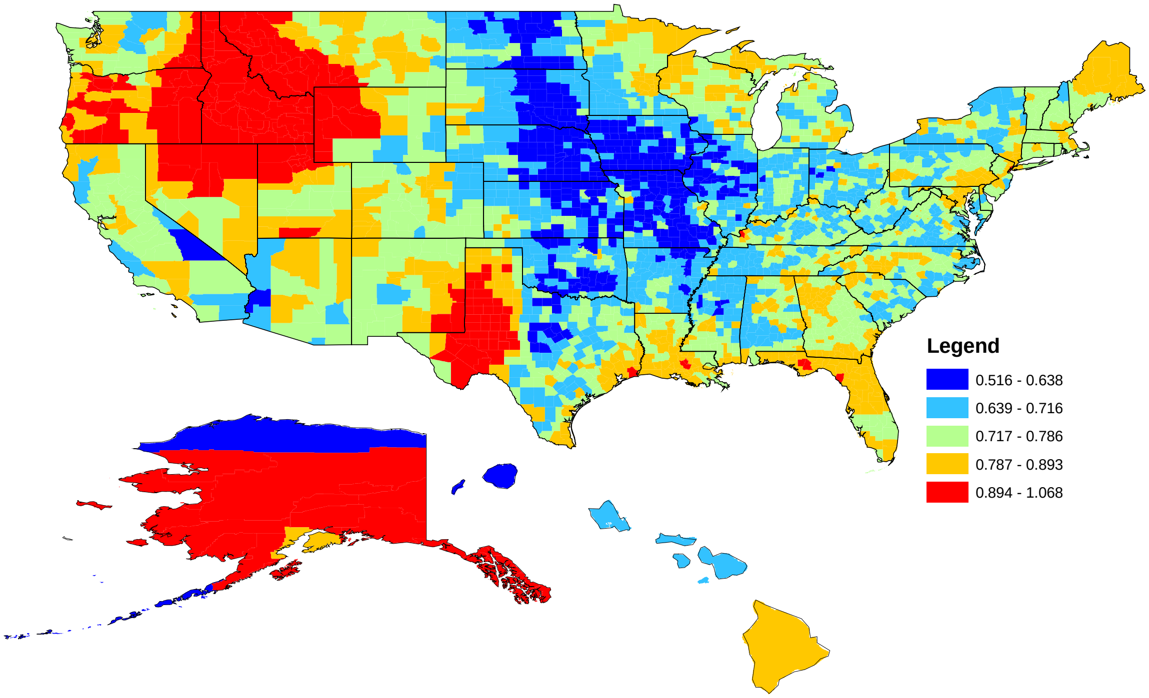
Table 3.2-21. National Average Total Concentrations (All Sources and Background) for 2015, 2020, and 2030 using both the 1999 Background and the Scaled Backgrounds (Data from Proposed Rule).

HAP	Total Concentrations ($\mu g\ m^{-3}$) using 1999 Background			Total Concentrations ($\mu g\ m^{-3}$) using Scaled Concentrations		
	2015	2020	2030	2015	2020	2030
1,3-Butadiene	9.81×10^{-2}	9.77×10^{-2}	1.00×10^{-1}	7.57×10^{-2}	7.50×10^{-2}	7.86×10^{-2}
Acetaldehyde	9.66×10^{-1}	9.36×10^{-1}	9.56×10^{-1}	7.77×10^{-1}	7.47×10^{-1}	7.78×10^{-1}
Benzene	9.13×10^{-1}	9.02×10^{-1}	9.24×10^{-1}	7.57×10^{-1}	7.40×10^{-1}	7.71×10^{-1}
Formaldehyde	1.22	1.22	1.25	9.56×10^{-1}	9.68×10^{-1}	1.01
Xylenes	1.55	1.61	1.65	1.50	1.56	1.60

The largest impacts were in the Midwest as can be seen in Figure 3.2-19, which depicts ratios of the ASPEN-modeled ambient benzene concentrations with an adjusted background versus the 1999 background in 2020. Data tables with results of the sensitivity comparison by U. S. County, along with maps of pollutant concentrations with and without an adjusted background can be found in the docket for the rule.

While accounting for impacts of emission reductions on background levels would reduce estimated population risks, it would increase estimated reductions in risk of control strategies in a given year, since background levels would be reduced. Also, if the modeling accounted for equipment and fuels in attached garages and increased risks from early lifetime exposures, estimated risks and risk reductions from fuel benzene control would be larger.

Figure 3.2-19. Ratios of Benzene Concentrations with and without an Adjusted Background, 2020 (from modeling done to support proposed rule).



3.2.1.4. Perspective on Cancer Cases

We have not quantified the cancer-related health benefits of expected MSAT reductions in terms of avoided cancer cases or dollars. The EPA Science Advisory Board (SAB) specifically commented in their review of the 1996 National Air Toxics Assessment (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.[164] While EPA has since improved many of these tools, there remain critical limitations for estimating cancer incidence. For the MSATs of greatest concern, for example, we are currently unable to estimate cessation lag, which is the time between reduction in exposure and decline in risk to "steady state level."[165] We have also not resolved the analytical challenges associated with quantifying partial lifetime probabilities of cancer for different age groups or estimating changes in survival rates over time. Indeed, some of these issues are likely to remain highly uncertain for the foreseeable future.

We can, however, present some perspective on how average individual risks could translate into cumulative excess cancer cases across the U.S. population over a lifetime, assuming continuous exposure at a given level for 70 years. Cancer cases were estimated by summing the distribution of individual cancer risks from the national-scale modeling done to support this rule.

To estimate annual incidence, this would be divided by 70. However, without knowing when within a lifetime cancer is more likely to occur, and without accounting for time-varying exposure, any estimate of incidence for a given calendar year is highly uncertain. We also note that a proper calculation would entail the use of a life table of incidence rates within discrete age ranges and a dose-response formulation expressing rate ratios as a function of benzene inhalation exposure concentration.

In 2030, the cumulative excess average individual cancer risk from outdoor emissions of mobile source air toxics is estimated at $2.1\text{x}10^{-5}$. If the entire U. S. population (projected to be about 364 million)[166] were exposed to this level of risk over a 70-year lifetime, it would result in about 7700 cancer cases, which translates into 110 annual cancer cases.

In its review of the 1996 NATA, SAB recommended that if cancer cases were calculated for benefits assessment, a "best estimate" of risk (rather than an upper bound), should be used. We believe that the maximum likelihood unit risk range for benzene represents a best estimate. In our analyses, we have used the upper end of this range, as did the 1999 NATA. If we used the lower end of this range, incidence estimates would be lower by a factor of about 3.5. Following is a discussion related to benzene specifically, including a discussion of the potential implications of the limitations of our national-scale modeling, which were noted in Section 3.2.1.4.

In 2030, the national average inhalation individual cancer risk from outdoor mobile and stationary sources of benzene, in the absence of the standards being finalized in this rule, is estimated at approximately $9.1\text{x}10^{-6}$, based on the modeling done for this rule. If the entire U. S. population were exposed to that level of risk over a 70-year lifetime, it would result in approximately 47 excess cancer cases per year (Equation 1).

$$
\begin{aligned}
&(1)\ \textit{Excess Cancer Cases at } 2030 \textit{ Exposure Level} = \\
&(\textit{Average Individual Cancer Risk}) \times (2030 \textit{ Population}) \\
&\quad = 9.1 \times 10^{-6} \ \times 3.64 \times 10^{8} \approx 3300 \\
&\quad \textit{Annual Cancer Cases} = 3300 / 70 = 47
\end{aligned}
$$

As discussed in Section 3.1.3.3, EPA's estimate of risk due to exposure to benzene could increase significantly if the influence of attached garages were included. When the exposures for people with attached garages are averaged across the population, time-weighted average individual exposures to benzene could increase by roughly 1.2 to 6.6 $\mu\text{g/m}^3$ (Appendix 3A). There is a great deal of uncertainty associated with these estimates. This could result in about another 3400 to 18700 excess cancer cases (equation 3). The numerical ranges expressed here may not fully address all sources of uncertainty involved in making these projections.

$$
\begin{aligned}
&(3)\ \textit{Attached Garage Excess Cancer Cases} = \\
&(\textit{Average Exposure})\ x\ (\textit{Benzene URE}) \times (\textit{Population}) \\
&= (1.2 - 6.6\ \mu g / m^3)\ x\ (7.8x10^{-6} / \mu g / m^3)\ \ x\ (3.64\ x\ 10^8) = 3400 - 18700 \\
&\textit{Annual Cancer Cases} = 49 - 268
\end{aligned}
$$

Thus, including attached garages would increase the number of benzene-related excess cancer cases to somewhere between 96 and 315 annually. This estimate would still not include higher exposure levels from occupational exposures, vapor emissions from leaking underground storage tanks, or other accidental releases into the environment. Any population risk characterization that does not account for these factors underestimates the excess cancer related to benzene.

With the controls being finalized in this rule, average individual risk, not including attached garage exposures, is reduced to 7.3×10^{-6}, which results in approximately 37 cancer cases per year. Thus, excess leukemia cases would be reduced by 10 annually. A roughly 40% reduction in overall benzene emissions could reduce attached garage exposures by approximately 0.5-2.6 $\mu g/m^3$ as well, thus reducing excess annual cancer cases from this source of exposure by another estimated 20 to 100 excess cancer cases. Thus, this rule would prevent roughly 30 to 110 benzene-related excess cancer cases annually, assuming continuous lifetime exposure to 2030 levels, given the assumptions of population size and lifetime above, and not including excess leukemia from occupational exposure or from leaking underground storage tanks. Emission reductions in 2030 would reduce cancer cases not just in 2030, but also well beyond this period. There would also be further unquantified reductions in incidence due to the other air toxics reductions.

Such estimates should be interpreted with extreme caution since they could imply an artificial sense of precision. Serious limitations include:

- As discussed in Chapter 1, the current unit risk estimate for benzene may underestimate risk from leukemia, because some recent epidemiology data, including key studies published after the most recent IRIS assessment, suggest a supralinear rather than linear dose-response at low doses. However, the studies published after the most recent IRIS assessment have not yet been formally evaluated by EPA as part of the IRIS review process, and it is not clear whether these data provide sufficient evidence to reject a linear dose-response curve. A better understanding of the biological mechanism of benzene-induced leukemia is needed.
- Geographically heterogeneous percentage emissions reductions do not translate directly into changes in ambient levels, exposure, and risk.
- The U.S. population would have experienced higher average exposures in previous years, but this is not accounted for.
- The extent to which available studies of indoor air homes in with attached garage are representative of the national housing stock is unknown.
- Cessation lag between reduction in exposure and reduction in risk is not accounted for.
- Differences in risk among various age groups are not known, and the age structure of the U.S. population is expected to change over time.

3.2.2 Local-Scale Modeling

Modeling at the national or regional scale, such the modeling done for the NATA National-Scale Assessment described in Section 3.2.1, is designed to identify and prioritize air toxics, emission source types and locations which are of greatest potential concern in terms of contributing to population risk. Such assessments also help elucidate patterns of exposure and risk across broad geographic areas, and can help characterize trends in air toxics risk and potential impacts of controls at a broad geographic scale, as demonstrated above. However, more localized assessments are needed to characterize and compare risks at local levels, and identify potential "hotspots."

National or regional-scale assessments typically rely on a "top down" approach to estimate emissions. Under a "top down" approach, emissions are estimated at the county level, typically starting from more aggregated information (e.g., state or national level) on activity. Spatial surrogates are then used to allocate emissions to grid cells or census tracts for modeling. Use of more local data can greatly improve the characterization of the magnitude and distribution of air toxic emissions. Air quality modeling can also be conducted with better spatial resolution than is computationally feasible in a regional or national-scale assessment. As a result, spatial gradients of air toxic concentrations and locations where the highest risks are likely to occur can be more accurately identified.

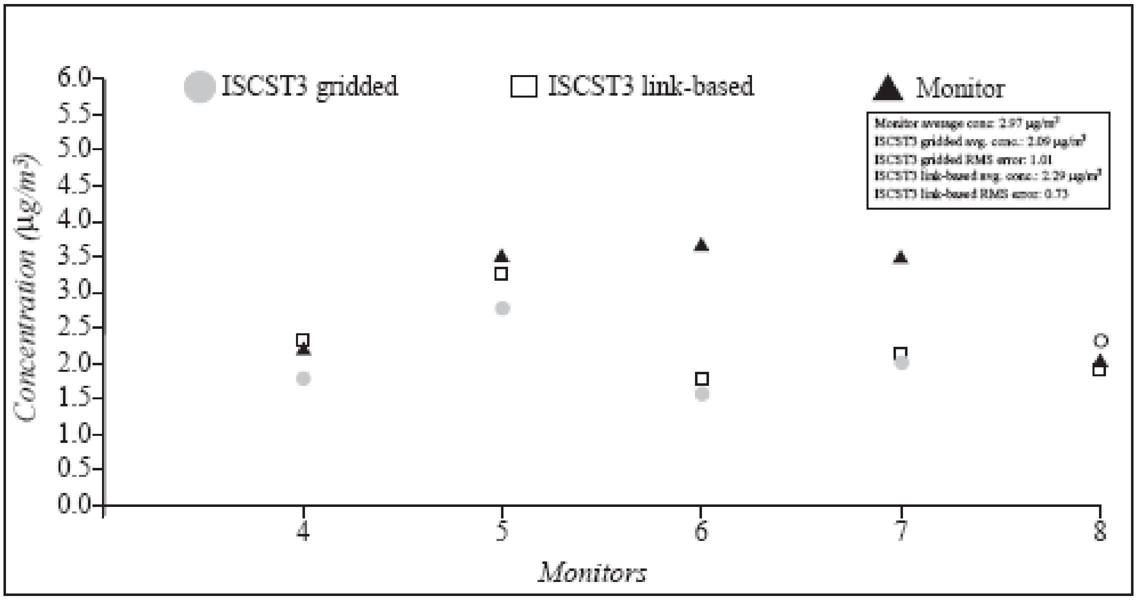
Local-scale modeling is typically done using steady-state plume dispersion models, such as the Integrated Source Complex (ISC) Model, the newly promulgated AERMOD (AMS/EPA Regulatory Model), or non-steady-state puff models such as CALPUFF. These models have a limited ability to simulate chemical reactions in the atmosphere. As discussed in Section 3.2.1, grid-based models, such as CMAQ, which better simulate chemical processes, do not yet have the spatial resolution of dispersion models. Significant advances are being made, however, in combining features of grid-based models and plume/puff models. These advances are described in a recent paper.[167] A case study of diesel exhaust particulate matter in Wilmington, CA was recently conducting employing some of these advances.[168] The researchers combined Gaussian and regional photochemical grid models. They found that local data, when modeled, provided a much more refined picture of the magnitude and distribution of possible community "hot spots" than more traditional, regional data, which rely on more default assumptions. An evaluation of the approach determined that spatial allocation and emission rates contribute most to uncertainty in model results, and this uncertainty could be substantially reduced through the collection and integration of site specific information about the location of emission sources, and the activity and emission rates of key sources affecting model concentrations. They conclude that for neighborhood assessments, incorporating site-specific data can lead to improvement in modeled estimates of concentrations, especially where site-specific data are lacking in regulatory databases.

The Wilmington study discussed above also allocated motor vehicle emissions to individual road "links," rather than using spatial surrogates to allocate county level vehicle emissions to grid cells. In using spatial surrogates to allocate emissions, high local concentrations may not be captured for environments near major roadways, which are often clustered in urban centers. One local-scale assessment done in the Minneapolis-St. Paul area of Minnesota, using such an inventory with the ISC model, found that the model tended to overpredict at low monitored benzene concentrations and underpredict at high monitored concentrations.[169] Local-scale modeling using activity data for individual road links can better characterize distributions of concentrations, and differentiate between locations near roadways and those further away, as observed in the following studies.

As discussed in Section 3.1.3.2, local-scale modeling in Houston assigned emissions to individual road links. [170] Researchers at US EPA developed a methodology which utilized a Geographic Information System (GIS) to allocate benzene emissions in Houston to major road segments in an urban area and model the segments as elongated area sources. The Industrial Source Complex Short Term (ISCST) dispersion model used both gridded and link-based emissions to evaluate the effect of improved spatial allocation of emissions on ambient modeled benzene concentrations. Allocating onroad mobile emissions to road segments improved the agreement between modeled concentrations when compared with monitor observations, and also resulted in higher estimated concentrations in the urban center where the density of neighborhood streets is greater and the largest amount of traffic found. The calculated annual average benzene model concentrations at monitor sites are compared to the observed annual average concentrations in Figure 3.2-20. Most of the gridded model emissions show lower benzene concentrations than both the link-based and observed monitor concentrations. Allocating the onroad mobile emissions to road segments resulted in an increase in the average benzene concentration, resulting in values that more closely match concentrations reported by monitors.

Recent air quality modeling in Portland, OR using the CALPUFF dispersion model assigned emissions to specific roadway links.[171] The resulting data were used to develop a regression model to approximate the CALPUFF predicted concentrations, determine the impacts of roadway proximity on ambient concentration of three hazardous air pollutants (1,3-butadiene, benzene, and diesel PM), and to estimate the zone of influence around roadways. Concentrations were modeled at several distances from major roadways (0-50, 5-200, 200-400, and > 400 meters). For benzene, the resulting average concentrations were 1.29, 0.64, 0.40, and 0.12 $\mu g/m^3$, respectively, illustrating the steep concentration gradient along roadways. There was a zone of influence between 200 and 400 meters, with concentrations falling to urban background levels beyond this distance. The overall mean motor vehicle benzene concentration modeled in Portland was about 0.21 $\mu g/m^3$, with concentrations increasing to 1.29 $\mu g/m^3$ at model receptor sites within 50 meters of a road. The results indicate that in order to capture localized impacts of hazardous air pollutants in a dispersion model, there is a need to include individual roadway links.

Figure 3.2-20. Model to Monitor Comparisons of Houston Benzene Concentrations



A recent review of local-scale modeling studies concluded that:[172]

1) Significant variations in air toxic concentrations occurred across the cities, with highest concentrations occurring near the highest emitting sources, illustrating the need for modeling on a local scale.
2) Increasing the receptor density near high emission sources changes the location of maximum concentrations, illustrating the concentration gradients that can occur near high emission sources and the importance of receptor placement and density for model performance.
3) Allocating on-road mobile emissions to road segments improved the agreement between modeled concentrations when compared with the observations, and also resulted in higher estimated concentrations in the urban center.
4) It is important to refine the national emissions inventory for input into local air quality model applications.

In another US EPA study, researchers provide a comparison of "top down" and "bottom up" approaches to developing a motor vehicle emissions inventory for one urban area, Philadelphia, in calendar year 1999.[173] Under the "top down" approach, emissions were estimated at the county level, typically starting from more aggregated information. Data on vehicle miles traveled (VMT) in the metropolitan statistical area were allocated to counties using population information. Default national model inputs (e.g. fleet characteristics, vehicle speeds) rather than local data were also used. The "bottom up" approach utilizes vehicle activity data from a travel demand model (TDM), and this "bottom up" approach estimates emission rates using more local input data to better estimate levels and spatial distribution of onroad motor vehicle emissions. TDM data can include information on the spatial distribution of vehicle activity, speeds along those roads (which can have a large impact on emissions), and the distribution of the VMT among vehicle classes for different speed ranges. These data can be used to more accurately estimate the magnitude of toxic emissions at the local scale and where they occur. Both the spatial distribution of emissions and the total county emissions in the Philadelphia area differed significantly between the top-down and the bottom-up methodologies as shown in Table 3.2-22.

Table 3.2-22. Comparison of Annual 1999 Benzene Emissions from Two Approaches in Philadelphia Area Counties

County	Local (TDM) Based	National (NEI)	Percent Difference
Camden	165	210	-27%
Delaware	162	160	1%
Gloucester	110	104	6%
Montgomery	333	209	59%
Philadelphia	255	467	-45%
Total	1,025	1,150	-12%

In the case of Philadelphia County, using local registration distribution data resulted in significantly lower air toxics emission factors and resultant emissions, while Montgomery County showed higher emissions. In the 1999 National Air Toxics Assessment, higher county-level emissions were generally associated with higher county-level average concentrations, so it is anticipated that county-level concentrations will follow similar trends. However, in microscale settings near specific road links, these results may not apply.

Local-scale modeling could also be improved by using local data on nonroad equipment activity for lawn and garden, recreational, construction and other sectors. EPA's county-level inventories used in NATA and other modeling are developed using activity allocated from the national or state level using surrogates.

The use of more spatially refined emission inventories, in conjunction with other refined air quality modeling techniques, improve the performance of air quality models. They also enable better characterization of the magnitude and distribution of air toxic emissions, exposure and risk in urban areas, including risks associated with locations heavily impacted by mobile sources.

In conclusion, local scale modeling studies indicated higher concentrations of air toxics than predicted by National scale analysis, particularly in near-source microenvironments such as near roads. Thus, National scale analyses such as 1999 NATA are likely underestimating high end exposures and risks.

3.3 Ozone

In this section we review the health and welfare effects of ozone. We also describe the air quality monitoring and modeling data which indicate that people in many areas across the country continue to be exposed to high levels of ambient ozone and will continue to be into the future. Emissions of volatile organic compounds (VOCs) from the gas cans subject to this final rule have been shown to contribute to these ozone concentrations. Information on air quality was gathered from a variety of sources, including monitored ozone concentrations, air quality modeling forecasts conducted for this rulemaking, and other state and local air quality information.

3.3.1 Science of Ozone Formation

Ground-level ozone pollution is formed by the reaction of VOCs and nitrogen oxides (NO_x) in the 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, gas cans, 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.[174] 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 would occur on a single high-temperature day. Ozone also can be transported into an area from pollution sources found hundreds of miles upwind, 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.

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 many rural 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.

Ozone concentrations in an area also can be lowered by the reaction of nitric oxide 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.

The Clean Air Act (CAA) requires EPA to set National Ambient Air Quality Standards (NAAQS) for wide-spread pollutants from diverse sources considered harmful to public health and the environment. The CAA established two types of NAAQS: primary standards to protect public health, secondary standards to protect public welfare. The primary and secondary ozone NAAQS are identical. The 8-hour ozone standard is met when the 3-year average of the annual 4th highest daily maximum 8-hour ozone concentration is less than or equal to 0.08 ppm. (62 FR 38855, July 18, 1997)

3.3.2 Health Effects of Ozone

Exposure to ambient ozone contributes to a wide range of adverse health effects.[e] These health effects are well documented and are critically assessed in the EPA ozone Air Quality Criteria Document (ozone AQCD) and EPA staff paper.[175,176] We are relying on the data and conclusions in the ozone AQCD and staff paper, regarding the health effects associated with ozone exposure.

Ozone-related health effects include lung function decrements, respiratory symptoms, aggravation of asthma, increased hospital and emergency room visits, increased asthma medication usage, inflammation of the lungs, and a variety of other respiratory effects and cardiovascular effects. People who are more susceptible to effects associated with exposure to ozone include children, asthmatics and the elderly. There is also suggestive evidence that certain people may have greater genetic susceptibility. Those with greater exposures to ozone, for instance due to time spent outdoors (e.g., 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 higher ambient ozone concentrations have been linked to lung function decrements, respiratory symptoms, increased hospital admissions and emergency room visits for respiratory problems.[177, 178, 179, 180, 181, 182] Repeated exposure to ozone can increase susceptibility to respiratory infection and lung inflammation and can aggravate preexisting respiratory diseases, such as asthma.[183, 184, 185, 186, 187] 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 lead to premature aging of the lungs and/or chronic respiratory illnesses, such as emphysema and chronic bronchitis.[188, 189, 190, 191]

Children and adults who are outdoors and active during the summer months, such as construction workers and other outdoor workers, are among those most at risk of elevated ozone exposures.[192] Children and outdoor workers tend to have higher ozone exposures 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.[193] For example, summer camp studies in the Eastern United States and Southeastern Canada have reported significant reductions in lung

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[e] 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 concentration but also by the individuals breathing route and rate.

function in children who are active outdoors.[194, 195, 196, 197, 198, 199, 200, 201] 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.[202, 203, 204, 205]

3.3.3 Current 8-Hour Ozone Levels

The gas can emission reductions will assist 8-hour ozone nonattainment areas in reaching the standard by each area's respective attainment date and assist 8-hour ozone maintenance areas in maintaining the 8-hour ozone standard in the future. In this section and the next section we present information on current and model-projected future 8-hour ozone levels.

A nonattainment area is defined in the CAA as an area that is violating a NAAQS or is contributing to a nearby area that is violating the NAAQS. EPA designated nonattainment areas for the 8-hour ozone NAAQS in June 2004. The final rule on Air Quality Designations and Classifications for the 8-hour Ozone NAAQS (69 FR 23858, April 30, 2004) lays out the factors that EPA considered in making the 8-hour ozone nonattainment designations, including 2001-2003 measured data, air quality in adjacent areas, and other factors.[f]

As of October 26, 2006, approximately 157 million people live in the 116 areas that are currently designated as nonattainment for either failing to meet the 8-hour ozone NAAQS or for contributing to poor air quality in a nearby area. There are 461 full or partial counties that make up the 116 8-hour ozone nonattainment areas. Figure 3.3-1 illustrates the widespread nature of these problems. Shown in this figure are counties designated as nonattainment for the 8-hour ozone NAAQS, also depicted are $PM_{2.5}$ nonattainment areas and the mandatory class I federal areas. The 8-hour ozone nonattainment areas, nonattainment counties and populations are listed in Appendix 3B to this RIA.

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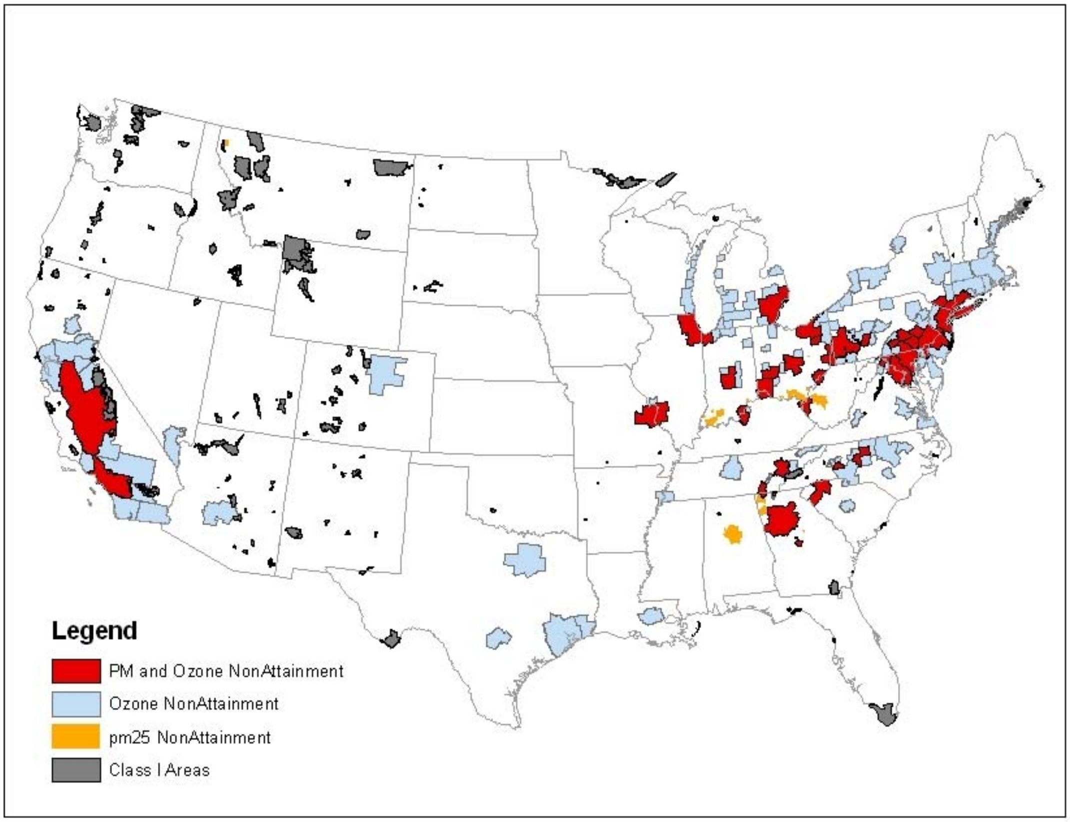
[f] An ozone design value is the concentration that determines whether the ozone levels recorded at a monitoring site meet the NAAQS for ozone. The level of a design value is determined based on three consecutive-year monitoring periods. For example, an 8-hour design value is the fourth highest daily maximum 8-hour average ozone concentration measured over a three-year period at a given monitor. Greater detail on how these values are determined (including how to account for missing values and other complexities) is given in Appendices H and I of 40 CFR Part 50. Due to the precision with which the standards are expressed (0.08 ppm for the 8-hour NAAQS value), a violation of the 8-hour standard is defined as any design value greater than or equal to 0.085 ppm, or 85 ppb. For any particular county, the design value is the highest design value from amongst all the monitors having valid design values within that county. If there are no ozone monitors located in a particular county, that county is not assigned a design value. However, readers should note that ozone design values represent air quality over a broad area and the absence of a design value for a specific county does not imply that that county is in compliance with the NAAQS for ozone**.** Therefore, our analysis may underestimate the number of counties with ozone levels, i.e., design values, which are above the level of the ozone NAAQS.

Figure 3.3.-1. 8-Hour Ozone and $PM_{2.5}$ Nonattainment Areas and Mandatory Class I Federal Areas



Counties designated as 8-hour ozone nonattainment were categorized, on the basis of their one-hour ozone design value, as Subpart 1 or Subpart 2 (69 FR 23951, April 30, 2004). Areas categorized as Subpart 2 were then further classified, on the basis of their 8-hour ozone design value, as marginal, moderate, serious, severe or extreme. The maximum attainment date assigned to an ozone nonattainment area is based on the area's classification.

Table 3B-1 presents the 8-hour ozone nonattainment areas, their 8-hour design values, and their category or classification. States with 8-hour ozone nonattainment areas are required to take action to bring those areas into compliance prior to the ozone season in the attainment year. Based on the final rule designating and classifying 8-hour ozone nonattainment areas, most 8-hour ozone nonattainment areas will be required to attain the 8-hour ozone NAAQS in the 2007 to 2013 time frame and then be required to maintain the 8-hour ozone NAAQS thereafter.[g] The gas can emission standards being finalized in this action will become effective in 2009. Thus,

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[g] The Los Angeles South Coast Air Basin 8-hour ozone nonattainment area will have to attain before June 15, 2021.

the expected ozone precursor emission inventory reductions from the standards finalized in this action will be useful to States in attaining and/or maintaining the 8-hour ozone NAAQS.

EPA's review of the ozone NAAQS is currently underway and a proposed decision in this review is scheduled for June 2007 with a final rule scheduled for March 2008. If the ozone NAAQS is revised then new nonattainment areas could be designated. While EPA is not relying on it for purposes of justifying this rule, the emission reductions from this rulemaking would also be helpful to states if there is an ozone NAAQS revision.

3.3.4 Projected 8-Hour Ozone Levels

Recent air quality modeling predicts that without additional local, regional or national controls there will continue to be a need for reductions in 8-hour ozone concentrations in some areas in the future. In the following sections we describe recent ozone air quality modeling from the CAIR analysis as well as results of the ozone response surface metamodel (RSM) analysis we completed to assess the potential ozone impacts resulting from the VOC emissions controls for gas cans.

3.3.4.1 CAIR Ozone Air Quality Modeling

Recently ozone air quality analyses were performed for the Clean Air Interstate Rule (CAIR), which was promulgated by EPA in 2005. The Comprehensive Air Quality Model with Extension (CAMx) was used as the tool for simulating base and future year concentrations of ozone in support of the CAIR ozone air quality assessment. The CAIR analysis included all final federal rules up to and including CAIR controls. Details on the air quality modeling are provided in the Air Quality Modeling Technical Support Document for the Final Clean Air Interstate Rule, included in the docket for this final rule.[206]

Air quality modeling performed for CAIR indicates that in the absence of additional controls, counties with projected 8-hour ozone concentrations greater than or equal to 85 ppb are likely to persist in the future. The CAIR analysis provided estimates of future ozone levels across the country. For example, in 2010, in the absence of controls beyond those relied on for the CAIR modeling, we project that 24 million people would live in 37 Eastern counties with 8-hour ozone concentrations at and above 85 ppb, see Table 3.3-1.[h] Table 3.3-1 also lists the 148 Eastern counties, where 61 million people are projected to live, with 2010 projected design values that do not violate the 8-hour ozone NAAQS but are within ten percent of it, in the absence of emission reductions beyond those considered in the CAIR modeling. These are counties that are not projected to violate the standard, but to be close to it. The rule may help ensure that these counties continue to maintain their attainment status and the emission reductions from this final rule will be included by the states in their baseline inventory modeling for their ozone maintenance plans.

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[h] Counties forecast to remain in nonattainment may need to adopt additional local or regional controls to attain the standards by dates set pursuant to the Clean Air Act. The emissions reductions associated with this proposed rule would help these areas attain the ozone standard by their statutory date.

Table 3.3-1. Eastern Counties with 2010 projected 8-hour Ozone Concentrations Above and within 10% of the 8-hour Ozone Standard

State	**County**	**2010 Projected 8-hour Ozone Concentration (ppb)**[a]	**2000 pop**[b]	**2010 pop**[c]
Arkansas	Crittenden Co	80.8	50,866	52,889
Connecticut	Fairfield Co	**92.2**	882,567	891,694
Connecticut	Hartford Co	80.1	857,183	859,080
Connecticut	Middlesex Co	**90.6**	155,071	164,202
Connecticut	New Haven Co	**91.3**	824,008	829,181
Connecticut	New London Co	83.4	259,088	267,199
Connecticut	Tolland Co	82.7	136,364	142,988
D.C.	Washington Co	**85.0**	572,058	554,474
Delaware	Kent Co	78.7	126,697	139,376
Delaware	New Castle Co	84.7	500,264	534,631
Delaware	Sussex Co	80.3	156,638	181,962
Georgia	Bibb Co	80.0	153,887	158,291
Georgia	Cobb Co	79.4	607,750	744,488
Georgia	Coweta Co	76.6	89,215	111,522
Georgia	De Kalb Co	81.9	665,864	698,335
Georgia	Douglas Co	78.7	92,174	114,380
Georgia	Fayette Co	76.7	91,263	117,580
Georgia	Fulton Co	**85.1**	816,005	855,826
Georgia	Henry Co	80.3	119,341	153,957
Georgia	Rockdale Co	80.4	70,111	87,977
Illinois	Cook Co	81.8	5,376,739	5,363,464
Illinois	Jersey Co	77.0	21,668	22,905
Illinois	Lake Co	76.8	644,356	731,690
Illinois	McHenry Co	76.6	260,077	307,400
Indiana	Boone Co	78.1	46,107	54,035
Indiana	Clark Co	78.4	96,472	107,096
Indiana	Hamilton Co	81.7	182,740	230,565
Indiana	Hancock Co	80.4	55,391	65,282
Indiana	La Porte Co	81.8	110,106	111,566
Indiana	Lake Co	82.8	484,563	489,220
Indiana	Madison Co	78.6	133,358	137,710
Indiana	Marion Co	79.6	860,453	879,932
Indiana	Porter Co	81.1	146,798	165,350
Indiana	Shelby Co	81.6	43,445	46,565
Indiana	St Joseph Co	77.8	265,559	275,031
Kentucky	Campbell Co	81.5	88,616	92,109
Louisiana	Bossier Parish	77.0	98,310	110,838
Louisiana	East Baton Rouge Parish	80.6	412,852	465,411
Louisiana	Iberville Parish	79.4	33,320	33,089
Louisiana	Jefferson Parish	78.6	455,466	493,359
Louisiana	Livingston Parish	77.8	91,814	124,895
Louisiana	West Baton Rouge Parish	78.8	21,601	22,672
Maine	Hancock Co	80.5	51,791	53,886

State	County	2010 Projected 8-hour Ozone Concentration (ppb)[a]	2000 pop[b]	2010 pop[c]
Maine	York Co	80.2	186,742	201,082
Maryland	Anne Arundel Co	**88.6**	489,656	543,785
Maryland	Baltimore Co	83.7	754,292	792,284
Maryland	Carroll Co	80.0	150,897	179,918
Maryland	Cecil Co	**89.5**	85,951	96,574
Maryland	Charles Co	78.7	120,546	145,763
Maryland	Frederick Co	78.1	195,277	234,304
Maryland	Harford Co	**92.8**	218,590	268,207
Maryland	Kent Co	**85.8**	19,197	20,233
Maryland	Montgomery Co	79.3	873,341	940,126
Maryland	Prince Georges Co	84.2	801,515	842,221
Massachusetts	Barnstable Co	83.6	222,230	249,495
Massachusetts	Bristol Co	83.0	534,678	558,460
Massachusetts	Essex Co	81.7	723,419	747,556
Massachusetts	Hampden Co	80.2	456,228	452,718
Massachusetts	Hampshire Co	78.0	152,251	158,130
Massachusetts	Middlesex Co	79.1	1,465,396	1,486,428
Massachusetts	Suffolk Co	78.1	689,807	674,179
Michigan	Allegan Co	82.1	105,665	121,415
Michigan	Benzie Co	77.9	15,998	17,849
Michigan	Berrien Co	78.1	162,453	164,727
Michigan	Cass Co	78.2	51,104	53,544
Michigan	Genesee Co	76.7	436,141	441,196
Michigan	Macomb Co	**85.4**	788,149	838,353
Michigan	Mason Co	78.9	28,274	30,667
Michigan	Muskegon Co	82.0	170,200	175,901
Michigan	Oakland Co	80.7	1,194,155	1,299,592
Michigan	Ottawa Co	76.6	238,314	277,400
Michigan	St Clair Co	80.6	164,235	178,391
Michigan	Washtenaw Co	81.0	322,895	344,398
Michigan	Wayne Co	84.7	2,061,161	1,964,209
Missouri	Clay Co	76.5	184,006	213,643
Missouri	Jefferson Co	76.7	198,099	230,539
Missouri	St Charles Co	80.5	283,883	341,686
Missouri	St Louis City	79.4	348,188	324,156
Missouri	St Louis Co	80.5	1,016,315	1,024,964
New Hampshire	Hillsborough Co	76.6	380,841	412,071
New Jersey	Atlantic Co	80.4	252,552	269,754
New Jersey	Bergen Co	**86.0**	884,118	898,450
New Jersey	Camden Co	**91.6**	508,932	509,912
New Jersey	Cumberland Co	84.4	146,438	149,595
New Jersey	Gloucester Co	**91.3**	254,673	278,612
New Jersey	Hudson Co	84.3	608,975	607,256
New Jersey	Hunterdon Co	**88.6**	121,989	139,641
New Jersey	Mercer Co	**95.2**	350,761	359,912
New Jersey	Middlesex Co	**92.1**	750,162	805,537

State	County	2010 Projected 8-hour Ozone Concentration (ppb)[a]	2000 pop[b]	2010 pop[c]
New Jersey	Monmouth Co	**86.4**	615,301	670,971
New Jersey	Morris Co	**85.5**	470,212	500,033
New Jersey	Ocean Co	**100.3**	510,916	572,364
New Jersey	Passaic Co	79.7	489,049	495,610
New York	Bronx Co	79.7	1,332,649	1,298,206
New York	Chautauqua Co	81.8	139,750	139,909
New York	Dutchess Co	81.0	280,150	291,098
New York	Erie Co	**86.9**	950,265	953,085
New York	Essex Co	77.6	38,851	39,545
New York	Jefferson Co	80.5	111,738	113,075
New York	Monroe Co	76.9	735,343	745,350
New York	Niagara Co	82.3	219,846	220,407
New York	Orange Co	77.1	341,367	371,434
New York	Putnam Co	82.3	95,745	107,967
New York	Queens Co	78.3	2,229,379	2,239,026
New York	Richmond Co	**87.1**	443,728	488,728
New York	Suffolk Co	**90.8**	1,419,369	1,472,127
New York	Westchester Co	84.7	923,459	944,535
North Carolina	Mecklenburg Co	81.4	695,453	814,088
North Carolina	Rowan Co	80.1	130,340	143,729
North Carolina	Wake Co	77.2	627,846	787,707
Ohio	Allen Co	76.8	108,473	106,900
Ohio	Ashtabula Co	83.5	102,728	104,850
Ohio	Butler Co	78.0	332,806	384,410
Ohio	Clermont Co	78.0	177,977	205,365
Ohio	Clinton Co	81.4	40,543	47,137
Ohio	Cuyahoga Co	77.3	1,393,977	1,348,313
Ohio	Delaware Co	77.3	109,989	136,125
Ohio	Franklin Co	81.9	1,068,977	1,142,894
Ohio	Geauga Co	**86.6**	90,895	102,083
Ohio	Hamilton Co	78.6	845,302	843,226
Ohio	Knox Co	76.5	54,500	59,435
Ohio	Lake Co	82.2	227,511	237,161
Ohio	Lorain Co	78.5	284,664	292,040
Ohio	Lucas Co	80.0	455,053	447,302
Ohio	Medina Co	76.5	151,095	173,985
Ohio	Portage Co	79.8	152,061	162,685
Ohio	Summit Co	82.4	542,898	552,567
Ohio	Trumbull Co	79.7	225,116	226,157
Ohio	Warren Co	80.0	158,383	186,219
Ohio	Wood Co	77.4	121,065	129,124
Oklahoma	Tulsa Co	79.2	563,299	610,536
Pennsylvania	Allegheny Co	81.9	1,281,665	1,259,040
Pennsylvania	Armstrong Co	79.7	72,392	72,829
Pennsylvania	Beaver Co	79.6	181,412	183,693
Pennsylvania	Berks Co	81.7	373,637	388,194

State	County	2010 Projected 8-hour Ozone Concentration (ppb)[a]	2000 pop[b]	2010 pop[c]
Pennsylvania	Bucks Co	**94.3**	597,635	648,796
Pennsylvania	Cambria Co	76.9	152,598	146,811
Pennsylvania	Chester Co	**85.4**	433,501	478,460
Pennsylvania	Dauphin Co	80.8	251,798	265,019
Pennsylvania	Delaware Co	84.0	550,863	543,169
Pennsylvania	Erie Co	79.1	280,843	284,835
Pennsylvania	Franklin Co	80.2	129,313	135,088
Pennsylvania	Lancaster Co	83.6	470,657	513,684
Pennsylvania	Lehigh Co	82.1	312,090	323,215
Pennsylvania	Mercer Co	78.1	120,293	122,546
Pennsylvania	Montgomery Co	**87.6**	750,097	772,849
Pennsylvania	Northampton Co	81.8	267,066	279,797
Pennsylvania	Philadelphia Co	**89.9**	1,517,549	1,420,803
Pennsylvania	Washington Co	77.3	202,897	205,153
Pennsylvania	Westmoreland Co	76.7	369,993	372,941
Pennsylvania	York Co	79.4	381,750	404,807
Rhode Island	Kent Co	**86.2**	167,090	174,126
Rhode Island	Providence Co	81.2	621,602	621,355
Rhode Island	Washington Co	84.2	123,546	137,756
South Carolina	Richland Co	76.9	320,677	349,826
Tennessee	Sevier Co	76.5	71,170	96,097
Tennessee	Shelby Co	76.7	897,471	958,501
Texas	Brazoria Co	84.1	241,767	281,960
Texas	Collin Co	82.5	491,675	677,868
Texas	Dallas Co	82.2	2,218,899	2,382,657
Texas	Denton Co	**86.8**	432,976	554,033
Texas	Galveston Co	84.6	250,158	283,963
Texas	Gregg Co	79.1	111,379	121,241
Texas	Harris Co	**97.4**	3,400,577	3,770,129
Texas	Jefferson Co	**85.0**	252,051	260,847
Texas	Johnson Co	78.2	126,811	157,545
Texas	Montgomery Co	81.2	293,768	413,048
Texas	Tarrant Co	**87.2**	1,446,219	1,710,920
Virginia	Alexandria City	80.9	128,283	130,422
Virginia	Arlington Co	**86.0**	189,453	193,370
Virginia	Charles City Co	77.7	6,926	7,382
Virginia	Fairfax Co	**85.4**	969,749	1,085,483
Virginia	Hampton City	78.7	146,437	153,246
Virginia	Hanover Co	80.9	86,320	98,586
Virginia	Henrico Co	78.2	262,300	294,174
Virginia	Loudoun Co	78.6	169,599	214,469
Virginia	Suffolk City	77.5	63,677	69,003
Wisconsin	Door Co	82.1	27,961	30,508
Wisconsin	Kenosha Co	**91.0**	149,577	166,359

State	County	2010 Projected 8-hour Ozone Concentration (ppb)[a]	2000 pop[b]	2010 pop[c]
Wisconsin	Kewaunee Co	79.9	20,187	20,538
Wisconsin	Manitowoc Co	80.0	82,887	83,516
Wisconsin	Milwaukee Co	82.1	940,164	922,943
Wisconsin	Ozaukee Co	**85.8**	82,317	95,549
Wisconsin	Racine Co	83.9	188,831	199,178
Wisconsin	Sheboygan Co	**87.7**	112,646	118,866
Number of Violating Counties		37		
Population of Violating Counties			22,724,010	24,264,574
Number of Counties within 10%		148		
Population of Counties within 10%			58,453,962	61,409,062

a) Bolded concentrations indicate levels above the 8-hour ozone standard.
b) Populations are based on 2000 census data.
c) Populations are based on 2000 census projections.

3.3.4.2 Ozone Response Surface Metamodel Methodology

We performed ozone air quality modeling simulations for the Eastern United States using the ozone RSM. The ozone RSM is a screening-level air quality modeling tool that allows users to quickly assess the estimated air quality changes over the modeling domain. The ozone RSM is a model of a full-scale air quality model and is based on statistical relationships between model inputs and outputs obtained from the full-scale air quality model. In other words, the ozone RSM uses statistical techniques to relate a response variable to a set of factors that are of interest, e.g., emissions of precursor pollutants from particular sources and locations. The following section describes the modeling methodology, including the development of the multi-dimensional experimental design for control strategies and implementation and verification of the RSM technique. Additional detail is available in the Air Quality Modeling Technical Support Document (AQMTSD) for this rule.[207]

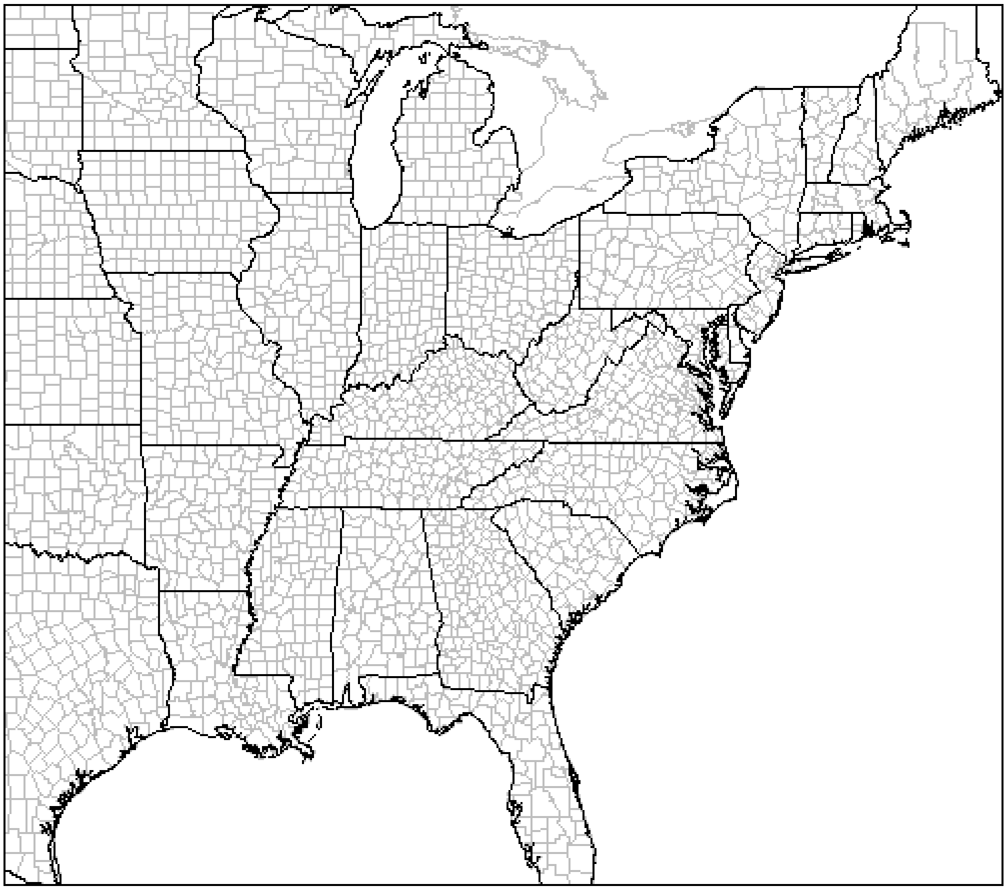
The foundation for the ozone response surface metamodeling analyses was the CAMx modeling done in support of the final Clean Air Interstate Rule (CAIR). The CAIR modeling is fully described in the CAIR Air Quality Modeling Technical Support Document, but a brief description is provided below.[208] The modeling procedures used in the CAIR analysis (e.g., domain, episodes, meteorology) have been used for several EPA rulemaking analyses over the past five years and are well-established at this point.

The ozone RSM uses the 2015 controlled CAIR emissions inventory as its baseline.[209] This inventory does not include the gas can emissions that are being controlled in this rule. The uncontrolled and controlled gas can emissions have been incorporated into the base and control runs of the ozone RSM (see Section 2.1 for more detail about the gas can emissions inventory). The inventory also does not include the higher estimates of cold temperature emissions for gasoline vehicles developed for this rule; however, these emissions are not likely to have a significant impact on ozone formation. Finally, the inventory includes an error in mobile source NOx for 13 Northeastern states. The impact of this error is minimized as the model is used in a relative way. Because the base years of our air quality modeling analysis are 2020 and 2030, we extrapolate the model from 2015 to 2020 and 2030. Additional detail on how the model was extrapolated to reflect gas can emissions and various projection years is included in the AQMTSD for this final rule.[210]

The modeling simulations that comprised the metamodeling were conducted using CAMx version 3.10. It should be noted that because the ozone RSM is built from CAMx air quality model runs, it therefore has the same strengths and limitations of the underlying model and its inputs. CAMx is a non-proprietary computer model that simulates the formation and fate of photochemical oxidants including ozone for given input sets of meteorological conditions and emissions. The gridded meteorological data for three historical episodes were developed using the Regional Atmospheric Modeling System (RAMS), version 3b.[211] In all, 30 episode days were modeled using frequently-occurring, ozone-conducive, meteorological conditions from the summer of 1995. Emissions estimates were developed for the evaluation year (1995) as well as a future year (2015).

The CAMx model applications were performed for a domain covering all, or portions of, 37 States (and the District of Columbia) in the Eastern U.S., as shown in Figure 3.3-2. The domain has nested horizontal grids of 36 km and 12 km. However, the output data from the metamodeling is provided at a 12 km resolution (i.e., cells from the outer 36 km cells populate the nine finer scale cells, as appropriate). Although the domain of the ozone RSM is the 37 Eastern states, the gas can controls are a nationwide program. Section 2.1.3 describes the nationwide inventory reductions that could be achieved by the gas can controls. Section 2.1.1.2 also details the states that have their own gas can control programs and how the controls finalized here impact states which already have gas can control programs.

Figure 3.3-2. Map of the CAMx Domain used for MSAT Ozone Metamodeling



The ozone RSM used for assessing the impacts of gas can emission reductions was developed broadly to look at various control strategies with respect to attaining the 8-hour ozone NAAQS. The experimental design for the ozone RSM covered three key areas: type of precursor emission (NOx or VOC), emission source type (i.e., onroad vehicles, nonroad vehicles, area sources, electrical generating utility (EGU) sources, and non-utility point sources), and location in or out of a 2015 model-projected residual ozone nonattainment area. This resulted in a set of 14 emissions factors. Since some of the spillage emissions associated with gas cans are currently included in the NONROAD emissions model, for the purposes of the ozone RSM we have included gas can emissions as part of the nonroad factor in our air quality modeling.

The 14 emission factors were randomly varied and used as inputs to CAMx. The experimental design for these 14 factors was developed using a Maximin Latin Hypercube method. Based on a rule of thumb of 10 runs per factor, we developed an overall design with 154 runs (a base case plus 139 control runs plus 10 evaluation runs plus 4 boundary condition runs). The range of emissions reductions considered within the metamodel ranged from 0 to 120 percent of the 2015 CAIR emissions. This experimental design resulted in a set of CAMx simulations that serve as the inputs to the ozone response surface metamodel. Because the metamodeling was going to be used to assess the impacts of the gas can standards, the experimental design also included oversampling in the range of 0 to 10 percent control for the nonroad VOC sector, as well as CAMx runs that only included VOC controls.

To develop a response surface approximation to CAMx, we used a multidimensional kriging approach, implemented through the MIXED procedure in SAS. We modeled the predicted changes in ozone in each CAMx grid cell as a function of the weighted average of the modeled responses in the experimental design. A response-surface was then fit for the ozone design value metric. Validation was performed and is summarized in the AQMTSD. The validation exercises indicated that the ozone RSM replicates CAMx response to emissions changes very well for most emissions combinations and in most locations.

The assessment of gas can controls conducted for this analysis involved adjusting the nonroad mobile source VOC emissions both in and out of ozone nonattainment areas and looking at the impact on the 8-hour ozone design value metric. We created an input or adjustment factor for the nonroad mobile source VOC emission factor by adding future year gas can emission estimates to the projected CAIR emission inventory and then relating the future year emissions estimate to 2015. For this assessment the future years modeled are 2020 and 2030.

3.3.4.3 Ozone Response Surface Metamodel Results

This section summarizes the results of our modeling of ozone air quality impacts in the future with and without the reductions in gas can emissions. Based upon our previous CAIR air quality modeling, we anticipate that without emission reductions beyond those already required under promulgated regulations and approved SIPs, ozone nonattainment will likely persist into the future.

The inventories that underlie the ozone modeling conducted for this rulemaking included emission reductions from all current or committed federal, state, and local controls, including the recent CAIR. There was no attempt to examine the prospects of areas attaining or maintaining the 8-hour ozone standard with possible additional future controls (i.e., controls beyond current or committed federal, State, and local controls).

According to the ozone response surface metamodel (RSM), the gas can controls are projected to result in a very small population-weighted net improvement in future ozone. The net improvement is generally so small as to be rendered insignificant when presenting design values. The model changes are smaller than the precision with which the ozone standard is expressed (0.08 parts per million (ppm)) and to which 8-hour ozone data is reported.[i] Nonetheless, there are some areas where the ozone improvement is more significant. These areas include Chicago, Milwaukee, Detroit and New York City. It is also important to note that the ozone RSM results indicate that the counties which are projected to experience the greatest improvement in ozone design values are generally also those that are projected to have the highest ozone design values. Those counties that are projected to experience an extremely small increase in ozone design values generally have design values that are lower, below 70 ppb. The results from the metamodeling projections indicate a net overall improvement in future 8-hour

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[i] Appendix I of 40 CFR Part 50.

ozone design values due to the gas can controls, when weighted by population. The AQMTSD, contained in the docket for this final rule, includes additional detail on the ozone RSM results.

3.3.5 Environmental Effects of Ozone Pollution

There are a number of public welfare effects associated with the presence of ozone in the ambient air.[212] In this section we discuss the impact of ozone on plants, including trees, agronomic crops and urban ornamentals.

3.3.5.1 Impacts on Vegetation

The ozone AQCD notes that "ozone affects vegetation throughout the United States, impairing crops, native vegetation, and ecosystems more than any other air pollutant."[213] Like carbon dioxide (CO_2) and other gaseous substances, ozone enters plant tissues primarily through apertures (stomata) in leaves in a process called "uptake." To a lesser extent, ozone can also diffuse directly through surface layers to the plant's interior.[214] 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.[215,216] This damage is commonly manifested as visible foliar injury such as chlorotic or necrotic spots, increased leaf senescence (accelerated leaf aging) and/or reduced photosynthesis. All these effects reduce a plant's capacity to form carbohydrates, which are the primary form of energy used by plants.[217] 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. 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 some 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.[218]

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 O_3 uptake through closure of stomata).[219,220,221] 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.[222] 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 shown conclusively to cause discernible injury to forest trees.[223,224] In terms of forest productivity and ecosystem diversity, ozone may be the pollutant with the greatest potential for regional-scale forest impacts.[225] Studies have demonstrated repeatedly that ozone concentrations commonly observed in polluted areas can have substantial impacts on plant function.[226,227]

Because plants are at the center 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.[228] 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.[229,230,231] 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 Unites States."[232] In addition, economic studies have shown reduced economic benefits as a result of predicted reductions in crop yields associated with observed ozone levels.[233,234,235]

Urban ornamentals represent an additional vegetation category likely to experience some degree of negative effects associated with exposure to ambient ozone levels and likely to impact large economic sectors. It is estimated that more than $20 billion (1990 dollars) are spent annually on landscaping using ornamentals, both by private property owners/tenants and by governmental units responsible for public areas.[236] This is therefore a potentially costly environmental effect. However, in the absence of adequate exposure-response functions and economic damage functions for the potential range of effects relevant to these types of vegetation, no direct quantitative analysis has been conducted. Methods are not available to allow for plausible estimates of the percentage of these expenditures that may be related to impacts associated with ozone exposure.

3.4 Particulate Matter

In this section we review the health and welfare effects of particulate matter (PM). We also describe air quality monitoring and modeling data that indicate many areas across the country continue to be exposed to levels of ambient PM above the NAAQS. Emissions of PM and VOC from the vehicles subject to this rule contribute to these PM concentrations. Information on air quality was gathered from a variety of sources, including monitored PM concentrations, air quality modeling done for recent EPA rulemakings and other state and local air quality information.

3.4.1 Science of PM Formation

Particulate matter (PM) represents 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. PM is further described by breaking it down into size fractions. PM_{10} refers to particles generally less than or equal to 10 micrometers (µm) in diameter. $PM_{2.5}$ refers to fine particles, those particles generally less than or equal to 2.5 µm in diameter. Inhalable (or “thoracic”) coarse particles refer to those particles generally greater than 2.5 µm but less than or equal to 10 µm in diameter. Ultrafine PM refers to particles with diameters generally less than 100 nanometers (0.1 µm). Larger particles (>10 µm) tend to be removed by the respiratory clearance mechanisms, whereas smaller particles are deposited deeper in the lungs.

Fine particles are produced primarily by combustion processes and by transformations of gaseous emissions (e.g., SOx, NOx and VOCs) in the atmosphere. The chemical and physical properties of $PM_{2.5}$ may vary greatly with time, region, meteorology and source category. Thus, $PM_{2.5}$, may include a complex mixture of different pollutants including sulfates, nitrates, organic compounds, elemental carbon and metal compounds. These particles can remain in the atmosphere for days to weeks and travel through the atmosphere hundreds to thousands of kilometers.

The vehicles that will be covered by the standards contribute to ambient PM levels through primary (direct) and secondary (indirect) PM. Primary PM is directly emitted into the air, and secondary PM forms in the atmosphere from gases emitted by fuel combustion and other sources. Along with primary PM, the vehicles controlled in this action emit VOC, which react in the atmosphere to form secondary $PM_{2.5}$, namely organic carbonaceous $PM_{2.5}$. The gas cans that will be covered by the standards also emit VOC which contribute to secondary $PM_{2.5}$. Both types of directly and indirectly formed particles from vehicles and gas cans are found principally in the fine fraction.

EPA has recently amended the PM NAAQS (71 FR 61144, October 17, 2006). The final rule, signed on September 21, 2006 and published on October 17, 2006, addressed revisions to the primary and secondary NAAQS for PM to provide increased protection of public health and welfare, respectively. The primary $PM_{2.5}$ NAAQS include a short-term (24-hour) and a long-term (annual) standard. The level of the 24-hour $PM_{2.5}$ NAAQS has been revised from 65µg/m^3 to 35 µg/m^3 to provide increased protection against health effects associated with short-term exposures to fine particles. The current form of the 24-hour $PM_{2.5}$ standard was retained (e.g., based on the 98th percentile concentration averaged over three years). The level of the annual $PM_{2.5}$ NAAQS was retained at $15 \mu g/m^3$, continuing protection against health effects associated with long-term exposures. The current form of the annual $PM_{2.5}$ standard was retained as an annual arithmetic mean averaged over three years, however, the following two aspects of the spatial averaging criteria were narrowed: (1) the annual mean concentration at each site shall be within 10 percent of the spatially averaged annual mean, and (2) the daily values for each monitoring site pair shall yield a correlation coefficient of at least 0.9 for each calendar quarter. With regard to the primary PM_{10} standards, the 24-hour PM_{10} NAAQS was retained at a level of $150 \mu g/m^3$ not to be exceeded more than once per year on average over a three-year period. Given that the available evidence does not suggest an association between long-term exposure to coarse particles at current ambient levels and health effects, EPA has revoked the annual PM_{10} standard.

With regard to the secondary PM standards, EPA has revised these standards to be identical in all respects to the revised primary standards. Specifically, EPA has revised the current 24-hour $PM_{2.5}$ secondary standard by making it identical to the revised 24-hour $PM_{2.5}$ primary standard, retained the annual $PM_{2.5}$ and 24-hour PM_{10} secondary standards, and revoked the annual PM_{10} secondary standards. This suite of secondary PM standards is intended to provide protection against PM-related public welfare effects, including visibility impairment, effects on vegetation and ecosystems, and material damage and soiling.

3.4.2 Health Effects of Particulate Matter

As stated in the EPA Particulate Matter Air Quality Criteria Document (PMAQCD), available scientific findings "demonstrate well that human health outcomes are associated with ambient PM."[j] We are relying primarily on the data and conclusions in the PM AQCD and PM staff paper, which reflects EPA's analysis of policy-relevant science from the PM AQCD, regarding the health effects associated with particulate matter.[237,238] We also present additional recent studies[k] published after the cut-off date for the PM AQCD.[239] Taken together this information supports the conclusion that PM-related emissions such as those controlled in this action are associated with adverse health effects.

3.4.2.1 Short-Term Exposure Mortality and Morbidity Studies

As discussed in the PM AQCD, short-term exposure to $PM_{2.5}$ is associated with premature mortality from cardiopulmonary diseases (PM AQCD, p. 8-305), hospitalization and

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[j] 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.

[k] These additional studies are included in the 2006 Provisional Assessment of Recent Studies on Health Effects of Particulate Matter Exposure. The provisional assessment did not and could not (given a very short timeframe) undergo the extensive critical review by EPA, CASAC, and the public, as did the PM AQCD. The provisional assessment found that the "new" studies expand the scientific information and provide important insights on the relationship between PM exposure and health effects of PM. The provisional assessment also found that the "new" studies generally strengthen the evidence that acute and chronic exposure to fine particles and acute exposure to thoracic coarse particles are associated with health effects.

emergency department visits for cardiopulmonary diseases (PMAQCD, p. 9-93), increased respiratory symptoms (PM AQCD, p. 9-46), decreased lung function (PM AQCD Table 8-34) and physiological changes or biomarkers for cardiac changes (PM AQCD, Section 8.3.1.3.4). In addition, the PM AQCD describes a limited body of new evidence from epidemiologic studies for potential relationships between short-term exposure to PM and health endpoints such as low birth weight, preterm birth, and neonatal and infant mortality (PM AQCD, Section 8.3.4).

Among the studies of effects from short-term exposure to $PM_{2.5}$, several studies specifically address the contribution of mobile sources to short-term $PM_{2.5}$ effects on daily mortality. These studies indicate that there are statistically significant associations between mortality and PM related to mobile source emissions (PM AQCD, p.8-85). The analyses incorporate source apportionment tools into daily mortality studies and are briefly mentioned here. Analyses incorporating source apportionment by factor analysis with daily time-series studies of daily death indicated a relationship between mobile source $PM_{2.5}$ and mortality.[240,241] Another recent study in 14 U.S. cities examined the effect of PM_{10} exposures on daily hospital admissions for cardiovascular disease. They found that the effect of PM_{10} was significantly greater in areas with a larger proportion of PM_{10} coming from motor vehicles, indicating that PM_{10} from these sources may have a greater effect on the toxicity of ambient PM_{10} when compared with other sources.[242] These studies provide evidence that PM-related emissions, specifically from mobile sources, are associated with adverse health effects.

3.4.2.2 Long-Term Exposure Mortality and Morbidity Studies

Long-term exposure to elevated ambient $PM_{2.5}$ is associated with mortality from cardiopulmonary diseases and lung cancer (PM AQCD, p. 8-307), and effects on the respiratory system such as decreased lung function or the development of chronic respiratory disease (PM AQCD, pp. 8-313, 8-314). Of specific importance to this rule, the PM AQCD also notes that the PM components of gasoline and diesel engine exhaust represent one class of hypothesized likely important contributors to observed ambient PM-related increases in lung cancer incidence and mortality (PM AQCD, p. 8-318).

The PM AQCD and PM Staff Paper emphasize the results of two long-term studies, the Six Cities and American Cancer Society (ACS) prospective cohort studies, based on several factors – the inclusion of measured PM data, the fact that the study populations were similar to the general population, and the fact that these studies have undergone extensive reanalysis (PM AQCD, p. 8-306, Staff Paper, p.3-18).[243,244,245] These studies indicate that there are significant associations for all-cause, cardiopulmonary, and lung cancer mortality with long-term exposure to $PM_{2.5}$. A variety of studies have been published since the completion of the AQCD. One such study, which was summarized in EPA's provisional assessment, was an analysis of a subset of the ACS cohort data, which was published after the PM AQCD was finalized but in time for the 2006 Provisional Assessment, found a larger association than had previously been reported between long-term $PM_{2.5}$ exposure and mortality in the Los Angeles area using a new exposure estimation method that accounted for variations in concentration within the city.[246] EPA is assessing the significance of this study within the context of the broader literature.

As discussed in the PM AQCD, the morbidity studies that combine the features of cross-sectional and cohort studies provide the best evidence for chronic exposure effects. Long-term studies evaluating the effect of ambient PM on children's development have shown some evidence indicating effects of $PM_{2.5}$ and/or PM_{10} on reduced lung function growth (PM AQCD, Section 8.3.3.2.3). A variety of studies have been published since the completion of the AQCD. One such study, which was summarized in EPA's provisional assessment, reported the results of a cross-sectional study of outdoor $PM_{2.5}$ and measures of atherosclerosis in the Los Angeles basin.[247] The study found significant associations between ambient residential $PM_{2.5}$ and carotid intima-media thickness (CIMT), an indicator of subclinical atherosclerosis, an underlying factor in cardiovascular disease. EPA is assessing the significance of this study within the context of the broader literature.

3.4.2.3 Roadway-Related Pollution Exposure

A recent body of studies reinforces the findings of these PM morbidity and mortality effects by looking at traffic-related exposures, PM measured along roadways, or time spent in traffic and adverse health effects. While many of these studies did not measure PM specifically, they include potential exhaust exposures which include mobile source PM because they employ indices such as roadway proximity or traffic volumes. One study with specific relevance to $PM_{2.5}$ health effects is a study that was done in North Carolina looking at concentrations of $PM_{2.5}$ inside police cars and corresponding physiological changes in the police personnel driving the cars. The authors report significant elevations in markers of cardiac risk associated with concentrations of $PM_{2.5}$ inside police cars on North Carolina state highways.[248] A number of studies of traffic-related pollution have shown associations between fine particles and adverse respiratory outcomes in children who live near major roadways.[249,250,251] Additional information on near-roadway health effects is included in Section 3.5 of this RIA.

3.4.3 Current and Projected PM Levels

The emission reductions from this rule will assist PM nonattainment areas in reaching the standard by each area's respective attainment date and assist PM maintenance areas in maintaining the PM standards in the future. In this section we present information on current and future attainment of the PM standards.

3.4.3.1 Current $PM_{2.5}$ Levels

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. In 2005, EPA designated 39 nonattainment areas for the 1997 $PM_{2.5}$ NAAQS based on air quality design values (using 2001-2003 or 2002-2004 measurements) and a number of other factors.[1] (70 FR 943, January 5, 2005; 70 FR 19844, April 14, 2005). These areas are comprised of 208 full or partial counties with a total population exceeding 88 million. The 1997 $PM_{2.5}$ nonattainment areas and populations, as of October 2006, are listed in Appendix 3C to this RIA. As mentioned in Section 3.4.1, the 1997 $PM_{2.5}$ NAAQS was recently revised and the 2006 $PM_{2.5}$ NAAQS became effective on December 18, 2006. Nonattainment areas will be designated with respect to the 2006 $PM_{2.5}$ NAAQS in early 2010. Table 3.4-1 presents the number of counties in areas

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[1] The full details involved in calculating a $PM_{2.5}$ design value are given in Appendix N of 40 CFR Part 50.

currently designated as nonattainment for the 1997 $PM_{2.5}$ NAAQS as well as the number of additional counties which have monitored data that is violating the 2006 $PM_{2.5}$ NAAQS.

Table 3.4-1. $PM_{2.5}$ Standards: Current Nonattainment Areas and Other Violating Counties

	Number of Counties	Population[1]
1997 $PM_{2.5}$ Standards: 39 areas currently designated	208	88,394,000
2006 $PM_{2.5}$ Standards: Counties with violating monitors[2]	49	18,198,676
Total	257	106,592,676

1) Population numbers are from 2000 census data.
2) This table provides an estimate of the counties violating the 2006 $PM_{2.5}$ NAAQS based on 2003-05 air quality data. The areas designated as nonattainment for the 2006 $PM_{2.5}$ NAAQS will be based on 3 years of air quality data from later years. Also, the county numbers in the summary table includes only the counties with monitors violating the 2006 $PM_{2.5}$ NAAQS. The monitored county violations 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 $PM_{2.5}$ nonattainment areas will be required to take action to bring those areas into compliance in the future. Most $PM_{2.5}$ 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.[m] The attainment dates associated with the potential nonattainment areas based on the 2006 $PM_{2.5}$ NAAQS would likely be in the 2015 to 2020 timeframe. The emission standards being finalized in this action will become effective between 2009 and 2015. The expected $PM_{2.5}$ and $PM_{2.5}$ precursor inventory reductions from the standards finalized in this action will be useful to states in attaining or maintaining the $PM_{2.5}$ NAAQS.

3.4.3.2 Current PM_{10} Levels

EPA designated PM_{10} nonattainment areas in 1990.[n] As of October 2006, approximately 28 million people live in the 46 areas that are designated as PM_{10} nonattainment, for either failing to meet the PM_{10} NAAQS or for contributing to poor air quality in a nearby area. There are 46 full or partial counties that make up the PM_{10} nonattainment areas. The PM_{10} nonattainment areas and populations are listed in Appendix 3C to this RIA.

As mentioned in Section 3.4.1, the 1997 PM NAAQS was recently revised and the 2006 PM NAAQS became effective on December 18, 2006. The annual PM_{10} NAAQS was revoked and the 24 hour PM_{10} NAAQS was not changed. The projected reductions in emissions from the controls finalized in this action will be useful to states to maintain the PM_{10} NAAQS.

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[m] The EPA finalized $PM_{2.5}$ attainment and nonattainment areas in April 2005. The EPA proposed the PM Implementation rule in November 2005 (70 FR 65984).

[n] A PM_{10} design value is the concentration that determines whether a monitoring site meets the NAAQS for PM_{10}. The full details involved in calculating a PM_{10} design value are given in Appendices H and I of 40 CFR Part 50.

3.4.3.3 Projected $PM_{2.5}$ Levels

Recent air quality modeling predicts that without additional controls there will continue to be a need for reductions in PM concentrations in the future. In the following sections we describe the recent PM air quality modeling and results of the modeling.

3.4.3.3.1 PM Modeling Methodology

Recently PM air quality analyses were performed for the PM NAAQS final rule, which was promulgated by EPA in 2006. The Community Multiscale Air Quality (CMAQ) model was used as the tool for simulating base and future year concentrations of PM, visibility and deposition in support of the PM NAAQS air quality assessment. The PM NAAQS analysis included all final federal rules up to and including Clean Air Interstate Rule (CAIR) and all final mobile source rule controls as of October 2006. Details on the air quality modeling are provided in the Regulatory Impact Analysis (RIA) for the Final PM NAAQS Rule, included in the docket for this final rule.[252]

3.4.3.3.2 Areas at Risk of Future $PM_{2.5}$ Violations

Air quality modeling performed for the final PM NAAQS indicates that in the absence of additional local, regional or national controls, there will likely continue to be counties that will not attain some combination of the annual 2006 $PM_{2.5}$ standard (15 µg/m^3) and the daily 2006 $PM_{2.5}$ standard (35 µg/m^3). The PM NAAQS analysis provides estimates of future $PM_{2.5}$ levels across the country. For example, in 2015 based on emission controls currently adopted or expected to be in place[o], we project that 53 million people will live in 52 counties with projected $PM_{2.5}$ design values at and above the 2006 standard, see Table 3.4-2.[p] The rule will assist these counties in attaining the $PM_{2.5}$ NAAQS. Table 3.4-2 also lists the 54 counties, where 27 million people are projected to live, with 2015 projected design values that do not violate the $PM_{2.5}$ NAAQS but are within ten percent of it. The rule may help ensure that these counties continue to maintain their attainment status.

Table 3.4-2. Counties with 2015 Projected Annual and Daily $PM_{2.5}$ Design Values Above and within 10% of the 2006 $PM_{2.5}$ Standard[a]

State	County	2015 Projected Annual $PM_{2.5}$ Design Value (µg/m^3)	2015 Projected Daily $PM_{2.5}$ Design Value (µg/m^3)	2015 Population[b]

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[o] Counties forecast to remain in nonattainment may need to adopt additional local or regional controls to attain the standards by dates set pursuant to the Clean Air Act. The emissions reductions associated with this rule will help these areas attain the PM standards by their statutory date.

[p] Note that this analysis identifies only counties projected to have a violating monitor; the number of counties to be designated and the associated population would likely exceed these estimates.

Alabama	Jefferson Co	**15.9**	**36.9**	669,850
California	Alameda Co	**13.3**	**59.4**	1,628,698
California	Butte Co	**13.4**	**50.7**	242,166
California	Colusa Co	9.5	33.5	23,066
California	Contra Costa Co	**12.6**	**61.3**	1,155,323
California	Fresno Co	**20.1**	**73.0**	960,934
California	Imperial Co	**14.8**	**45.7**	173,482
California	Inyo Co	**6.1**	**38.1**	19,349
California	Kern Co	**21.3**	**81.4**	804,940
California	Kings Co	**17.2**	**70.6**	161,607
California	Los Angeles Co	**23.7**	**62.2**	9,910,805
California	Merced Co	**15.8**	**54.4**	250,152
California	Orange Co	**20.0**	**41.1**	3,467,120
California	Placer Co	**11.4**	**38.1**	403,624
California	Riverside Co	**27.8**	**73.5**	2,015,955
California	Sacramento Co	**12.2**	**49.8**	1,488,456
California	San Bernardino Co	**24.6**	**65.7**	2,157,926
California	San Diego Co	**15.8**	**40.7**	3,489,368
California	San Francisco Co	**11.3**	**52.5**	765,846
California	San Joaquin Co	**15.4**	**51.1**	675,362
California	San Luis Obispo Co	**9.4**	**35.8**	304,079
California	San Mateo Co	**10.5**	**41.9**	785,949
California	Santa Clara Co	**10.7**	**48.5**	1,899,727
California	Solano Co	**11.7**	**57.7**	529,784
California	Sonoma Co	**10.0**	**38.9**	569,486
California	Stanislaus Co	**16.6**	**61.9**	547,041
California	Sutter Co	**11.2**	**39.3**	99,716
California	Tulare Co	**21.2**	**77.2**	441,185
California	Ventura Co	**14.1**	**38.8**	923,205
California	Yolo Co	10.2	33.0	206,388
Connecticut	Fairfield Co	11.0	31.6	893,629
Georgia	Bibb Co	13.7	27.0	160,468
Georgia	Clayton Co	13.9	28.7	280,476
Georgia	DeKalb Co	13.6	31.5	715,947
Georgia	Floyd Co	14.0	30.9	97,674
Georgia	Fulton Co	**15.5**	**32.2**	877,365
Georgia	Muscogee Co	13.4	34.2	197,634
Georgia	Wilkinson Co	13.6	29.3	11,259
Idaho	Ada Co	8.9	32.2	397,456
Idaho	Bannock Co	**9.1**	**40.2**	88,033
Idaho	Canyon Co	9.2	32.6	154,137
Idaho	Power Co	**10.5**	**36.6**	8,932
Idaho	Shoshone Co	**12.4**	**36.2**	15,646
Illinois	Cook Co	**15.5**	**37.1**	5,362,931
Illinois	Madison Co	**15.2**	**35.5**	271,854
Illinois	St. Clair Co	14.6	30.4	251,612
Illinois	Will Co	13.2	32.0	634,068
Indiana	Clark Co	13.6	31.1	112,523
Indiana	Lake Co	**13.4**	**40.8**	490,795

Indiana	Marion Co	13.5	33.1	889,645
Kentucky	Jefferson Co	13.8	33.4	710,231
Maryland	Anne Arundel Co	11.1	33.2	574,322
Maryland	Baltimore city	13.0	35.5	596,076
Maryland	Baltimore Co	11.3	32.6	810,172
Massachusetts	Hampden Co	11.6	32.9	452,055
Michigan	Kalamazoo Co	12.8	32.7	257,817
Michigan	Kent Co	12.0	31.9	654,449
Michigan	Oakland Co	13.0	33.2	1,355,670
Michigan	St. Clair Co	12.5	32.5	185,970
Michigan	Wayne Co	**17.4**	**39.0**	1,921,253
Montana	Lincoln Co	**15.0**	**42.4**	19,875
Montana	Missoula Co	10.6	32.1	118,303
New Jersey	Camden Co	11.1	32.1	512,135
New Jersey	Hudson Co	12.0	32.8	604,036
New Jersey	Union Co	12.2	32.8	525,096
New York	Bronx Co	12.8	33.2	1,283,316
New York	New York Co	14.0	33.2	1,551,641
Ohio	Cuyahoga Co	**15.4**	**40.0**	1,325,507
Ohio	Franklin Co	13.7	33.5	1,181,578
Ohio	Hamilton Co	14.3	34.2	841,858
Ohio	Jefferson Co	14.2	34.2	68,909
Ohio	Lucas Co	12.5	32.2	443,230
Ohio	Scioto Co	**15.6**	**34.3**	81,013
Ohio	Trumbull Co	12.1	34.2	227,546
Oregon	Jackson Co	**10.9**	**37.6**	250,169
Oregon	Klamath Co	**10.1**	**39.1**	69,423
Oregon	Lane Co	**12.9**	**53.6**	387,237
Oregon	Washington Co	9.0	32.0	639,839
Pennsylvania	Allegheny Co	**16.5**	**53.4**	1,245,917
Pennsylvania	Beaver Co	12.1	33.2	184,648
Pennsylvania	Berks Co	**12.0**	**35.5**	396,410
Pennsylvania	Dauphin Co	11.0	33.3	272,748
Pennsylvania	Lancaster Co	12.2	33.7	535,622
Pennsylvania	Lehigh Co	10.5	34.7	328,523
Pennsylvania	Mercer Co	11.0	31.6	123,577
Pennsylvania	Northampton Co	10.9	35.0	286,838
Pennsylvania	Philadelphia Co	13.3	35.2	1,372,037
Pennsylvania	York Co	**12.3**	**35.9**	417,408
Tennessee	Knox Co	13.6	29.6	448,931
Utah	Box Elder Co	**8.6**	**39.0**	49,878
Utah	Cache Co	**12.5**	**51.9**	114,729
Utah	Salt Lake Co	**12.6**	**49.3**	1,133,410
Utah	Utah Co	**9.3**	**36.7**	508,106
Utah	Weber Co	**9.1**	**36.2**	229,807
Washington	Clark Co	9.2	34.3	479,002
Washington	King Co	10.8	34.0	2,013,808
Washington	Pierce Co	**11.1**	**43.0**	879,363
Washington	Snohomish Co	**11.3**	**40.1**	782,319
Washington	Thurston Co	8.9	34.9	264,364

Washington	Yakima Co	9.6	34.9	261,452
West Virginia	Berkeley Co	12.0	32.7	99,349
West Virginia	Hancock Co	13.4	32.7	30,857
West Virginia	Kanawha Co	13.9	28.9	196,498
Wisconsin	Milwaukee Co	12.1	32.1	908,336
Wisconsin	Waukesha Co	11.8	32.4	441,482
Wyoming	Sheridan Co	10.5	31.8	28,623
Number of Violating Counties		52		
Population of Violating Counties				53,468,515
Number of Counties within 10%		54		
Population of Counties within 10%				26,896,926

a) Bolded concentrations indicate levels above the $PM_{2.5}$ standard.
b) Populations are based on 2000 census projections.

3.4.4 Environmental Effects of PM Pollution

In this section we discuss public welfare effects of PM and its precursors including visibility impairment, atmospheric deposition, and materials damage and soiling.

3.4.4.1 Visibility Impairment

Visibility can be defined as the degree to which the atmosphere is transparent to visible light.[253] Visibility impairment manifests in two principal ways: as local visibility impairment and as regional haze.[q] Local visibility impairment may take the form of a localized plume, a band or layer of discoloration appearing well above the terrain as a result from complex local meteorological conditions. Alternatively, local visibility impairment may manifest as an urban haze, sometimes referred to as a "brown cloud." This urban haze is largely caused by emissions from multiple sources in the urban areas and is not typically attributable to only one nearby source or to long-range transport. The second type of visibility impairment, regional haze, usually results from multiple pollution sources spread over a large geographic region. Regional haze can impair visibility over large regions and across states.

Visibility is important because it has direct significance to people's enjoyment of daily activities in all parts of the country. Individuals value good visibility for the well-being it provides them directly, where they live and work, and in places where they enjoy recreational opportunities. Visibility is also highly valued in significant natural areas such as national parks and wilderness areas, and special emphasis is given to protecting visibility in these areas. For more information on visibility see the 2004 PMAQCD as well as the 2005 PM Staff Paper.[254,255]

Fine particles are the major cause of reduced visibility in parts of the United States. To address the welfare effects of PM on visibility, EPA set secondary $PM_{2.5}$ standards which would

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[q] See discussion in U.S. EPA , National Ambient Air Quality Standards for Particulate Matter; Proposed Rule; January 17, 2006, Vol71 p 2676. This information is available electronically at http://epa.gov/fedrgstr/EPA-AIR/2006/January/Day-17/a177.pdf.

act in conjunction with the establishment of a regional haze program. In setting this secondary standard, EPA 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. The secondary (welfare-based) $PM_{2.5}$ NAAQS was established as equal to the suite of primary (health-based) NAAQS. Furthermore, Section 169A of the Act provides additional authority to address existing visibility impairment and prevent future visibility impairment in the 156 national parks, forests and wilderness areas categorized as mandatory class I federal areas (62 FR 38680-81, July 18, 1997).[r] In July 1999 the regional haze rule (64 FR 35714) was put in place to protect the visibility in mandatory class I federal areas. Visibility can be said to be impaired in both $PM_{2.5}$ nonattainment areas and mandatory class I federal areas.

Data showing $PM_{2.5}$ nonattainment areas and visibility levels above background at the Mandatory Class I Federal Areas demonstrate that visibility impairment is experienced throughout the U.S., in multi-state regions, urban areas, and remote mandatory Federal class I areas. The PM and PM precursor emissions from the vehicles and gas cans subject to this proposed rule contribute to these visibility effects.

3.4.4.1.1 Current Visibility Impairment

The need for reductions in the levels of $PM_{2.5}$ is widespread. Currently, high ambient $PM_{2.5}$ levels are measured throughout the country. Fine particles may remain suspended for days or weeks and travel hundreds to thousands of kilometers, and thus fine particles emitted or created in one county may contribute to ambient concentrations in a neighboring region.[256]

As mentioned above the secondary $PM_{2.5}$ standards were set as equal to the suite of primary $PM_{2.5}$ standards. Recently designated $PM_{2.5}$ nonattainment areas indicate that almost 90 million people live in 208 counties that are in nonattainment for the 1997 $PM_{2.5}$ NAAQS, see Appendix 3C. Thus, at least these populations (plus others who travel to these areas) would likely be experiencing visibility impairment.

3.4.4.1.2 Current Visibility Impairment at Mandatory Class I Federal Areas

Detailed information about current and historical visibility conditions in mandatory class I federal areas is summarized in the EPA Report to Congress and the 2002 EPA Trends Report.[257,258] The conclusions draw upon the Interagency Monitoring of Protected Visual Environments (IMPROVE) network data. One of the objectives of the IMPROVE monitoring network program is to provide regional haze monitoring representing all mandatory class I federal areas where practical. The National Park Service report also describes the state of national park visibility conditions and discusses the need for improvement.[259]

The regional haze rule requires states to establish goals for each affected mandatory class I federal area to improve visibility on the haziest days (20% most impaired days) and ensure no degradation occurs on the cleanest days (20% least impaired days). Although there have been

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[r] These areas are defined in Section 162 of the Act as those national parks exceeding 6,000 acres, wilderness areas and memorial parks exceeding 5,000 acres, and all international parks which were in existence on August 7, 1977.

general trends toward improved visibility, progress is still needed on the haziest days. Specifically, as discussed in the 2002 EPA Trends Report, without the effects of pollution a natural visual range in the United States is approximately 75 to 150 km in the East and 200 to 300 km in the West. In 2001, the mean visual range for the worst days was 29 km in the East and 98 km in the West. [260]

3.4.4.1.3 Future Visibility Impairment

Recent modeling for the final PM NAAQS rule was used to project $PM_{2.5}$ levels in the U.S. in 2015. The results suggest that $PM_{2.5}$ levels above the 2006 NAAQS will persist in the future. We predicted that in 2015, there will be 52 counties with a population of 53 million where annual $PM_{2.5}$ levels will exceed the 2006 $PM_{2.5}$ NAAQS, see Table 3.4-1. Thus, in the future, a percentage of the population may continue to experience visibility impairment in areas where they live, work and recreate.

The PM and PM precursor emissions from the vehicles and gas cans subject to the proposed controls contribute to visibility impairment. These emissions occur in and around areas with $PM_{2.5}$ levels above the annual 1997 $PM_{2.5}$ NAAQS. Thus, the emissions from these sources contribute to the current and anticipated visibility impairment and the emission reductions finalized here may help improve future visibility impairment.

3.4.4.1.4 Future Visibility Impairment at Mandatory Class I Federal Areas

Achieving the $PM_{2.5}$ NAAQS will help improve visibility across the country, but it will not be sufficient to meet the statutory goal of no manmade impairment in the mandatory class I federal areas (64 FR 35714, July 1, 1999 and 62 FR 38652, July 18, 1997). In setting the NAAQS, EPA discussed how the NAAQS in combination with the regional haze program, is deemed to improve visibility consistent with the goals of the Act. In the East, there are and will continue to be areas with $PM_{2.5}$ concentrations above the $PM_{2.5}$ NAAQS and where light extinction is significantly above natural background. Thus, large areas of the Eastern United States have air pollution that is causing and will continue to cause visibility impairment. In the West, scenic vistas are especially important to public welfare. Although the $PM_{2.5}$ NAAQS is met in most areas outside of California, virtually the entire West is in close proximity to a scenic mandatory class I federal area protected by 169A and 169B of the CAA.

Recent modeling for CAIR was also used to project visibility conditions in mandatory class I federal areas across the country in 2015. The results for the mandatory class I federal areas suggest that these areas are predicted to continue to have visibility impairment above background on the 20% worst days in the future.

The overall goal of the regional haze program is to prevent future visibility impairment and remedy existing visibility impairment in mandatory class I federal areas. As shown by the future visibility estimates in Appendix 3D it is projected that there will continue to be mandatory class I federal areas with visibility levels above background in 2015. [261] Additional emission reductions will be needed from the broad set of sources that contribute, including the vehicles and gas cans subject to this rule. The reductions being finalized in this action are a part of the overall strategy to achieve the visibility goals of the Act and the regional haze program.

3.4.4.2 Atmospheric Deposition

Wet and dry deposition of ambient particulate matter delivers a complex mixture of metals (e.g., mercury, zinc, lead, nickel, aluminum, cadmium), organic compounds (e.g., POM, dioxins, furans) and inorganic compounds (e.g., nitrate, sulfate) to terrestrial and aquatic ecosystems. The chemical form of the compounds deposited is impacted by a variety of factors including ambient conditions (e.g., temperature, humidity, oxidant levels) and the sources of the material. Chemical and physical transformations of the particulate compounds occur in the atmosphere as well as the media onto which they deposit. These transformations in turn influence the fate, bioavailability and potential toxicity of these compounds. Atmospheric deposition has been identified as a key component of the environmental and human health hazard posed by several pollutants including mercury, dioxin and PCBs.[262]

Adverse impacts on water quality can occur when atmospheric contaminants deposit to the water surface or when material deposited on the land enters a waterbody through runoff. Potential impacts of atmospheric deposition to waterbodies include those related to both nutrient and toxic inputs. Adverse effects to human health and welfare can occur from the addition of excess particulate nitrate nutrient enrichment which contributes to toxic algae blooms and zones of depleted oxygen, which can lead to fish kills, frequently in coastal waters. Particles contaminated with heavy metals or other toxins may lead to the ingestion of contaminated fish, ingestion of contaminated water, damage to the marine ecology, and limited recreational uses. Several studies have been conducted in U.S. coastal waters and in the Great Lakes Region in which the role of ambient PM deposition and runoff is investigated.[263,264,265,266,267]

Adverse impacts on soil chemistry and plant life have been observed for areas heavily impacted by atmospheric deposition of nutrients, metals and acid species, resulting in species shifts, loss of biodiversity, forest decline and damage to forest productivity. Potential impacts also include adverse effects to human health through ingestion of contaminated vegetation or livestock (as in the case for dioxin deposition), reduction in crop yield, and limited use of land due to contamination.

In the following subsections, atmospheric deposition of heavy metals and particulate organic material is discussed.

3.4.4.2.1 Heavy Metals

Heavy metals, including cadmium, copper, lead, chromium, mercury, nickel and zinc, have the greatest potential for influencing forest growth (PM AQCD, p. 4-87).[268] Investigation of trace metals near roadways and industrial facilities indicate that a substantial burden of heavy metals can accumulate on vegetative surfaces. Copper, zinc, and nickel have been documented to cause direct toxicity to vegetation under field conditions (PM AQCD, p. 4-75). Little research has been conducted on the effects associated with mixtures of contaminants found in ambient PM. While metals typically exhibit low solubility, limiting their bioavailability and direct toxicity, chemical transformations of metal compounds occur in the environment, particularly in the presence of acidic or other oxidizing species. These chemical changes influence the mobility and toxicity of metals in the environment. Once taken up into plant tissue, a metal compound can undergo chemical changes, accumulate and be passed along to herbivores or can re-enter the soil and further cycle in the environment.

Although there has been no direct evidence of a physiological association between tree injury and heavy metal exposures, heavy metals have been implicated because of similarities between metal deposition patterns and forest decline (PM AQCD, p. 4-76).[269] Contamination of plant leaves by heavy metals can lead to elevated soil levels. Some trace metals absorbed into the plant and can bind to the leaf tissue (PM AQCD, p. 4-75). When these leaves fall and decompose, the heavy metals are transferred into the soil.[270,271]

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 a portion of emitted mercury to travel far from the primary source before being deposited and accumulating in the aquatic ecosystem. Localized or regional impacts are also observed for mercury emitted from combustion sources. The major source of mercury in the Great Lakes is from atmospheric deposition, accounting for approximately eighty percent of the mercury in Lake Michigan.[272,273] Over fifty percent of the mercury in the Chesapeake Bay has been attributed to atmospheric deposition.[274] Overall, the National Science and Technology Council (NSTC, 1999) identifies atmospheric deposition as the primary source of mercury to aquatic systems. 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.[275,276] 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.[277] Plant uptake of platinum has been observed at these locations.

3.4.4.2.2 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.[278] 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.[279]

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.[280,281] Analyses of PAH deposition to Chesapeake and Galveston Bay indicate that dry deposition and gas exchange from the atmosphere to the surface water predominate.[282,283] 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.[284] PAHs that enter a waterbody through gas exchange likely partition into organic rich particles and be biologically recycled, while dry deposition of aerosols containing PAHs tends to be more resistant to biological recycling.[285] 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.[286] Van Metre et al. (2000) noted PAH concentrations in urban reservoir sediments have increased by 200-300% over the last forty years and correlates with increases in automobile use.[287]

Cousins et al. (1999) estimates that greater than ninety percent of semi-volatile organic compound (SVOC) emissions in the United Kingdom deposit on soil.[288] An analysis of polycyclic aromatic hydrocarbon (PAH) concentrations near a Czechoslovakian roadway indicated that concentrations were thirty times greater than background.[289]

3.4.4.3 Materials Damage and Soiling

The deposition of airborne particles can also reduce the aesthetic appeal of buildings and culturally important articles through soiling, and can contribute directly (or in conjunction with other pollutants) to structural damage by means of corrosion or erosion.[290] Particles affect materials principally by promoting and accelerating the corrosion of metals, by degrading paints, and by deteriorating building materials such as concrete and limestone. Particles contribute to these effects because of their electrolytic, hygroscopic, and acidic properties, and their ability to sorb corrosive gases (principally sulfur dioxide). The rate of metal corrosion depends on a number of factors, including the deposition rate and nature of the pollutant; the influence of the metal protective corrosion film; the amount of moisture present; variability in the electrochemical reactions; the presence and concentration of other surface electrolytes; and the orientation of the metal surface.

3.5 Health and Welfare Impacts of Near-Roadway Exposure

Over the years there have been a large number of studies that have examined associations between living near major roads and different adverse health endpoints. These studies generally examine people living near heavily-trafficked roadways, typically within several hundred meters, where fresh emissions from motor vehicles are not yet fully diluted with background air.

As discussed in Chapter 3.1.3, many studies have measured elevated concentrations of pollutants emitted directly by motor vehicles near large roadways, as compared to overall urban background levels. These elevated concentrations generally occur within approximately 200 meters of the road, although the distance may vary depending on traffic and environmental conditions. Pollutants measured with elevated concentrations include benzene, polycyclic aromatic hydrocarbons, carbon monoxide, nitrogen dioxide, black carbon, and coarse, fine, and ultrafine particles. In addition, resuspended road dust, and wear particles from tire and brake use also show concentration increases in proximity of major roadways.

As noted in section 3.2, HAPEM6 estimates the changes in time-weighted exposures associated with proximity to roadways for individual pollutants. The studies discussed in this section address exposures and health effects that are at least partially captured by our modeling, but there may be additional exposures and health effects associated with pollutants, singly or in combination, that are not explicitly quantified. However, because the studies discussed in this section often employ exposure estimation metrics associated with multiple pollutants, exposure-response information from these studies may not be suitable for risk assessment geared around one or several chemicals.

At this point, there exists no exposure metric specific to "traffic," although as noted above, a wide variety of gaseous, particulate, and semi-volatile species are elevated near roadways. As a result, the exposure metrics employed generally indicate the presence and/or intensity of a mixture of air pollutants for exposure assessment. Many of the health studies discussed below employ non-specific exposure metrics, including traffic on roads nearest home or school, distance to the nearest road, measured outdoor nitrogen dioxide concentrations, air quality dispersion modeling of specific traffic-generated chemicals, and exposure assignment based on land use. These exposure metrics represent the mixture of traffic-generated pollutants, rather than individual pollutants. Accordingly, such results are not directly comparable with community epidemiology studies that employ ambient measurements of particulate matter or ozone over a fixed time period, or to toxicological studies employing a single pollutant to evaluate responses in humans or animals.

A wide range of health effects are reported in the literature related to near roadway and in-vehicle exposures. This is not unexpected, given the chemical and physical complexity of the mixture to which people are exposed in this environment. These effects overlap with those identified in our discussion of the effects of PM and ozone. The discussion below addresses the studies in detail. However, in general terms, the near-roadway health studies provide stronger evidence for some health endpoints than others. Epidemiologic evidence of adverse responses to traffic-related pollution is strongest for non-allergic respiratory symptoms, and several well-conducted epidemiologic studies have shown associations with cardiovascular effects, premature adult mortality, and adverse birth outcomes, including low birth weight and size. Traffic-related pollutants have been repeatedly associated with increased prevalence of asthma-related respiratory symptoms in children, although epidemiologic evidence remains inconclusive for a hypothesized link between traffic and the development of allergies and new onset asthma.

For childhood cancer, in particular childhood leukemia, epidemiologic studies have shown less ability to detect the risks predicted from toxicological studies. Several small studies report positive associations, though such effects have not been observed in two larger studies. As described above in Chapter 1.3, benzene and 1,3-butadiene are both known human leukemogens in adults from occupational exposures. As previously mentioned, epidemiologic studies have shown an increased risk of leukemia among children whose parents have been occupationally exposed to benzene. While epidemiologic studies of near-roadway exposures have not always shown a statistically significant association with childhood leukemias, the results are consistent with the risks predicted from the studies at higher exposure levels. As a whole the toxicology and epidemiology are consistent with a potentially serious children's health concern and additional research is needed.

Significant scientific uncertainties remain in research on health effects near roads, including the exposures of greatest concern, the importance of chronic versus acute exposures, the role of fuel type (e.g. diesel or gasoline) and composition (e.g., percent aromatics), and relevant traffic patterns. Furthermore, in these studies, it is often difficult to understand the role of co-stressors including noise and socioeconomic status (e.g., access to health care, nutritional status), and the role of differential susceptibility.

3.5.1 Mortality

The quantifiable effects of this rule on premature mortality associated with exposure to $PM_{2.5}$ are assessed as part of the benefits estimates for this rule. In addition to studies that have documented the relationship between ambient PM and premature mortality, a few recent studies have investigated the relationship between premature mortality and broader indicators of transportation emissions, such as residence near traffic. The extent to which these studies are detecting any additional effects not accounted for in the ambient PM-premature mortality relationship is unclear.

Living near major roads has been investigated in both long-term and short-term mortality studies. Long-term studies track subjects over time and investigate the mortality rates among groups with different levels of exposure to ambient pollutants. Short term studies employ daily variation in ambient concentrations to estimate the daily deaths attributable to air pollution.

A total of three cohort studies have examined premature mortality in relation to residence near traffic, another examined county-level traffic density, while one other has examined stroke mortality. In addition, one study accounted for the effect of residence along a major road on associations with daily deaths in a time-series study. These studies constitute all of the studies examining mortality with reference to proximity to traffic.

Premature mortality in adults in association with living near high-traffic roadways has been studied in three recent cohort studies for all-cause and cardiopulmonary mortality from the Netherlands, Ontario, Canada, and most recently, Germany.[291,292,293] Canadian vehicles and emission standards largely mirror the U.S. vehicle fleet. Both studies defined living near a major road as having a residence within 100 meters of a highway or within 50 meters of a major urban roadway. In the first study, involving approximately 5,000 people over 55 years old living throughout the Netherlands, residence near major roadways was associated with a 41% increase in the mortality rate from all causes and a 95% increase in the cardiopulmonary mortality rate.[294]

The second study involved over 5,200 subjects aged 40 years or more, all living in the Hamilton, Ontario area. This study examined total mortality, finding a statistically significant 18% increase associated with living near a major roadway. No difference in response was found among those with pre-existing respiratory illness. The study also calculated "rate advancement periods," which describe the effect of an exposure in terms of the time period by which exposed persons reach prematurely the same disease risk as unexposed persons reach later on. The rate advancement period for total mortality was 2.5 years. The rate advancement periods were also calculated for other risk factors for mortality, including chronic pulmonary disease excluding asthma (3.4 years), chronic ischemic heart disease (3.1 years), and diabetes mellitus (4.4 years). A subsequent follow-up study found elevated mortality rates from circulatory causes in the Canadian study population.

Most recently, German investigators followed up a series of cross-sectional studies on women age 50-59 living in the North Rhine-Westphalia region during the late 1980's and 1990's, tracking vital status and migration to the years 2002-2003.[295] In total, the cohort consisted of approximately 4800 women. Exposures were categorized using ambient NO_2 and PM_{10} (estimated from TSP), and an indicator of residence within 50 m of a "major road", defined at ≥10,000 cars/day. Overall, living within 50 meters of a major road was associated with a significant 70% increase in the rate of cardiopulmonary mortality. Nearest-monitor NO_2 and PM_{10} were also associated with a 57% and 34% increase in the rate of cardiopulmonary mortality. Exposure to NO_2 was also associated with a 17% increase in all-cause mortality.

Despite differences in the vehicle fleets of Europe and Canada, whose emission standards largely mirror those of the U.S., the results of these studies are similar.

In another study evaluating a cohort of older, hypertensive male U.S. veterans, county-level traffic index and pollution estimates were employed in estimating exposure to traffic activity and other air pollutants.[296] Area-based traffic density was significantly associated with increased mortality rates, as were constituents of motor vehicle exhaust, such as elemental carbon.

One cohort study conducted in the United Kingdom examined cardiocerebral (stroke) mortality in relation to living near traffic.[297] Those living in census areas near roadways had significantly higher stroke mortality rates. In a study involving nearly 190,000 stroke deaths in 1990-1992, Maheswaran and Elliott (2002) examined stroke mortality rates in census districts throughout England and Wales. Census districts closest to major roads showed significant increases in stroke mortality rates for men and women. Compared to those living in census districts whose center was greater than 1000 m from a main road, men and women living in census regions with centers less than 200 m away had stroke mortality rates 7% and 4% higher, respectively.

One study from the Netherlands used time-series analysis to evaluate the change in the magnitude of the association between daily concentrations of black smoke, an air metric related to black carbon, and daily deaths, for populations living along roads with at least 10,000 vehicles per day.[298] Compared with the population living elsewhere, the traffic-exposed population had significantly higher associations between black smoke and daily mortality.

Although the studies of mortality have employed different study designs and metrics of exposure, they provide evidence for increased mortality rates in proximity of heavy traffic. In evaluating the generalizability of these study results, questions remain regarding differences in housing stock, residential ventilation, vehicle type and fuel differences, personal activity patterns, and the appropriate exposure metric. Furthermore, in the cohort studies, although controls for income level were incorporated based on postal code or census area, it is possible that other unmeasured covariates explain the associations with traffic.

3.5.2 Non-Allergic Respiratory Symptoms

Our analysis of the benefits associated with reduced exposure to $PM_{2.5}$ includes chronic bronchitis, hospital admissions for respiratory causes, emergency room visits for asthma, acute bronchitis, upper and lower respiratory symptoms and exacerbation of asthma. In addition, studies in Europe, Asia and North America have found increased risk of respiratory symptoms such as wheeze, cough, chronic phlegm production, and dyspnea (shortness of breath) in children and adults with increased proximity to roadways and/or associated with local traffic density. Most of these studies were cross-sectional and relied solely on questionnaire assessments of health outcomes, in combination with simple exposure indicators. There are a large number of studies available, but for the sake of brevity, only studies conducted in the United States are discussed here. European studies reach similar conclusions, as summarized in a recent review of the European literature.[299] The discussion below covers all studies conducted in the United States. EPA has not formally evaluated the extent to which these studies may be documenting health effects that are already included in the benefits analysis associated with PM.

Most recently, a study from Cincinnati, OH examined the prevalence of wheezing in a group of infants less than one year of age.[300] Infants with at least one atopic parent qualified for enrollment. The study compared infants living near stop-and-go truck traffic with others living near smoothly-flowing truck traffic, and others further from traffic. Infants with wheeze were significantly more likely to live near stop-and-go traffic than either those living near smoothly-flowing traffic or those living away from traffic. Truck volume was not associated with wheeze.

A respiratory health study in the east San Francisco Bay area looked at a series of community schools upwind and downwind of major roads along a major transportation corridor, where ambient air quality was monitored.[301] Over 1,100 children in grades three through five attending the schools were assessed for respiratory symptoms and physician's diagnosis of asthma. Overall, concentrations of traffic-related air pollutants measured at each school were associated with increased prevalence of bronchitis symptoms and physician confirmed asthma, both within the last 12 months.

A case-control study in Erie County, NY compared home proximity to traffic among children admitted into local hospitals for asthma with those admitted for non-respiratory conditions.[302] Overall, children hospitalized for asthma were more likely to live within 200 meters of roads above the 90th percentile of daily vehicle miles traveled, and to have trucks and trailers passing within 200 meters of their residences. However, hospitalization for asthma was not associated with residential distance from major state routes.

A study in San Diego County, CA compared the residential location of asthmatic children with children having a non-respiratory diagnosis within the state Medicaid system.[303] Traffic volumes on streets nearby the home were not associated with the prevalence of asthma. However, among asthmatic children, high street volumes on the nearest street were associated with an increased annual frequency of medical visits for asthma.

In the only U.S. study examining adult respiratory symptoms, Massachusetts veterans were evaluated for traffic-health relationships.[304] In the study, living within 50 m of a major roadway was associated with increased reporting of persistent wheeze. This trend held only for roads with at least 10,000 vehicles per day. Patients experiencing chronic phlegm were also more likely to live within 50 meters of roads with at least 10,000 vehicles per day. However, chronic cough was not associated with living near traffic.

The studies described above employ different exposure metrics and health endpoints, making evaluation difficult. However, numerous other studies from around the world also provide evidence for increased prevalence of respiratory symptoms among people living near major roads. For a detailed listing, refer to the docket of this rule. Taken together, these studies provide evidence that respiratory symptoms may be associated with living near major roadways, particularly in children, upon whom the preponderance of studies have focused.

3.5.3 Development of Allergic Disease and Asthma

A significant number of studies have examined evidence of a role of traffic-generated pollution in the development (e.g. new onset) of atopic illnesses (i.e., hypersensitivity to allergens), such as asthma, allergic rhinitis, and dermatitis. A critical review of evidence, primarily generated in European studies, was recently published.[305] Overall, the review concluded that there is some limited evidence of an association between traffic-generated pollutants and asthma incidence. More recent studies have also found significant associations between prevalent asthma and living near major roads.[306] Toxicological evidence provides some evidence that particles from diesel engine exhaust may serve as adjuvants to IgE-mediated immune responses. EPA's Health Assessment Document for Diesel Engine Exhaust addresses many of the toxicological studies on diesel exhaust. However, in community epidemiology studies, the evidence remains tentative. The potential for these effects is not taken into account in the benefits analysis for PM because EPA's various scientific advisors have argued that the literature is not strong enough to support a causal association.

3.5.4 Cardiovascular Effects

Cardiovascular effects are currently seen as a potentially important set of mechanisms whereby $PM_{2.5}$ may be leading to premature mortality. In Chapter 12, we estimate the quantifiable benefits of PM-related non-fatal acute myocardial infarction and cardiovascular hospital admissions. The studies described in Section 3.5.1 found higher relative risks for cardiopulmonary causes of death.

In addition to cardiopulmonary mortality, some studies have looked at morbidity. A recent study from Germany also found significant increased odds of coronary heart disease (CHD) in a cohort of approximately 3400 participants.[307] Residents living within 150 meters of major roads were compared to those living further ways. Overall, controlling for background air pollution and individual risk factors, the adjusted odds ratio for CHD prevalence was significantly elevated (1.85). Subgroup analyses indicated stronger effects in men, in participants under 60 year of age, and in never-smokers.

Several additional studies have provided suggestive evidence that exposure to fresh emissions from traffic predispose people to adverse cardiovascular events. Studies have focused on both short-term variations in exposure, as well as long-term residential history. As discussed in the summary section below, there are stressors in the roadway environment in addition to ambient air pollutants (e.g., noise, anxiety) that also have an impact on cardiovascular activity. The potential role of these co-stressors has not been adequately investigated.

A study from Augsburg, Germany interviewed survivors of myocardial infarction (MI) shortly after they had recovered to examine ambient pollution and activities that might predispose someone to having a heart attack.[308] Survivors of MI were nearly three times as likely to be in a car, in transit, or on a bicycle in the hour prior to the event as they were to be in traffic at other times. Ambient air pollutants measured in the hour prior to MI at a central site in the city were not associated with the risk of MI.

A study of healthy young North Carolina state patrolmen conducted by EPA's Office of Research and Development monitored in-vehicle concentrations of $PM_{2.5}$, VOCs, and metals.[309] In-vehicle $PM_{2.5}$ concentrations were associated with altered heart rate variability, an indicator of cardiac stress. In-vehicle concentrations were also associated with increased concentrations of factors in the blood associated with long-term cardiac risk, such as C-reactive protein, an indicator of inflammation. This study provides information on possible mechanisms by which cardiac stress could be induced by exposures to traffic-generated air pollution.

Heart rate variability has also been measured in a study of elderly residents of the Boston area.[310] In the study, ambient $PM_{2.5}$ was associated with changes consistent with reduced autonomic control of the heart. Black carbon, often a more reliable index of traffic-related pollution, was also associated with these changes. In a related study, ST-segment depression, a cardiographic indicator of cardiac ischemia or inflammation, was associated with black carbon levels as well.[311] These studies further document a hypothesized mechanism associated with motor vehicle emissions, but do not necessarily suggest effects independent of those identified in our discussion of PM health effects.

3.5.5 Birth Outcomes

A few studies examining birth outcomes in populations living near major traffic sources have found evidence of low birth weight, preterm birth, reduced head circumference and heart defects among children of mothers living in close proximity to heavy traffic. Our discussion of PM health effects also quantitatively accounts for premature mortality effects in infants and qualitatively accounts for low birth weight.

One measure of exposure to traffic-generated pollution is “distance-weighted traffic density,” where traffic volume is treated as a measure that “disperses” along a Gaussian bell-shaped curve evenly on both sides of a roadway. This approach captures some of the patterns of dispersion from line sources, but does not account for micrometeorology. One study from Los Angeles County, California employed this metric in a study of birth outcomes for births from 1994 to 1996. The study showed associations between distance-weighted traffic volume near women’s residences during pregnancy and premature birth and low birth weight in their babies.[312] The elevated risks occurred primarily for mothers whose third trimesters fell during fall or winter months.

The same researchers had conducted an earlier study of births occurring between 1989 and 1993. In that study, consisting of over 125,000 births, exposures to ambient carbon monoxide (CO), an indicator of traffic pollution, during the third trimester were significantly associated with increased risk of low birth weight.[313] In another study, preterm birth was associated with ambient PM_{10} and CO.[314] These authors have also reported in a separate study on the increase in cardiac ventricular septal defects with increasing CO exposure during the second month of pregnancy.[315] The role of socioeconomic status and factors associated with it should be investigated in future study design.

Although the exposure metrics employed in these studies are based on surrogate approaches to exposure estimation, other researchers have shown associations between New York mothers’ measured personal exposure to polycyclic aromatic hydrocarbons (PAHs) during pregnancy and an increased risk of low birth weight and size.[316] Subsequent follow-up of the same birth cohort to age three found evidence of neurodevelopmental deficits associated with maternal exposure to PAHs during pregnancy, particularly in cognitive development.[317]

Overall, although the number of studies examining perinatal exposures is small, there is some evidence that exposure to traffic-related pollutants may be associated with adverse birth outcomes, including low birth weight and preterm birth. However, given the variety of exposure metrics employed and the relatively limited geographic extent of studies, the generalization of the conclusions requires a better understanding of relevant sources, pollutants, susceptibility, and local factors.

3.5.6 Childhood Cancer

Several MSATs are associated with cancer in adult populations. However, children have physical and biochemical differences that may affect their susceptibility to and metabolism of MSATs. Particularly in the first year or two after birth, infants' liver enzyme profiles undergo rapid change. As such, children may respond to MSATs in different ways from adults. Some evidence exists that children may face different cancer risks from adults as a result of exposure to certain MSATs and other components of motor vehicle exhaust. EPA recently recommended default adjustments to cancer risk estimates for compounds with a mutagenic mode of action to account for early life exposures in the Supplemental Guidance for Assessing Susceptibility from Early-Life Exposure to Carcinogens.[318]

Evidence from human and animal studies suggests that increases in childhood leukemia may be associated with *in utero* exposures to benzene and maternal and paternal exposure prior to conception. Furthermore, there is some evidence that key changes related to the development of childhood leukemia occur in the developing fetus.[319]

In the last 15 years, several studies have evaluated the association between maternal or childhood residence near busy roads and the risk of cancer in children. Most studies to date have been ecological in nature, with several employing individual-level exposure estimates within cohort designs. The studies employed widely varying exposure metrics, including modeled air quality, proximity to sources, and distance-weighted traffic volumes. Positive studies tend to have used small population sizes, although one recent positive study used a large population. Due to differences in ages studied, study design, exposure metrics, and study location (e.g. Europe vs. U.S.), a systematic comparison between studies is difficult. A description of several key studies from this literature follows.

One early study from Colorado showed significant elevated risk of childhood leukemia in children under age 15 associated with living near roads with higher traffic volumes. The strongest associations were with roads with at least 10,000 vehicles per day.[320] The study was reanalyzed using an approach to combine traffic volume with residential distance from major roads to assess "distance-weighted traffic volume."[321] The study found that the significant, monotonically increasing risks associated with increased distance-weighted traffic volume.

NO_2 has been used as an indicator of traffic emissions in some studies; however, it is important to note that NO_2 is not implicated as causing cancer. For instance, a study used a dispersion model of NO_2 from traffic to conduct a case-control study of childhood cancer in Sweden.[322] The study found that in the highest-exposed group, risk of any cancer was significantly elevated. Risks in the most-exposed group were also elevated for leukemia and central nervous system tumors, but were not statistically significant.

These earlier studies were based on relatively small populations of children with cancer. In response, subsequent studies focused on either replicating the earlier studies or studying larger groups of children. A study in Los Angeles, California applied the same distance-weighted traffic volume approach as the earlier Colorado study, but found no elevation in risk in a larger group of children.[323] A large study of nearly 2,000 Danish children with cancer found no association between modeled concentrations of benzene and NO_2 at home and the risk of leukemia, central nervous system tumors, or total cancers.[324] However, the study did find a dose-dependent relationship between Hodgkin's disease and modeled air pollution from traffic.

Several large studies were conducted in California using a statewide registry of cancer. These studies employed study sizes of several thousand subjects. In one cross-sectional study, the potency-weighted sum of concentrations of 25 air toxics modeled using EPA's ASPEN model was not associated with mobile source emissions, but increased rates of childhood leukemia were found when accounting for all sources of air toxics together, and for point sources separately.[325] Another study from the same researchers found that roadway density and traffic density within 500 meters of children's homes was not associated with risk of cancer.[326]

Most recently, a novel approach to assessing childhood leukemia in relation to early life exposures was employed in the United Kingdom. The study examined all children dying of cancer between 1955 and 1980, consisting of over 22,000 cases. Birth and death addresses of children with cancer who moved before death were compared with regard to proximity to nearby sources and emissions of specific chemicals.[327] An excess of births near sources, relative to deaths, was used to indicate sources in early life associated with greatest cancer. Greater risks were associated with birth addresses within 300 meters of high emissions of benzene, 1,3-butadiene, NO_x, PM_{10}, dioxins, and benzo[a]pyrene. In addition, births within 1.0 km of bus stations, hospitals, freight terminals, railways, and oil installations were associated with elevated risk. Overall, locations with the highest emissions of 1,3-butadiene and carbon monoxide showed the greatest risk.

In summary, the lack of consistency in results between large studies and the multiplicity of study designs makes it difficult to draw firm conclusions. Epidemiologic methods for detection of childhood cancer risks may lack sufficient power to detect risks with precision. However, given the well-established carcinogenicity of benzene and 1,3-butadiene in the toxicological and occupational epidemiologic literature, and data suggesting exposure to benzene prior to conception and *in utero* can lead to increased risk of childhood leukemia, the potential for public health concern is present. The standards proposed in this rule will reduce such exposures.

3.5.7 Summary of Near-Roadway Health Studies

Taken together, the available studies of health effects in residents near major roadways suggest a possible public health concern. These studies' exposure metrics are reflective of a complex mixture from traffic, and the standards will reduce a broad range of pollutants present in higher concentrations near roadways. It is unclear to what extent these health effects are attributable to PM versus other components of the complex mixture. Note that the benefits associated with the direct PM reductions from the cold temperature vehicle standards are presented in Chapter 12 of this RIA.

3.5.8 Size and Characteristics of Populations Living near Major Roads

In assessing the public health implications of near-roadway health concerns, some understanding of the population living near major roads is required. Those living near major roadways are a subpopulation of the total population included in quantitative analysis, and to the extent that there may be additional exposures and health effects not captured in analyses for the total population, we enumerate the size and characteristics of the subpopulation. A study of the populations nationally using geographic information systems indicated that more than half of the population lives within 200 meters of a major road (see file USbytract.txt in the docket for this rule).[s] It should be noted that this analysis relied on the Census Bureau definition of a major road, which is not based on traffic volume. Thus, some of the roads designated as "major" may carry a low volume of traffic. Detailed analyses of data were conducted in three states, Colorado, Georgia, and New York. In Colorado, 22% live within 75 meters of a major road, while an additional 33% live between 75 and 200 meters of major roads. In Georgia, the respective percentages are 17% living within 75 meters and an additional 24% living between 75 and 200 meters. In New York, the percentages are 31% and 36%.[328]

To date, the only source of national data on populations living in close proximity to major transportation sources is the American Housing Survey, conducted by the U.S. Census Bureau.[329] This study characterizes the properties and neighborhood characteristics of housing units throughout the U.S. According to the Census Bureau's summaries of the 2003 survey, among approximately 120,777,000 housing units in the nation, 15,182,000 were within 300 feet of a "4-or-more-lane highway, railroad, or airport." This constitutes 12.6% of total U.S. housing units. A simple assumption that the U.S. population is uniformly distributed among all types of housing leads to the conclusion that approximately 37.4 million people live in what might be considered a "mobile source hot spot."

According to the American Housing Survey's summary tables, occupied housing units in central cities are 35% more likely to be close to major transportation sources than housing units in suburban areas.[330] Furthermore, nationally, housing units that are renter-occupied are 2.3 times more likely to be close to major transportation sources, compared to housing units that are owner-occupied. In the 2003 American Housing Survey, median household income for owner-occupied units was $52,803, while only $26,983 for renter-occupied units. These statistics imply that those houses sited near major transportation sources are likely to be lower in income than houses not located near major transportation sources.

A few population-based epidemiology studies have also examined whether discrete groups of people live close to major roadways. In one study of veterans living in southeastern Massachusetts, 23% lived within 50 meters of a "major road," 33% lived within 100 meters, and 51% within 200 meters. [331] In examining traffic volumes, 13% lived within 50 meters of a road with annual average daily traffic of 10,000 vehicles or more, while other distances were not analyzed.

In another study using 150 meters as a definition of "near" a road, 2.3% of California

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[s] Major roads are defined as those roads defined by the U.S. Census as one of the following: "limited access highway," "highway," "major road (primary, secondary and connecting roads)," or "ramp."

public schools were found to be near a road with more than 50,000 vehicles per day, while 7.2% were near roads with between 25,000 and 49,999 vehicles per day.[332] This corresponded to 2.6% and 9.8% of total enrollment, respectively. In that study, traffic exposure increased, the fractions of school populations comprised of black and Hispanic students also increased, as did the fraction of children in government-subsidized meal programs.

Another study in California defined the issue differently, examining the child population living in census block groups and traffic density.[333] The study found that approximately 3% of the state child population resided in the highest traffic density census tracts. Furthermore, block groups with lower income were more likely to have high traffic density. Children of color were more likely than white children to live in high traffic density areas.

In summary, a substantial fraction of the U.S. population lives within approximately 200 meters of major roads.

Appendix 3A: Influence of Emissions in Attached Garages on Indoor Air Benzene Concentrations and Human Exposure

Introduction

Measurement studies provide strong evidence that VOC sources in attached garages can significantly increase VOC concentrations inside homes.[334] Preliminary analyses of data from a pilot study for the National Human Exposure Assessment Survey (NHEXAS) in Arizona also found indoor concentrations of mobile source-related VOC compounds significantly higher in homes with attached garages than in homes without them.[335] This population-based exposure study included measurements from 187 homes. A study in 50 Alaska residences found that in homes with attached garages, indoor benzene levels averaged 70.8 μg/m^3, while in homes without attached garages, concentrations averaged 8.6 μg/m^3.[336] Multiple factors, including house architecture, ventilation design, garage configuration, and climate can all play roles as well.

National-scale air toxics modeling efforts, such as those discussed in RIA Section 3.2.1.2, employ Gaussian dispersion models in combination with human exposure models to calculate the concentrations of air toxics in various microenvironments. Exposure models calculate an average exposure resulting from the movement of a simulated population through a time-activity pattern that brings them into contact with air in the various microenvironments.

At this point, the NATA and the analyses performed for this rulemaking have only included exposures from outdoor sources. Although the HAPEM6 exposure model is capable of addressing indoor sources, more thorough analyses of the prevalence and use of emission sources within attached garages are required to develop quantitative estimates of model parameters to address attached garage contributions across the U.S. population.

This appendix addresses the potential impact of all benzene sources within an attached garage on residential indoor air quality.

Methods

Calculation of Within-garage Source Emission Rate

Emission rates for indoor sources of VOCs can be derived by several methods. Most accurately, the actual emission rates of an indoor VOC source can be measured through the use of a Sealed Housing for Evaporative Determination (SHED). However, test conditions must be representative of real world applications. Short of SHED-based measurement, several surrogate approaches may be employed. For evaporative losses from a sealed container, the change in weight of a container over time may be used to calculate a total mass loss rate, which can be assumed to be in the form of VOC. Alternatively, if the air concentrations and ventilation conditions of a defined indoor space are known, mass balance equations can be employed to derive a “virtual” emission rate for all sources within the space.

This appendix employs the latter approach in calculating source emission factors. The general approach of a mass balance equation is to calculate the change in mass over a given time, accounting for the mass of a pollutant transported into a space, the mass of pollutant transported out of a space, the emission rate of a source within the space, and the decay of any pollutants within the space, which can be treated as a first-order decay. A simple space like a garage can be treated as a single zone. The differential equation representing this mass balance is as follows:

$$\frac{dM_{t,i}}{dt} = C_o k \frac{dV}{dt} + \frac{dM_i}{dt} - C_i \frac{dV}{dt} \qquad (1)$$

Here, $dM_{t,i}/dt$ represents the rate of change of total indoor mass, C_i is the indoor concentration, C_o is the outdoor concentration, dV/dt is the volumetric air flow through the space, k is the penetration fraction indicating the proportion of mass that passes through the wall of the compartment, and dM_i/dt represents the mass emission rate inside the space. Note that all air entering the garage is assumed to enter from outdoors.

Assuming steady-state conditions, $dM_{t,i}/dt$ assumes the value of zero, meaning that the concentration in the garage does not change over time. Algebraically, this allows the equation above to be represented as:

$$\left(\frac{dV}{dt}\right)\left(C_i - C_o k\right) = \frac{dM_i}{dt} \qquad (2)$$

In other words, the indoor source terms can be calculated if the volumetric flow through the space and concentrations indoor and outdoor are known. Any gradient in concentration between indoor and outdoor concentrations is explained by indoor sources and the fraction of mass that does not penetrate from indoors to outdoors.

The volumetric flow can be calculated by multiplying the volume of the space by the number of times per hour that the air within the space is turned over. As such:

$$\frac{dV}{dt} = \alpha V \qquad (3)$$

Here, α is the "air exchange rate," expressed in air changes per hour (ACH). Combining equations (2) and (3), the mass emission rate is represented as:

$$\alpha V\left(C_i - C_o k\right) = \frac{dM_i}{dt} \qquad (4)$$

A recent study in Ann Arbor, MI measured the air exchange rates and the in-garage and outdoor concentrations of VOCs needed to perform these calculations.[337] The homes in the study were based on a convenience sample, and so may not be generally representative of the local or national housing stock. All garages but one adjoined a house. All attached garages had between one and three walls adjoining a residence. The distributions of garage benzene concentration and ACH are shown in Figure 3A-1. The distributions of each were not significantly different from lognormal, judging by the Kolmogorov-Smirnov Z statistic.

Values of k, the penetration factor, are dependent on the physical pathways through which air passes into a garage, as well as the presence and chemical composition of any insulating material through which air passes. In the case of garages, the infrequency of insulated garages and the low reactivity of benzene justifies the assumption that k=1.[338]

These data from the Ann Arbor, MI study were used to solve equation (2) to derive a distribution of benzene mass emission rates in each garage in the study, based on variability in measurements of outdoor concentrations. Equation 4 was implemented using a Microsoft Excel spreadsheet with the @Risk probabilistic simulation add-in (version 4.5).[339] Monte Carlo sampling was used for all terms in deriving the emission rates.

As described below, this distribution can be used to evaluate the effect of various fuel control measures on indoor benzene concentrations. A single lognormal distribution was used to represent C_o in equation 4, based on other studies of ambient air, which have found that many pollutants' concentrations are lognormally distributed.

Calculation of Garage Contributions to Indoor Air

In the same way that a mass balance calculation can be used to calculate emission rates for sources within garages, a mass balance equation can be used to estimate the additional concentration in a home that will occur as a result of elevated concentrations in the garage. However, unlike the garage case, it is not valid to assume that all air entering the home comes directly from outdoors.

Recent studies have provided indications that over multiple sequential days, variability in within-home benzene concentration is relatively small. A recent study from Ann Arbor, MI found a coefficient of variation (COV) of 4.6% for benzene.[340] Furthermore, recent data obtained by EPA through the Environmental and Occupational Health Sciences Institute (EOHSI) on homes in the Elizabeth, NJ area indicates no significant differences in within-home concentrations at a 95% confidence level.[t,341] These data are preliminary, and analyses are still in progress.

Given the fraction of air entering the home through the home-garage interface, the appropriate mass balance equation for a single-compartment (e.g. well-mixed) home can be represented as such:

$$(5) \qquad \frac{dM_{t,i}}{dt} = kC_o(1 - f_g)\frac{dV}{dt} + kC_g f_g \frac{dV}{dt} - C_i \frac{dV}{dt}$$

Here, C_i is the in-house concentration, C_o is the outdoor concentration, C_g is the concentration in the garage, dV/dt is the volumetric air flow through the house, and f_g is the fraction of air entering the home from the garage. One assumption made here is that the penetration factor for the air moving through the house-garage interface is the same as air moving through the house-outdoors interface. Reactive decay is assumed to be zero. Such mass balance equations are standard approaches in environmental science and engineering, and are frequently found in textbooks on these subjects.[342]

Again assuming steady-state conditions, $dM_{t,i}/dt = 0$, the equation above simplifies to:

$$(6) \qquad C_i = kC_o(1 - f_g) + kC_g f_g$$

Or more simply, the indoor concentration under steady state conditions is proportional to the fraction of air entering the house through the garage.

Figure 3A-2 is a contour plot illustrating the range of average indoor air concentrations that could plausibly arise given a range of values of C_g and f_g, with a background concentration of zero. However, Figure 3A-2 does not answer the question of what the likely indoor air values are in a sample of real homes.

The text below describes procedures and results of a small-scale modeling study.

Modeling Approach

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[t] In that study, one air sample was obtained in the room adjacent to an attached garage in each home and another was obtained in another location. The New Jersey Department of Environmental Protection and EPA provided joint funding for the study. A two-sided paired t-test was applied to data obtained from 36 homes over approximately 24 hours.

All modeling analyses employed Equation 6 in a Microsoft Excel spreadsheet with the @Risk probabilistic modeling add-in was the software employed in all modeling analyses. Where appropriate, each of the terms in Equation 6 was treated as a random variable represented as either a parametric distribution or as an empirical distribution based on measured data.

Often, in employing data obtained from more than one study, combining data into a single distribution was not justified on *a priori* grounds. In ventilation studies, ambient conditions such as temperature and geography can substantially affect air flow patterns and building constructions. For instance, residential air exchange rates differ significantly between regions with substantially different climates.[343] Furthermore, based on the limited number of studies available, combining data from multiple studies into a single data set had the potential to apply *de facto* weights to data, potentially shifting the fitted model parameters away from truly "representative" distributions.

Another consideration is the potential for independence of the f_g and C_g variables. There is no *a priori* reason why the "leakiness" of the house-garage envelope should be related to the concentration of benzene in the garage.

Because of these considerations, data on f_g or C_g from studies in different areas were not formally combined. Rather, distributions fit separately to data from each study were used to develop several model "scenarios." As described below, four different studies provided data for C_g and three different studies provided data for f_g. As such, a minimum of 12 (3 x 4) scenarios were needed to represent the totality of available data.

For each scenario modeled, @Risk sampled from each distribution 20,000 times using a proprietary Latin Hypercube sampling framework. The large number of samples and Latin Hypercube strategy were employed to ensure that modeled concentration distributions achieved stability.

Lastly, for comparison to the current approaches for exposure modeling, the following equation was used, paralleling the approach taken by HAPEM5 with no garage emissions:

$$C_i = kC_o \tag{7}$$

Data for Populating Model Parameters

Fraction of Air Entering Home through the Garage (f_g)

Several studies have examined the fraction of air entering the home from the garage. Except for one, all of these studies took place in northern states and Canada, where homes are built with more insulation. A recent study of a set of homes in Ontario, Canada found that approximately 13% of the air entering the home came from the garage.[344] One study from Minnesota found that in newer homes, houses built in the year 1994 had an average of 17.4% of total air leakage coming through their garages, houses build in 1998 had an average leakage fraction of 10.5%, and houses built in 2000 had an average leakage fraction of 9.4%.[345] Two recent studies have employed perfluorocarbon tracer (PFT) gases to estimate air transport between different "zones" of houses with attached garages. A recent study by Isbell et al. (2005) based in Fairbanks, Alaska found that in a modern air-tight Alaskan home ventilated with an air-to-air heat exchanger, 12.2% of the air entering a home entered through the garage, while 47.4% of the air entering an older home ventilated passively by structural defects came through the attached garage.[346] Another study of a home in Ann Arbor, Michigan built in 1962 found that

16% of the air entering the home originated in the garage.[347] In a more recent study from Ann Arbor, investigators deployed PFT tracers in 15 homes and calculated the fraction of air entering each home through an attached garage, with an average of 6.5±5.3% of the air entering through the garage.[348] From these studies, it is apparent that across homes, the fraction of air entering through the garage is highly variable, making it necessary to acknowledge significant uncertainties in characterizing "typical" infiltration patterns.

Benzene Concentrations in Garage Air (C_g)

Four sources of in-garage concentration data are available in the format relevant for steady-state modeling over extended periods of time. First, there is the study by Batterman et al. (2005), in which average garage concentrations of benzene were measured over a period of four days in each of 15 homes using passive sampling badges. The average garage concentration reported was 36.6 $\mu g/m^3$, with a standard deviation of 38.5 $\mu g/m^3$.

Second, a study in Alaska by George et al. (2002) measured benzene concentrations in 28 Alaska homes and 48 garages with passive diffusion badges.[349] One disadvantage of this study is the relatively high detection limit for benzene, 7 ppb (22 $\mu g/m^3$). As a result, many of the data available are based on a reported value of 50% of the detection limit. In the Alaska study, in-garage benzene concentrations averaged 103 $\mu g/m^3$, and the standard deviation was 135 $\mu g/m^3$. The study included concurrent in-home measurement of benzene in homes with attached garages, allowing evaluation of the modeled indoor concentrations. However, it is not apparent that this study underwent scientific peer review.

A third study in one New Jersey home also evaluated garage and indoor benzene, as part of an investigation into in-garage emissions of vehicles fueled with methanol blends.[350] Only one home was sampled, but it was sampled multiple times inside the garage and at multiple locations inside the residence. A fourth study from Fairbanks, Alaska conducted measurements in 12-hour periods on four separate days in two houses in two seasons, summer and winter.[351] The study obtained two daily measurements of benzene concentration within each garage over a 12-hour sampling period. One home was a modern, well-insulated home with an air-to-air heat exchanger for ventilation. The other was an older home ventilated passively by structural defects in the building envelope. Because of the large differences in concentrations between homes and seasons, data from each home-season combination was treated as a separate distribution within the indoor air model (Equation 6 in Excel/@Risk). Treating these data as separate distributions increased the number of modeled "scenarios" to 21 (3 f_g x 7 C_g).

Penetration Factor (k)

The values of k in this case were obtained from the HAPEM5 user's manual, using the PEN-1 factor, representing the fraction of benzene from outdoor air penetrating indoors. The values in HAPEM5 are presented as a distribution that assigns a 2/3 weight to the value 0.8 and a 1/3 weight to the value 1. These estimates are based on a comprehensive review of indoor and outdoor air quality studies.

Outdoor Ambient Concentration (C_o)

The 1999 National Air Toxics Assessment (NATA) provided ambient concentration estimates for every census tract in the U.S. For this modeling exercise, a lognormal distribution was fit to these data.

Results

Within-Garage Emission Rates

Equation 4 was used with Monte Carlo sampling to calculate a distribution of emission factors for each home, based on the variability in outdoor concentrations reported in Batterman et al. (2005). As shown in Figure 3-A3, the within-garage variation was a very small component of overall variability compared to between-garage variation. This finding implies that the factors in individual garages, such as storage of vehicles, nonroad equipment, and fuels, have a major effect on in-garage concentrations.

In aggregate, the mean emission rate for all garages sampled fell along a lognormal distribution ($p > 0.05$). The mean emission rate was 3049 μg/hr (73 mg/day), with a standard deviation of 4220 μg/hr (101 mg/day).

To evaluate the plausibility of these steady-state emission factors, known emission factors for other emission sources were evaluated. The California Air Resources Board (CARB) conducted a study of emissions from portable fuel containers, finding that volume-specific emissions rates for total VOC due to evaporation and permeation was 0.37 g/gal-day. Assuming an average fuel container volume of two gallons, the average emission factor per can would be 0.74 g VOC/day.

To evaluate the derived emission rates relative to CARB's measurements, a benzene fuel vapor pressure fraction of 0.5-1% was assumed, based on MOBILE6.2 evaporative emission factors. Given that assumption, the average benzene emission rate from CARB's study is 3.7-7.4 mg/day. This value is in the lower range of emission rates shown in Figure 3A-3. This comparison suggests that emissions due to permeation and evaporation from portable fuel containers may be a relatively small fraction of overall garage benzene.

Subsequently, one additional study used perfluorocarbon tracers (PFT) and VOC measurement in two Fairbanks, Alaska homes to estimate two garages' "source strengths" for benzene.[352] For a new, energy efficient "tight" home with an air-to-air heat exchanger, median garage emission estimates for benzene were 21 mg/h in summer and 14 mg/h in winter. In an older home with passive ventilation due to structural defects, median benzene source strengths were calculated at 40 and 22 mg/h in summer and winter, respectively. These values are substantially higher than those calculated based on Batterman et al. (2005). However, the difference may be attributable to higher fuel benzene in Fairbanks than in Michigan. Study design may also play a key role. In the Fairbanks study, the measurement periods were 12 hours each in duration. In the Michigan study, measurement periods lasted four days each. The Michigan study's longer duration may have allowed for a broader range of emissions activities than the Fairbanks study.

Garage Contributions to Benzene in Indoor Air

Figures 3A-4 to 3A-8 display the results of @Risk simulations of indoor air. Each figure represents the modeled outputs as cumulative probability distributions. In the legend of each figure, the label of each distribution describes its f_g and C_g sources. For instance, "George et al. (2002) / Fugler FG Ci" indicates a distribution using garage concentration data from George et al. (2002) and f_g data from Fugler et al.

Figure 3A-4 presents the output of Equation 6, a daily average indoor benzene concentration including contributions from outdoor air and from attached garages. As noted in the "Methods" section of this appendix, it was necessary to run a large number of scenarios to account for different combinations of f_g and C_g data sources. The figure depicts results using studies that contain C_g data from multiple homes as bold solid lines, while the model simulations based on studies that employ C_g data from only one home are shown in dashed lines. As indicated in the figure, there is no major difference in the C_i distributions predicted by using C_g data from multiple homes or by using C_g measured from a single home. The average modeled indoor benzene concentrations ranged from 2.9 to 16.4 $\mu g/m^3$.

For comparison, Figure 3A-5 presents cumulative distributions of the observed results from several studies that measured indoor air concentrations in homes with attached garages. Schlapia and Morris (1998) measured integrated 24-hour benzene concentrations inside 91 homes with attached garages in Anchorage, Alaska between 1994 and 1996.[353] George et al. (2002) reported average benzene concentrations in 36 homes in Anchorage, Alaska, but no distributional data. Mentioned above, Isbell et al. (2005) also measured integrated 12-hour benzene in two seasons in one modern air-tight home ("Home V" in Figures 3A-4 to 3A-8) and one older passively-ventilated home ("Home NV" in Figures 3A-4 to 3A-8).[354] Both homes were located in Fairbanks, Alaska. Batterman et al. (2006) measured indoor air benzene concentrations in 15 homes in southeastern Michigan over four-day sampling periods throughout spring and summer of 2005.[355] Lastly, Weisel (2006) conducted a study of indoor air in 21 homes in Union County, NJ between April 2005 and January 2006. One monitor in each home was sited in the room adjacent to the garage, while another was located in another part of the house.[356]

Comparing Figures 3A-4 and 3A-5, it is apparent that the distributions of modeled indoor air concentrations of benzene are very similar to those observed in monitoring studies. Both figures indicate that there is substantial variability in concentrations between homes and between studies.

Figure 3A-6 presents the mean concentrations from modeling scenarios and from monitoring studies. In general, the range of mean concentrations is close to the values monitored in the indoor air studies. Notable exceptions are the indoor air values by George et al. (2002), the winter data from the passively-ventilated "NV" home from Isbell et al. (2005), and by Schlapia and Morris (1998). All of these studies took place in Alaska, which may have uniquely high benzene fuel levels or housing architectures that create higher garage air infiltration indoors.

Of particular note, all of these studies included substantial numbers of homes with "tuck-under" garages where one or more rooms of a house are situated above a garage. Schlapia and Morris (1998) reported a very high average value that was not matched by the "average" conditions of any other run. It is notable that this high value is the average across 91 homes with attached garages.

Another consistent trend shown in Figure 3A-6 is that scenarios employing f_g data from Batterman et al. (2006) produced consistently lower average benzene concentrations than scenarios employing other sources. This trend is attributable to the lower average f_g reported in Batterman et al. (2006), 6.5%, as compared to values found in Sheltersource (11.7%) and Fugler et al. (13.6%).

It is unclear whether the studies measuring C_g, f_g, and C_i constitute a representative sample of homes. In general Alaskan studies report higher concentrations, but not consistently. The relatively greater prevalence of homes with "tuck under" garages in some Alaskan studies may explain this discrepancy.

In comparison to the values reported in Figures 3A-4 and 3A-5, indoor air concentrations calculated with the default $C_i = kC_o$ approach, similar to that employed in the national-scale modeling for this rule, averaged 1.2 $\mu g/m^3$.

Overall, modeled concentrations presented here appear to provide a credible estimate of indoor benzene concentration in homes with attached garages. However, it is unclear whether the homes included in the studies employed herein may be considered "representative."

Implications

Effect on Exposures Nationwide

In calculating the hypothetical effect of attached garage on national estimates of chronic, time-weighted average (TWA) human exposure, precise estimates are not possible. As noted previously, the extent to which available studies of indoor air of homes with attached garages is representative of the entire population of such homes is unclear. Furthermore, the distribution of housing stock by climate and meteorology is not well understood. However, despite these limitations, a bounding exercise is still feasible.

One simple approach for such a bounding exercise is determined by the following equation:

$$E_g = C_{i,g} * P_g * T_g \qquad (8)$$

Here, E_g represents the national average exposure to benzene in air attributable to attached garages. $C_{i,g}$ represents the average indoor concentration attributable to an attached garage, P_g represents the fraction of the population living in a home with an attached garage, and T_g represents the time spent in a home with an attached garage.

$C_{i,g}$ is derived from Equation 6, and can be derived by setting the outdoor concentration term (C_o) to zero. An estimate of the attached garage contribution to indoor air can be made for studies with only indoor measurements as well. This can be accomplished by substituting ASPEN concentration estimates for the county in which each study took place. For Equation 6, C_o estimates from NATA for each census tract in the relevant county were assembled into a lognormal distribution. With this data and the other assumptions of Equation 6, an estimate of $C_{i,g}$ could be derived from the measurement studies.

To estimate P_g, an estimate of the national fraction of homes with attached garages is required. The Residential Energy Consumption Survey (RECS), run by the U.S. Energy Information Administration, provides an estimate of the fraction of homes with attached garages.[357] RECS estimates a total of 107.0 million housing units nationally, 37.1 million (34.7%) of which are homes with attached garages. Assuming that the population is uniformly distributed across housing units allows this figure to serve as an estimate of P_g.

Information on the fraction of time spent in a residence (T_g) is required to determine how the microenvironmental concentration in homes with attached garages affects overall time-weighted exposure concentrations. As cited in EPA's Exposure Factors Handbook, the average person studied by the National Human Activity Pattern Survey (NHAPS) spent 1001.39 minutes (16.68 hours) per day indoors within any room of a residence.[358]

Results of model simulations using Equation 7 are shown in Figure 3A-7. As before, the results of each combination of C_g and f_g data source are shown. For each study, the legend lists the source for both C_g and f_g data. As described above, the estimates $C_{i,g}$ derived from indoor air measurements are also presented in Figure 3A-7. In the legend of Figure 3A-6, these studies are denoted by the term "Direct Ci Measure." As shown, there tends to be a greater degree of agreement between modeling scenarios for lower concentration estimates, but less agreement for higher concentration estimates.

As described above, it is unclear to what the extent to which the homes studied for benzene related to attached garages are representative of homes nationally. As such, in summarizing the scenarios, several different approaches to "averaging" across scenarios are presented here. Figure 3A-8 shows the results of these different averaging scenarios. In the "All Data" distribution shown in the figure, all scenarios are averaged together. In the "Weighted Average" distribution, weights are equal to the number of homes included in each study. In the "Model Only" distribution, only scenarios involving modeling C_i are shown. In the "Measure Only" distribution, only those studies in which C_i was measured directly are shown. In the "AK Only" distribution, only scenarios employing Alaskan C_g or f_g studies are shown. In the "Non-AK Only" distribution, only scenarios excluding Alaskan C_g or f_g data are shown. These scenarios are intended to span a range of estimates for the national estimate.

The average concentrations from these "summary scenarios" are shown in Table 3A-1. As shown in Table 3A-1 and in Figure 3A-8, scenarios employing only measured indoor data resulted in higher predicted benzene TWA exposure concentrations than the studies employing only modeling. Scenarios employing Alaskan data result in higher benzene concentrations than scenarios excluding Alaskan data. Also weighting scenarios by the number of homes resulted in higher benzene concentrations.

Accordingly, the national average TWA exposure concentration attributable to attached garages is estimated to be 1.2 – 6.6 $\mu g/m^3$. This range is intended to span possible values of average TWA exposure from attached garages, given currently available information. The actual average TWA exposure concentration due to attached garages could be outside of this range. Because of limited information on the representativeness of the homes studied, a more precise "central estimate" is not appropriate at this time. The width of the range, with the upper end being 5.5 times the lower end, is an indicator of the magnitude of uncertainty in the estimate. It is not a confidence interval in the traditional sense. As more data become available, more precise estimates will hopefully emerge.

In comparison, the national average exposure concentration of census tract median exposure concentrations in this rule is estimated at 1.4 $\mu g/m^3$ for calendar year 1999.

Accordingly, if the attached garage exposure contribution is considered, the estimate of national average exposure to benzene rises to 2.6 – 8.0 $\mu g/m^3$, corresponding to an increase of 85-471%.

Effects of Emission Standards

Several limitations prevent precise estimation of the effect of the standards in this rule on garage-related exposures. First, cold temperature vehicle ignition and evaporative vehicle, engine, and fuel container emissions can occur either in a garage or outdoors. Second, detailed tracking of the time during which people are inside a house during cold vehicle starting or hot vehicle soaking, when a majority of benzene emissions are likely to occur, is limited. However, a bounding exercise can provide some estimates as to the effect of the standards in this rule.

First, assuming full mixing and steady-state conditions, concentrations within a garage is estimable[359] as:

$$C_g = (dM_i/dt) / \alpha V \qquad (9)$$

Here, the terms are similar to Equations 1-7.

Given a change in the mass benzene emission rates from vehicle cold temperature ignition, fuel evaporation from vehicles, engines, and fuel containers, an estimate of a change in C_g is feasible. Table 2.2-52 of the RIA displays the emission reductions attributable to each program. By splitting the emission reductions into evaporative and exhaust emissions and applying several simple assumptions about where emissions occur (in garage vs. outdoors), the fraction of emission reductions occurring within attached garages can be estimated. This estimate is calculated by assuming ranges of values for the fraction of evaporative and exhaust emissions from each program that occur within an attached garage.[u] As such, while the total benzene mobile source and PFC emission reductions occurring as a result of the rule in 2030 are 37% less than the projected emissions without controls (Table 2.2-52 of the RIA), emissions inside attached garages are reduced by an estimated 43-44%.

Applying this fraction to Equation 8 and Equation 7, for the "average" scenarios modeled presented in Table 1, this amounts to a national average exposure reduction of approximately 0.5 – 2.6 $\mu g/m^3$.

Limitations

As apparent in the wide range of "scenario" averages, there remains considerable uncertainty in ascertaining the true magnitude of attached garage exposure contributions nationally. There are a number of limitations in the approaches undertaken here. First, although comparison with measured indoor data shows reasonable performance for the modeling approach employed here, the selection of simple one-compartment mass balance models for both garage and home modeling may substantially understate the variation in concentrations within these microenvironments. All estimates here assumed steady-state conditions, and this may not be

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[u] The assumed fraction of evaporative and exhaust emission reductions from each source occurring within an attached garage are as follows. Ranges are represented as [min, max]. For LDGV, about 90% of emission reductions are exhaust-related, of which P_g*[25%,75%] occur within attached garages; the fraction of evaporative reductions occurring within attached garages are P_g *[25%,50%]. For small nonroad gasoline equipment, about 72% of emissions are from exhaust, of which P_g *[0%,2%] occur in attached garages; 24% are evaporative, of which P_g *[90%,100%] occur in attached garages, 4% are refilling-related, of which P_g *[25%,75%] occur in attached garages. For portable fuel containers, P_g *[25%,75%] of emissions are assumed to occur in attached garages.

appropriate for a source like a garage, where door opening, car entry and ignition, and other major sources of benzene are likely to produce short-term spikes in exposure not accounted for with steady-state assumptions.

Second, the preponderance of these data were collected in locations with cold climates, so the results may not be applicable to warmer locations where houses are not built with the same degree of weather-tightness. Furthermore, studies suggest that indoor concentrations arising from attached garages vary considerably in response to emission-related activities in a garage such as cold vehicle ignition and parking a hot vehicle.[360] Ambient temperatures may affect the magnitude of emissions from these activities.

Lastly, the extent to which the houses studied in the publications cited here are "representative" of the national housing stock is unknown.

Conclusions

Modeled indoor benzene concentrations indicate that indoor air concentrations in homes with attached garages may be substantially higher than in homes without attached garages.

Garage concentrations of benzene appear to be a major source of indoor benzene in homes with attached garages. According to the modeling conducted here, this source could explain the majority of exposures experienced by typical residents of such homes. Given this finding, interventions that result in a reduction in emissions within the garage would be a relatively efficient means of reducing overall personal exposure, particularly in areas geographically similar to the areas of the studies upon which this analysis relies. Given the proximity of this source to homes, one major set of beneficiaries of the rule's emission controls is likely to be people with homes with attached garages, particularly in areas with high fuel benzene levels. Emissions from vehicles and fuel containers also may have greater relative impacts on those with attached garages. An elementary calculation of the intake fraction (iF) of emissions occurring within attached garages with very basic assumptions indicates that for benzene emitted in a garage, approximately 3-18 parts per thousand are inhaled by a person in an attached garage. This estimate is far in excess of estimated iF from ambient sources, and similar to estimated iF estimates for indoor sources.[361]

Table 3A-1. Summary of National Average Exposure Estimates Attributable to Attached Garages. Different “averaging” assumptions shown.

"Averaging" Scenario	Benzene TWA (ug/m3)
All Data	4.3
Weighted Average	6.6
Measure Only	6.1
Model Only	3.4
AK Only	5.5
Non-AK Only	1.2

Figure 3A-1a. Density of Garage Benzene Concentrations from Batterman et al. (2005)

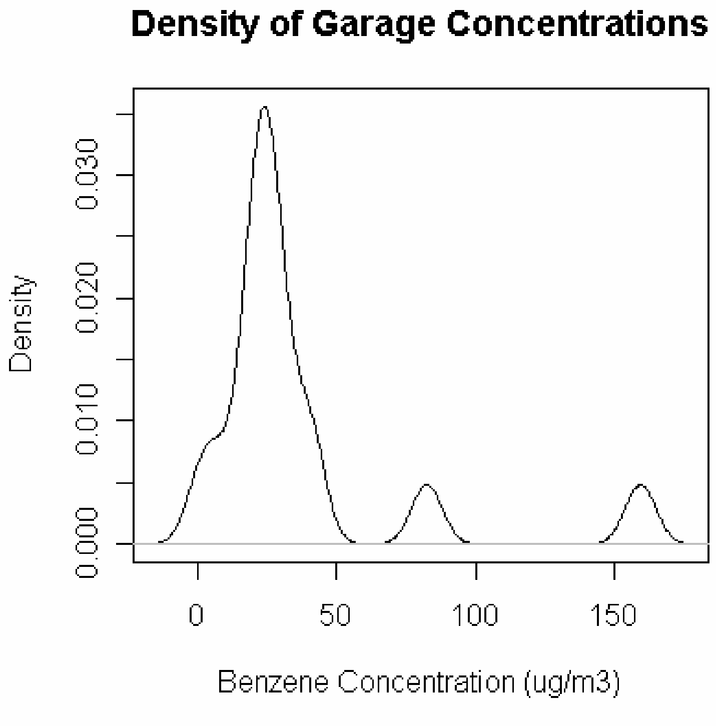


Figure 3A-1b. Density of Air Exchange Rates (ACH)

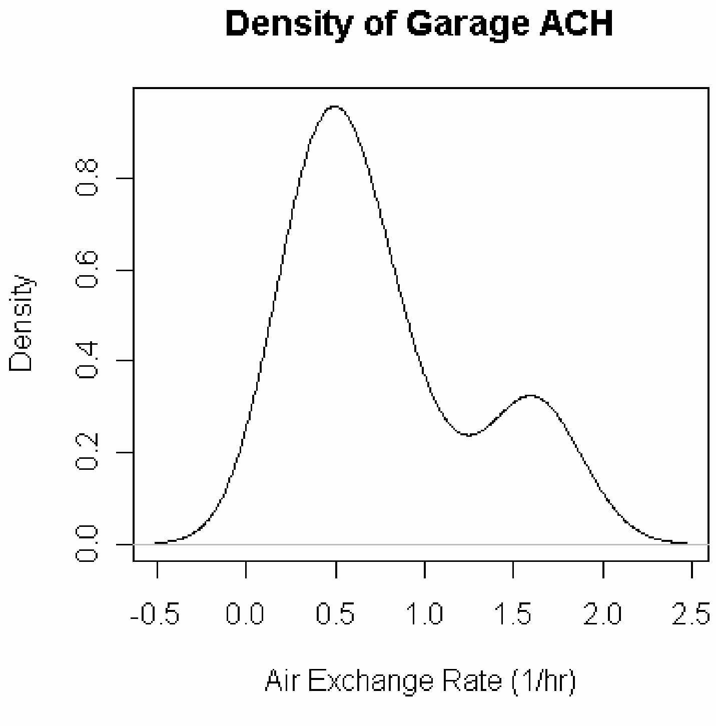


Figure 3A-2. Additional Indoor Air Concentrations from Garage as a Function of C_g and f_g

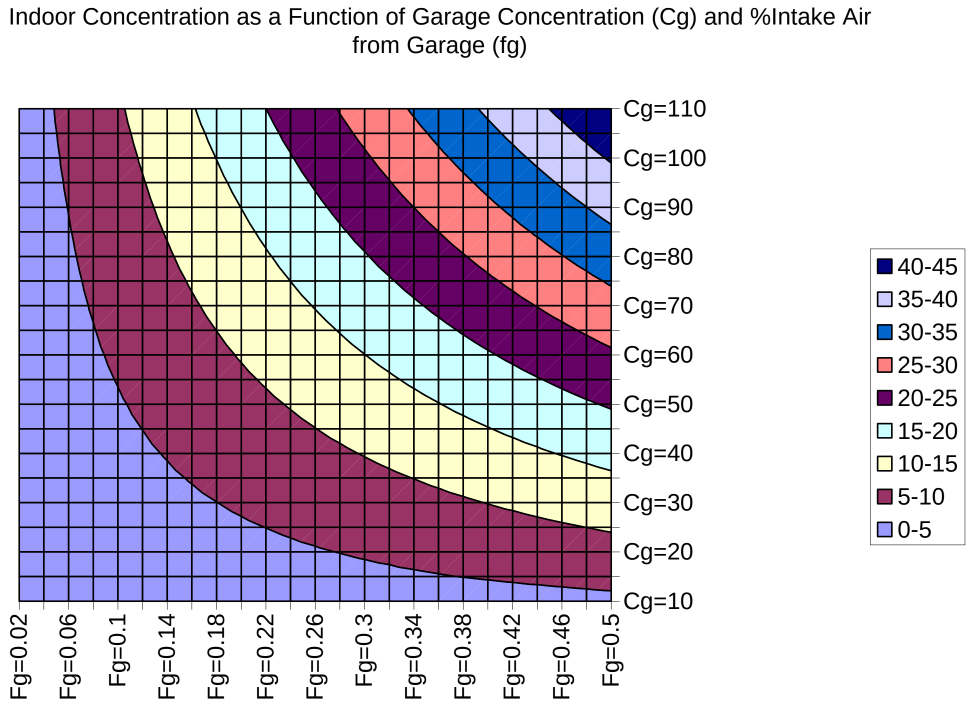


Figure 3A-3. Distributions of Individual Garage Emission Factors

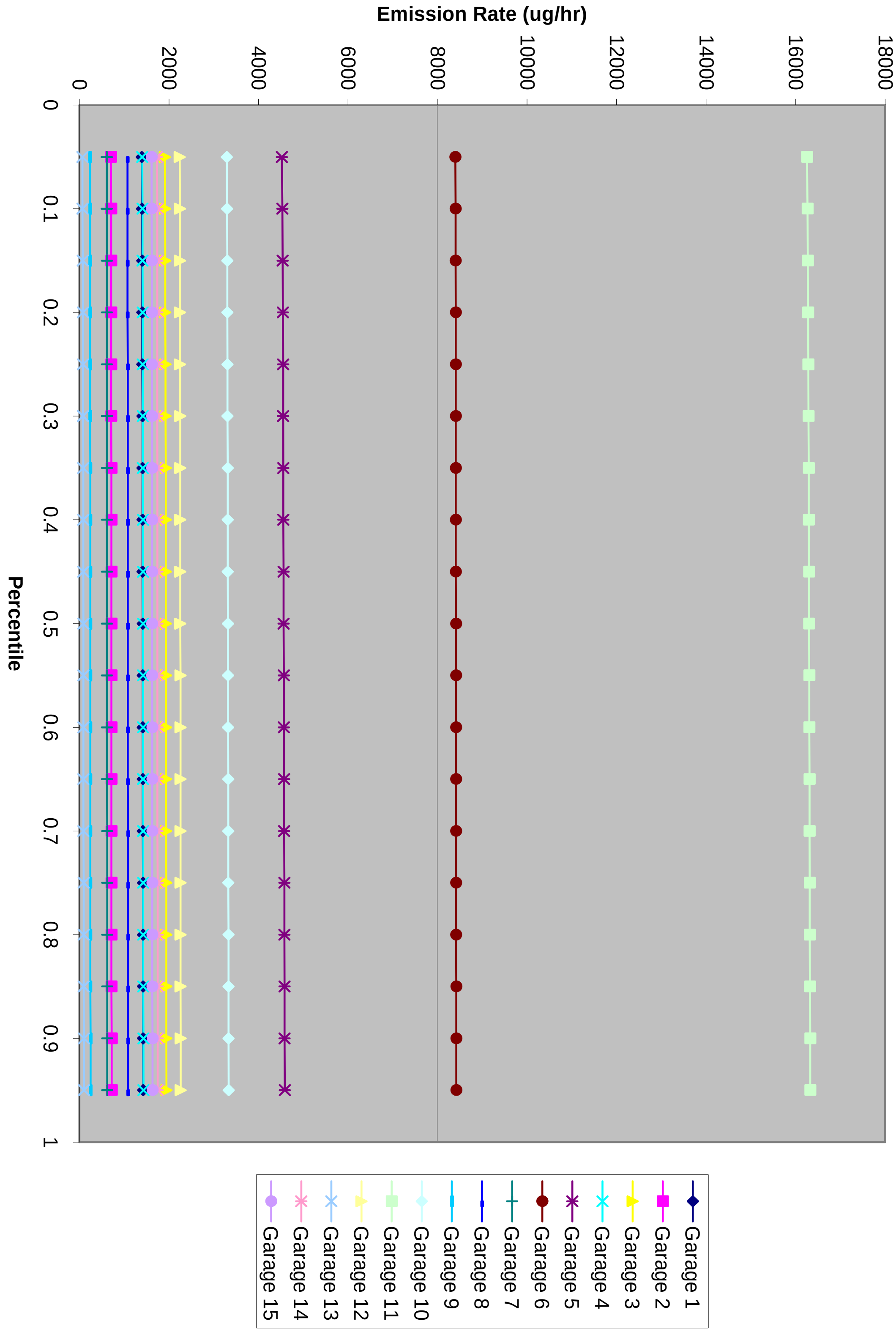


Figure 3A-4. Cumulative Distribution of Modeled Indoor Benzene Concentrations

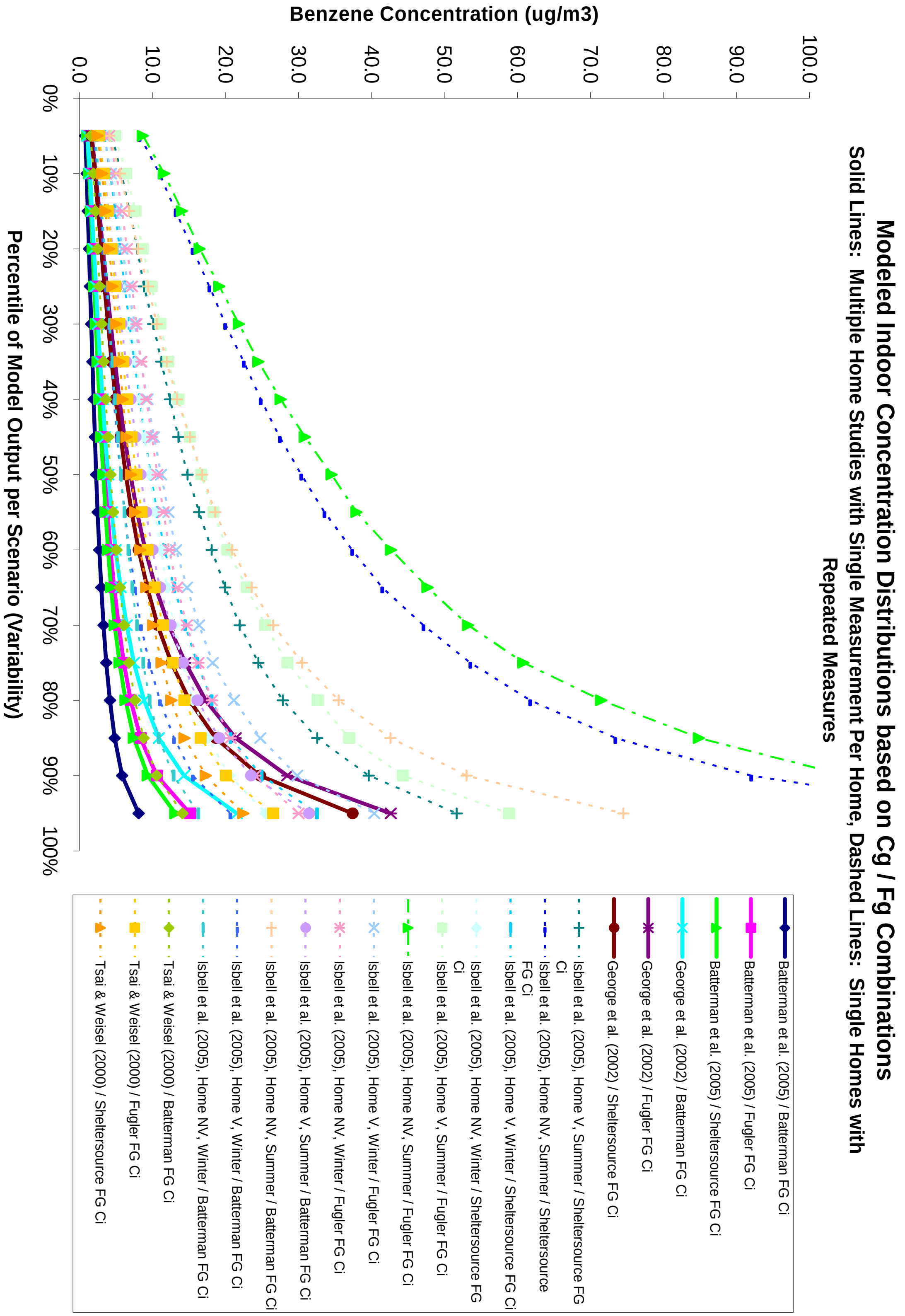
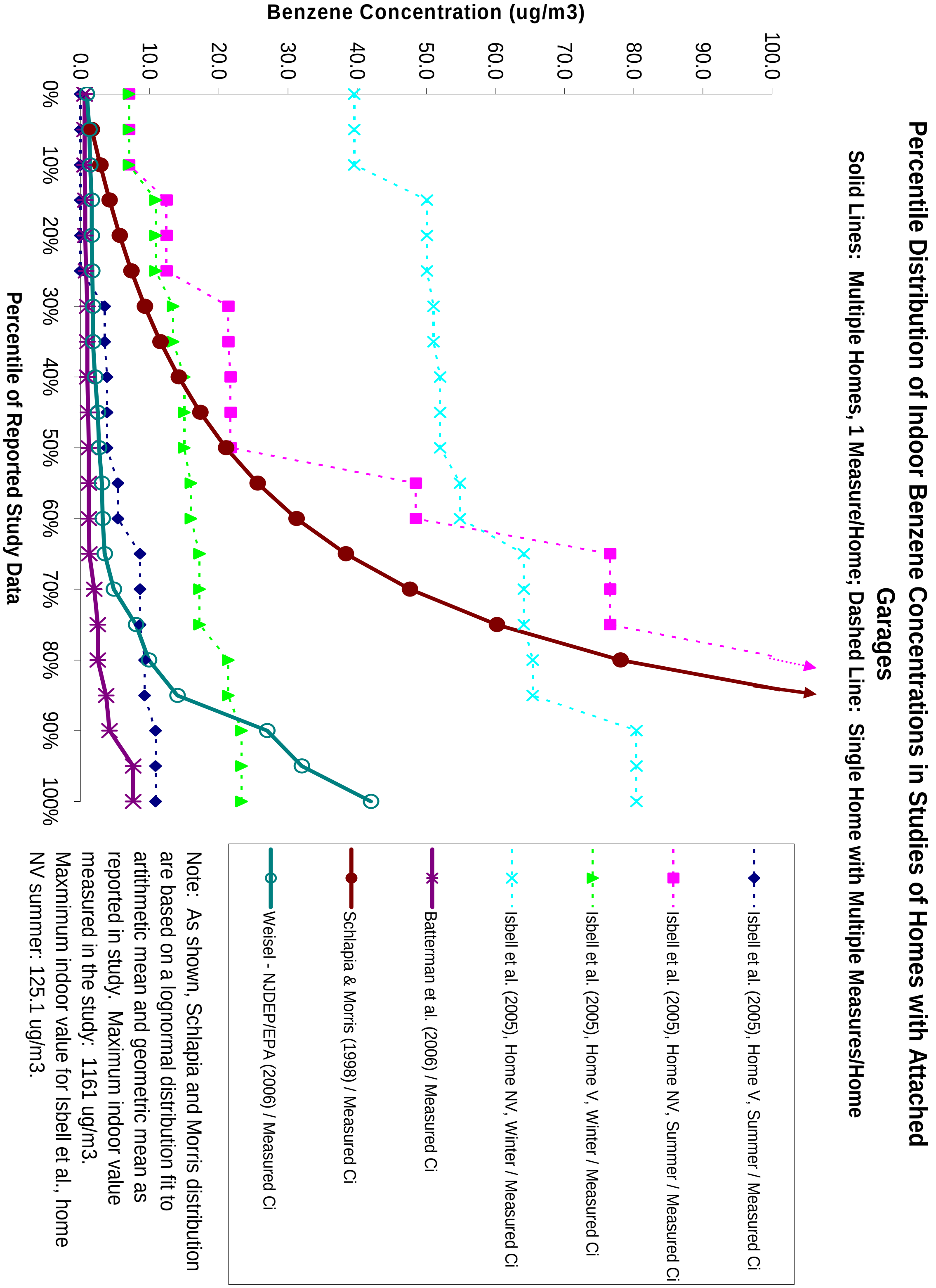


Figure 3A-5. Cumulative Distributions of Observed Benzene Levels in Homes with Attached Garages



Note: As shown, Schlapia and Morris distribution are based on a lognormal distribution fit to arithmetic mean and geometric mean as reported in study. Maximum indoor value measured in the study: 1161 ug/m3. Maxmimum indoor value for Isbell et al., home NV summer: 125.1 ug/m3.

Figure 3A-6. Comparison of Modeled and Observed Indoor Benzene Concentrations

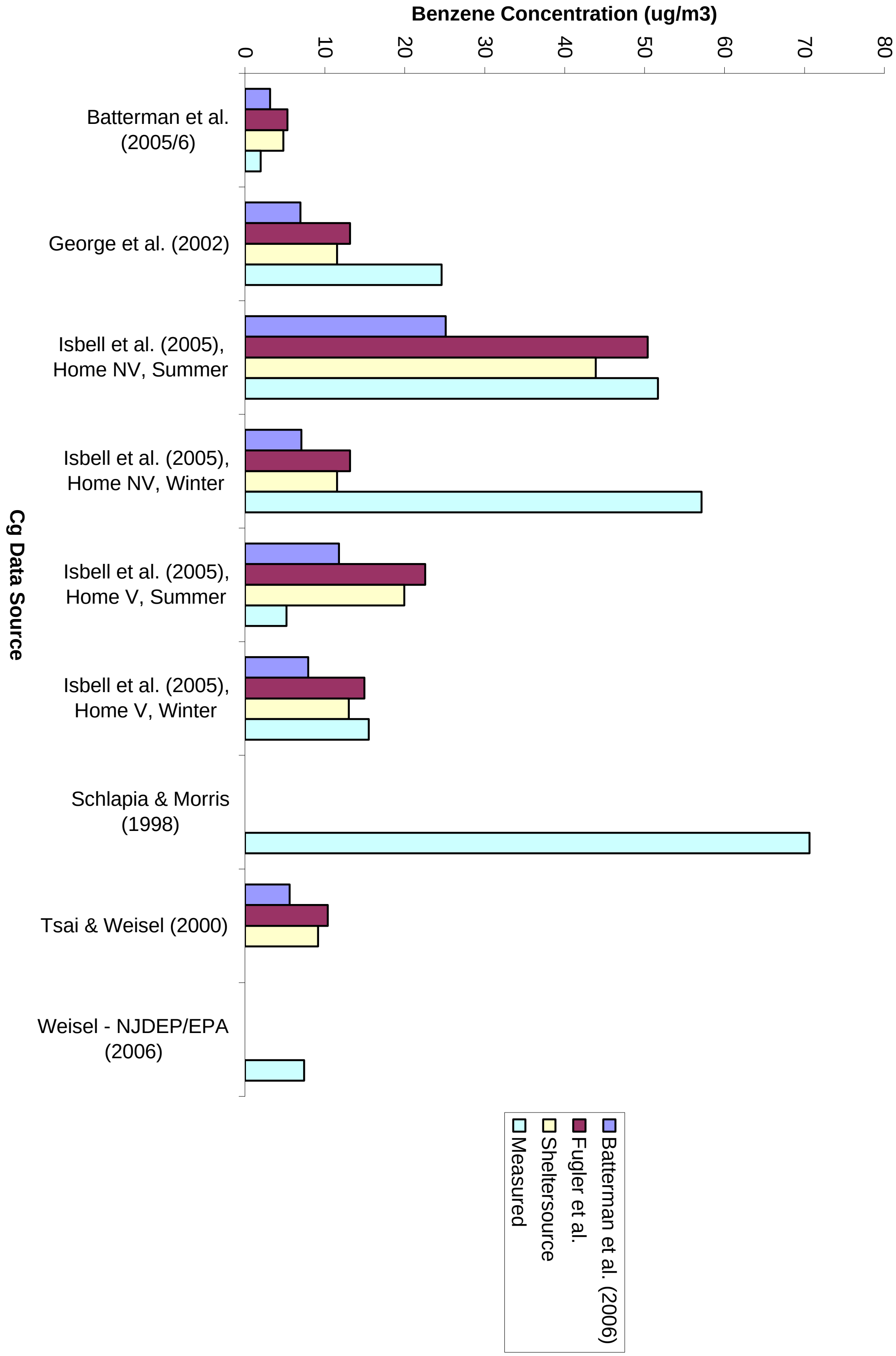


Figure 3A-7. Multiple Scenario Output of Predicted National Average Benzene Exposure Attributable to Attached Garages

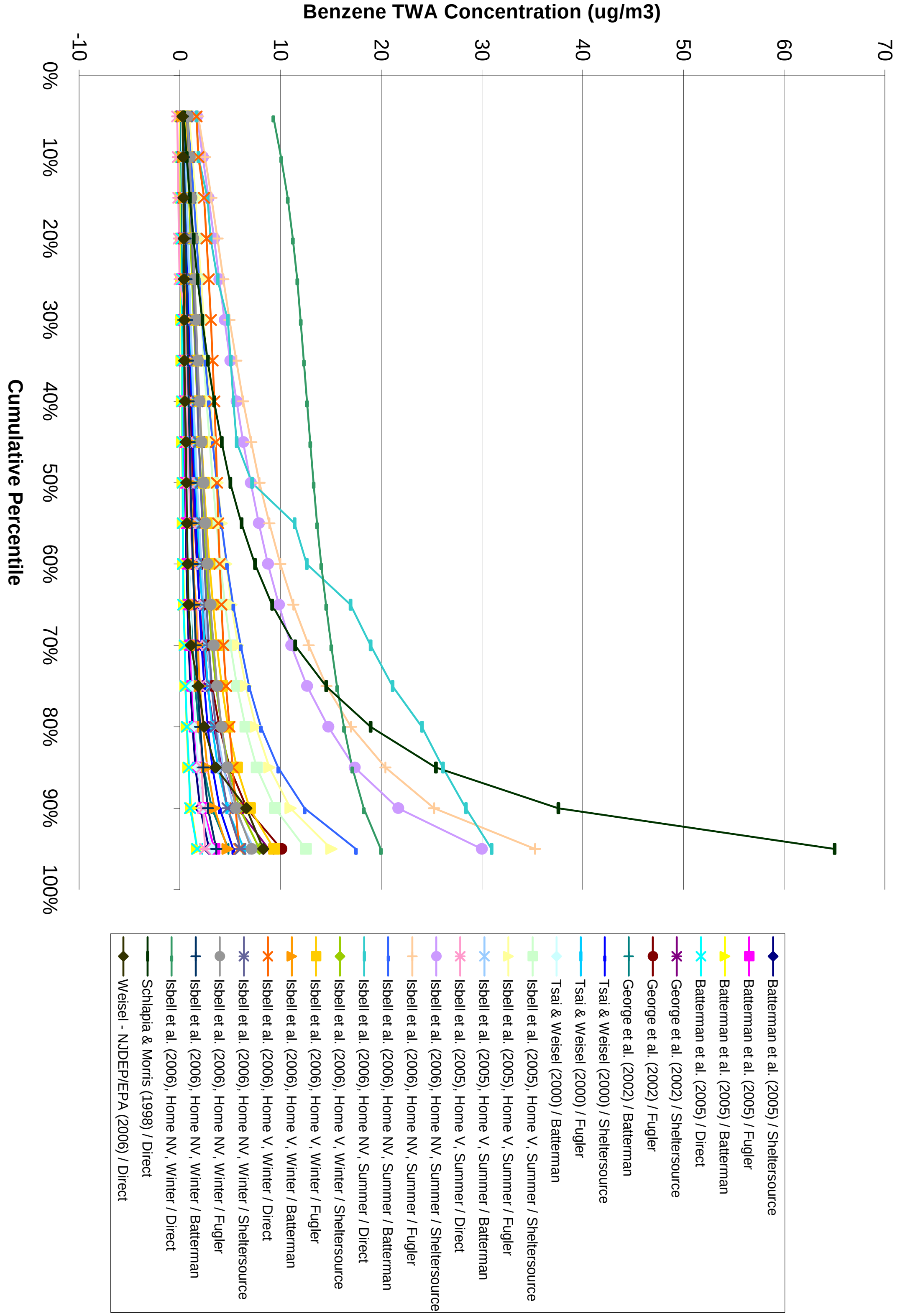
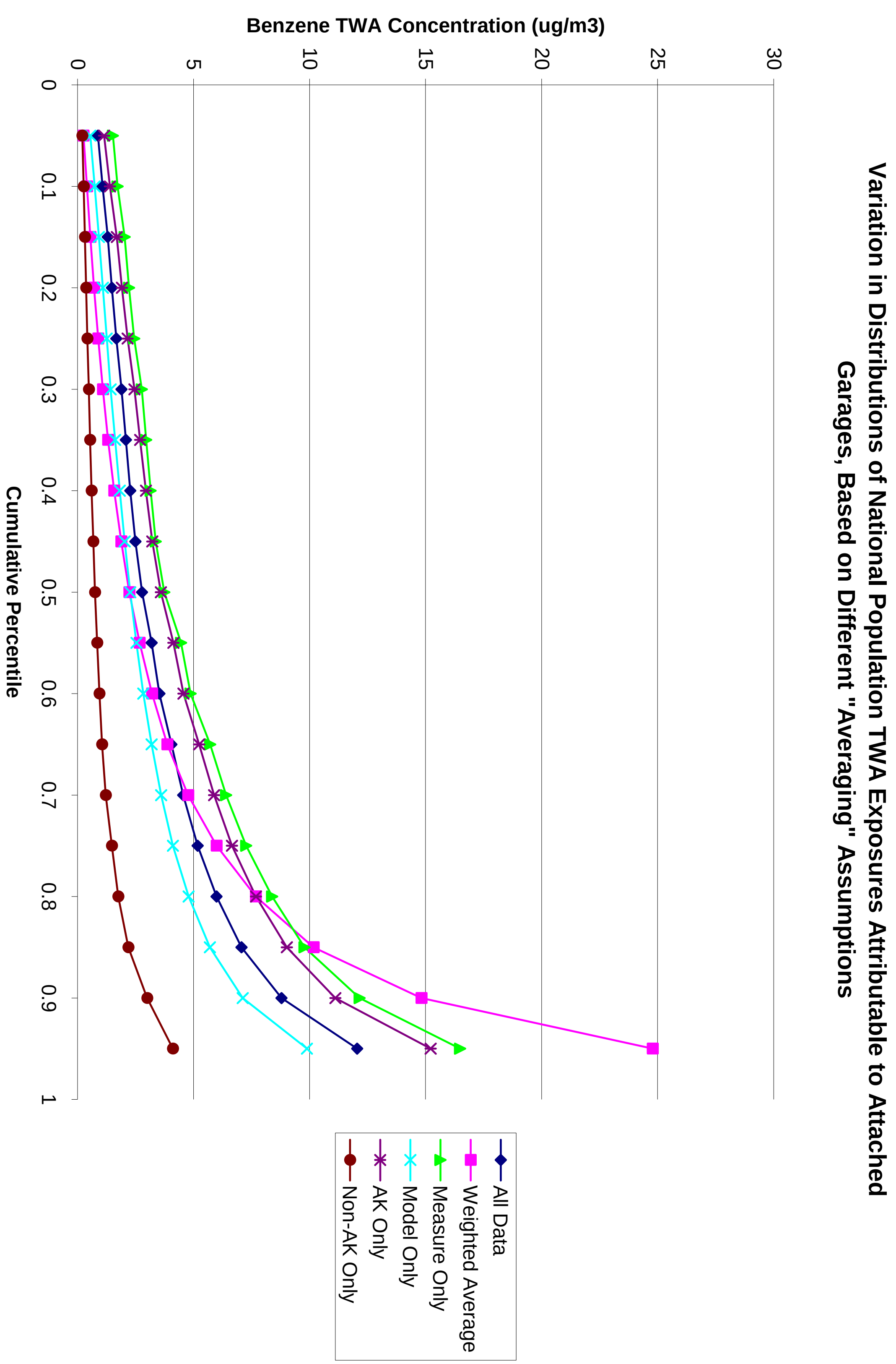


Figure 3A-8. Average “Summarized” Benzene Exposure Distributions



Appendix 3B: 8-Hour Ozone Nonattainment

Table 3B-1. 8-Hour Ozone Nonattainment Areas, Counties and Populations (Data is Current through October 2006 and Population Numbers are from 2000 Census Data)

8-hour Ozone Nonattainment Area	State	Classification[a,b]	County Name	Whole /Part	2000 Cty Pop
Albany-Schenectady-Troy Area	NY	Subpart 1	Albany Co	W	294,565
Albany-Schenectady-Troy Area	NY	Subpart 1	Greene Co	W	48,195
Albany-Schenectady-Troy Area	NY	Subpart 1	Montgomery Co	W	49,708
Albany-Schenectady-Troy Area	NY	Subpart 1	Rensselaer Co	W	152,538
Albany-Schenectady-Troy Area	NY	Subpart 1	Saratoga Co	W	200,635
Albany-Schenectady-Troy Area	NY	Subpart 1	Schenectady Co	W	146,555
Albany-Schenectady-Troy Area	NY	Subpart 1	Schoharie Co	W	31,582
Allegan County Area	MI	Subpart 1	Allegan Co	W	105,665
Allentown-Bethlehem-Easton Area	PA	Subpart 1	Carbon Co	W	58,802
Allentown-Bethlehem-Easton Area	PA	Subpart 1	Lehigh Co	W	312,090
Allentown-Bethlehem-Easton Area	PA	Subpart 1	Northampton Co	W	267,066
Altoona Area	PA	Subpart 1	Blair Co	W	129,144
Amador and Calaveras Counties (Central Mountain Counties) Area	CA	Subpart 1	Amador Co	W	35,100
Amador and Calaveras Counties (Central Mountain Counties) Area	CA	Subpart 1	Calaveras Co	W	40,554
Atlanta Area	GA	Subpart 2/Marginal	Barrow Co	W	46,144
Atlanta Area	GA	Subpart 2/Marginal	Bartow Co	W	76,019
Atlanta Area	GA	Subpart 2/Marginal	Carroll Co	W	87,268
Atlanta Area	GA	Subpart 2/Marginal	Cherokee Co	W	141,903
Atlanta Area	GA	Subpart 2/Marginal	Clayton Co	W	236,517
Atlanta Area	GA	Subpart 2/Marginal	Cobb Co	W	607,751
Atlanta Area	GA	Subpart 2/Marginal	Coweta Co	W	89,215
Atlanta Area	GA	Subpart 2/Marginal	De Kalb Co	W	665,865
Atlanta Area	GA	Subpart 2/Marginal	Douglas Co	W	92,174
Atlanta Area	GA	Subpart 2/Marginal	Fayette Co	W	91,263
Atlanta Area	GA	Subpart 2/Marginal	Forsyth Co	W	98,407
Atlanta Area	GA	Subpart 2/Marginal	Fulton Co	W	816,006
Atlanta Area	GA	Subpart 2/Marginal	Gwinnett Co	W	588,448
Atlanta Area	GA	Subpart 2/Marginal	Hall Co	W	139,277

Atlanta Area	GA	Subpart 2/Marginal	Henry Co	W	119,341
Atlanta Area	GA	Subpart 2/Marginal	Newton Co	W	62,001
Atlanta Area	GA	Subpart 2/Marginal	Paulding Co	W	81,678
Atlanta Area	GA	Subpart 2/Marginal	Rockdale Co	W	70,111
Atlanta Area	GA	Subpart 2/Marginal	Spalding Co	W	58,417
Atlanta Area	GA	Subpart 2/Marginal	Walton Co	W	60,687
Baltimore Area	MD	Subpart 2/Moderate	Anne Arundel Co	W	489,656
Baltimore Area	MD	Subpart 2/Moderate	Baltimore (City)	W	651,154
Baltimore Area	MD	Subpart 2/Moderate	Baltimore Co	W	754,292
Baltimore Area	MD	Subpart 2/Moderate	Carroll Co	W	150,897
Baltimore Area	MD	Subpart 2/Moderate	Harford Co	W	218,590
Baltimore Area	MD	Subpart 2/Moderate	Howard Co	W	247,842
Baton Rouge Area	LA	Subpart 2/Marginal	Ascension Par	W	76,627
Baton Rouge Area	LA	Subpart 2/Marginal	East Baton Rouge Par	W	412,852
Baton Rouge Area	LA	Subpart 2/Marginal	Iberville Par	W	33,320
Baton Rouge Area	LA	Subpart 2/Marginal	Livingston Par	W	91,814
Baton Rouge Area	LA	Subpart 2/Marginal	West Baton Rouge Par	W	21,601
Beaumont-Port Arthur Area	TX	Subpart 2/Marginal	Hardin Co	W	48,073
Beaumont-Port Arthur Area	TX	Subpart 2/Marginal	Jefferson Co	W	252,051
Beaumont-Port Arthur Area	TX	Subpart 2/Marginal	Orange Co	W	84,966
Benton Harbor Area	MI	Subpart 1	Berrien Co	W	162,453
Benzie County Area	MI	Subpart 1	Benzie Co	W	15,998
Berkeley and Jefferson Counties Area	WV	Subpart 1 - EAC	Berkeley Co	W	75,905
Berkeley and Jefferson Counties Area	WV	Subpart 1 - EAC	Jefferson Co	W	42,190
Boston-Lawrence-Worcester (E. Mass) Area	MA	Subpart 2/Moderate	Barnstable Co	W	222,230
Boston-Lawrence-Worcester (E. Mass) Area	MA	Subpart 2/Moderate	Bristol Co	W	534,678
Boston-Lawrence-Worcester (E. Mass) Area	MA	Subpart 2/Moderate	Dukes Co	W	14,987
Boston-Lawrence-Worcester (E. Mass) Area	MA	Subpart 2/Moderate	Essex Co	W	723,419

Boston-Lawrence-Worcester (E. Mass) Area	MA	Subpart 2/Moderate	Middlesex Co	W	1,465,396
Boston-Lawrence-Worcester (E. Mass) Area	MA	Subpart 2/Moderate	Nantucket Co	W	9,520
Boston-Lawrence-Worcester (E. Mass) Area	MA	Subpart 2/Moderate	Norfolk Co	W	650,308
Boston-Lawrence-Worcester (E. Mass) Area	MA	Subpart 2/Moderate	Plymouth Co	W	472,822
Boston-Lawrence-Worcester (E. Mass) Area	MA	Subpart 2/Moderate	Suffolk Co	W	689,807
Boston-Lawrence-Worcester (E. Mass) Area	MA	Subpart 2/Moderate	Worcester Co	W	750,963
Boston-Manchester-Portsmouth (SE) Area	NH	Subpart 2/Moderate	Hillsborough Co	P	336,518
Boston-Manchester-Portsmouth (SE) Area	NH	Subpart 2/Moderate	Merrimack Co	P	11,721
Boston-Manchester-Portsmouth (SE) Area	NH	Subpart 2/Moderate	Rockingham Co	P	266,340
Boston-Manchester-Portsmouth (SE) Area	NH	Subpart 2/Moderate	Strafford Co	P	82,134
Buffalo-Niagara Falls Area	NY	Subpart 1	Erie Co	W	950,265
Buffalo-Niagara Falls Area	NY	Subpart 1	Niagara Co	W	219,846
Canton-Massillon Area	OH	Subpart 1	Stark Co	W	378,098
Cass County Area	MI	Subpart 2/Marginal	Cass Co	W	51,104
Charlotte-Gastonia-Rock Hill Area	NC	Subpart 2/Moderate	Cabarrus Co	W	131,063
Charlotte-Gastonia-Rock Hill Area	NC	Subpart 2/Moderate	Gaston Co	W	190,365
Charlotte-Gastonia-Rock Hill Area	NC	Subpart 2/Moderate	Iredell Co	P	39,885
Charlotte-Gastonia-Rock Hill Area	NC	Subpart 2/Moderate	Lincoln Co	W	63,780
Charlotte-Gastonia-Rock Hill Area	NC	Subpart 2/Moderate	Mecklenburg Co	W	695,454
Charlotte-Gastonia-Rock Hill Area	NC	Subpart 2/Moderate	Rowan Co	W	130,340
Charlotte-Gastonia-Rock Hill Area	NC	Subpart 2/Moderate	Union Co	W	123,677
Charlotte-Gastonia-Rock Hill Area	SC	Subpart 2/Moderate	York Co	P	102,000
Chattanooga Area	GA	Subpart 1 - EAC	Catoosa Co	W	53,282
Chattanooga Area	TN	Subpart 1 - EAC	Hamilton Co	W	307,896
Chattanooga Area	TN	Subpart 1 - EAC	Meigs Co	W	11,086
Chicago-Gary-Lake County Area	IL	Subpart 2/Moderate	Cook Co	W	5,376,741
Chicago-Gary-Lake County Area	IL	Subpart 2/Moderate	Du Page Co	W	904,161
Chicago-Gary-Lake County Area	IL	Subpart 2/Moderate	Grundy Co	P	6,309
Chicago-Gary-Lake County Area	IL	Subpart 2/Moderate	Kane Co	W	404,119
Chicago-Gary-Lake County Area	IL	Subpart 2/Moderate	Kendall Co	P	28,417

Chicago-Gary-Lake County Area	IL	Subpart 2/Moderate	Lake Co	W	644,356
Chicago-Gary-Lake County Area	IL	Subpart 2/Moderate	Mc Henry Co	W	260,077
Chicago-Gary-Lake County Area	IL	Subpart 2/Moderate	Will Co	W	502,266
Chicago-Gary-Lake County Area	IN	Subpart 2/Moderate	Lake Co	W	484,564
Chicago-Gary-Lake County Area	IN	Subpart 2/Moderate	Porter Co	W	146,798
Chico Area	CA	Subpart 1	Butte Co	W	203,171
Cincinnati-Hamilton Area	IN	Subpart 1	Dearborn Co	P	10,434
Cincinnati-Hamilton Area	KY	Subpart 1	Boone Co	W	85,991
Cincinnati-Hamilton Area	KY	Subpart 1	Campbell Co	W	88,616
Cincinnati-Hamilton Area	KY	Subpart 1	Kenton Co	W	151,464
Cincinnati-Hamilton Area	OH	Subpart 1	Butler Co	W	332,807
Cincinnati-Hamilton Area	OH	Subpart 1	Clermont Co	W	177,977
Cincinnati-Hamilton Area	OH	Subpart 1	Clinton Co	W	40,543
Cincinnati-Hamilton Area	OH	Subpart 1	Hamilton Co	W	845,303
Cincinnati-Hamilton Area	OH	Subpart 1	Warren Co	W	158,383
Clearfield and Indiana Counties Area	PA	Subpart 1	Clearfield Co	W	83,382
Clearfield and Indiana Counties Area	PA	Subpart 1	Indiana Co	W	89,605
Cleveland-Akron-Lorain Area	OH	Subpart 2/Moderate	Ashtabula Co	W	102,728
Cleveland-Akron-Lorain Area	OH	Subpart 2/Moderate	Cuyahoga Co	W	1,393,978
Cleveland-Akron-Lorain Area	OH	Subpart 2/Moderate	Geauga Co	W	90,895
Cleveland-Akron-Lorain Area	OH	Subpart 2/Moderate	Lake Co	W	227,511
Cleveland-Akron-Lorain Area	OH	Subpart 2/Moderate	Lorain Co	W	284,664
Cleveland-Akron-Lorain Area	OH	Subpart 2/Moderate	Medina Co	W	151,095
Cleveland-Akron-Lorain Area	OH	Subpart 2/Moderate	Portage Co	W	152,061
Cleveland-Akron-Lorain Area	OH	Subpart 2/Moderate	Summit Co	W	542,899
Columbia Area	SC	Subpart 1 - EAC	Lexington Co	P	181,265
Columbia Area	SC	Subpart 1 - EAC	Richland Co	P	313,253
Columbus Area	OH	Subpart 1	Delaware Co	W	109,989
Columbus Area	OH	Subpart 1	Fairfield Co	W	122,759
Columbus Area	OH	Subpart 1	Franklin Co	W	1,068,978
Columbus Area	OH	Subpart 1	Knox Co	W	54,500
Columbus Area	OH	Subpart 1	Licking Co	W	145,491
Columbus Area	OH	Subpart 1	Madison Co	W	40,213
Dallas-Fort Worth Area	TX	Subpart 2/Moderate	Collin Co	W	491,675
Dallas-Fort Worth Area	TX	Subpart 2/Moderate	Dallas Co	W	2,218,899

Dallas-Fort Worth Area	TX	Subpart 2/Moderate	Denton Co	W	432,976
Dallas-Fort Worth Area	TX	Subpart 2/Moderate	Ellis Co	W	111,360
Dallas-Fort Worth Area	TX	Subpart 2/Moderate	Johnson Co	W	126,811
Dallas-Fort Worth Area	TX	Subpart 2/Moderate	Kaufman Co	W	71,313
Dallas-Fort Worth Area	TX	Subpart 2/Moderate	Parker Co	W	88,495
Dallas-Fort Worth Area	TX	Subpart 2/Moderate	Rockwall Co	W	43,080
Dallas-Fort Worth Area	TX	Subpart 2/Moderate	Tarrant Co	W	1,446,219
Dayton-Springfield Area	OH	Subpart 1	Clark Co	W	144,742
Dayton-Springfield Area	OH	Subpart 1	Greene Co	W	147,886
Dayton-Springfield Area	OH	Subpart 1	Miami Co	W	98,868
Dayton-Springfield Area	OH	Subpart 1	Montgomery Co	W	559,062
Denver-Boulder-Greeley-Ft. Collins-Love. Area	CO	Subpart 1 - EAC	Adams Co	W	348,618
Denver-Boulder-Greeley-Ft. Collins-Love. Area	CO	Subpart 1 - EAC	Arapahoe Co	W	487,967
Denver-Boulder-Greeley-Ft. Collins-Love. Area	CO	Subpart 1 - EAC	Boulder Co	W	269,814
Denver-Boulder-Greeley-Ft. Collins-Love. Area	CO	Subpart 1 - EAC	Broomfield Co	W	38,272
Denver-Boulder-Greeley-Ft. Collins-Love. Area	CO	Subpart 1 - EAC	Denver Co	W	554,636
Denver-Boulder-Greeley-Ft. Collins-Love. Area	CO	Subpart 1 - EAC	Douglas Co	W	175,766
Denver-Boulder-Greeley-Ft. Collins-Love. Area	CO	Subpart 1 - EAC	Jefferson Co	W	525,507
Denver-Boulder-Greeley-Ft. Collins-Love. Area	CO	Subpart 1 - EAC	Larimer Co	P	239,000
Denver-Boulder-Greeley-Ft. Collins-Love. Area	CO	Subpart 1 - EAC	Weld Co	P	172,000
Detroit-Ann Arbor Area	MI	Subpart 2/Marginal	Lenawee Co	W	98,890
Detroit-Ann Arbor Area	MI	Subpart 2/Marginal	Livingston Co	W	156,951
Detroit-Ann Arbor Area	MI	Subpart 2/Marginal	Macomb Co	W	788,149
Detroit-Ann Arbor Area	MI	Subpart 2/Marginal	Monroe Co	W	145,945
Detroit-Ann Arbor Area	MI	Subpart 2/Marginal	Oakland Co	W	1,194,156
Detroit-Ann Arbor Area	MI	Subpart 2/Marginal	St Clair Co	W	164,235
Detroit-Ann Arbor Area	MI	Subpart 2/Marginal	Washtenaw Co	W	322,895
Detroit-Ann Arbor Area	MI	Subpart 2/Marginal	Wayne Co	W	2,061,162
Door County Area	WI	Subpart 1	Door Co	W	27,961
Erie Area	PA	Subpart 1	Erie Co	W	280,843

Essex County (Whiteface Mtn.) Area	NY	Subpart 1	Essex Co	P	1,000
Fayetteville Area	NC	Subpart 1 - EAC	Cumberland Co	W	302,963
Flint Area	MI	Subpart 1	Genesee Co	W	436,141
Flint Area	MI	Subpart 1	Lapeer Co	W	87,904
Fort Wayne Area	IN	Subpart 1	Allen Co	W	331,849
Franklin County Area	PA	Subpart 1	Franklin Co	W	129,313
Frederick County Area	VA	Subpart 1 - EAC	Frederick Co	W	59,209
Frederick County Area	VA	Subpart 1 - EAC	Winchester	W	23,585
Grand Rapids Area	MI	Subpart 1	Kent Co	W	574,335
Grand Rapids Area	MI	Subpart 1	Ottawa Co	W	238,314
Greater Connecticut Area	CT	Subpart 2/Moderate	Hartford Co	W	857,183
Greater Connecticut Area	CT	Subpart 2/Moderate	Litchfield Co	W	182,193
Greater Connecticut Area	CT	Subpart 2/Moderate	New London Co	W	259,088
Greater Connecticut Area	CT	Subpart 2/Moderate	Tolland Co	W	136,364
Greater Connecticut Area	CT	Subpart 2/Moderate	Windham Co	W	109,091
Greene County Area	PA	Subpart 1	Greene Co	W	40,672
Greensboro-Winston-Salem-High Point Area	NC	Subpart 2/Marginal - EAC	Alamance Co	W	130,800
Greensboro-Winston-Salem-High Point Area	NC	Subpart 2/Marginal - EAC	Caswell Co	W	23,501
Greensboro-Winston-Salem-High Point Area	NC	Subpart 2/Marginal - EAC	Davidson Co	W	147,246
Greensboro-Winston-Salem-High Point Area	NC	Subpart 2/Marginal - EAC	Davie Co	W	34,835
Greensboro-Winston-Salem-High Point Area	NC	Subpart 2/Marginal - EAC	Forsyth Co	W	306,067
Greensboro-Winston-Salem-High Point Area	NC	Subpart 2/Marginal - EAC	Guilford Co	W	421,048
Greensboro-Winston-Salem-High Point Area	NC	Subpart 2/Marginal - EAC	Randolph Co	W	130,454
Greensboro-Winston-Salem-High Point Area	NC	Subpart 2/Marginal - EAC	Rockingham Co	W	91,928
Greenville-Spartanburg-Anderson Area	SC	Subpart 1 - EAC	Anderson Co	W	165,740
Greenville-Spartanburg-Anderson Area	SC	Subpart 1 - EAC	Greenville Co	W	379,616
Greenville-Spartanburg-Anderson Area	SC	Subpart 1 - EAC	Spartanburg Co	W	253,791
Hancock, Knox, Lincoln and Waldo	ME	Subpart 1	Hancock Co	P	29,805

Counties (Central Maine Coast) Area					
Hancock, Knox, Lincoln and Waldo Counties (Central Maine Coast) Area	ME	Subpart 1	Knox Co	P	33,563
Hancock, Knox, Lincoln and Waldo Counties (Central Maine Coast) Area	ME	Subpart 1	Lincoln Co	P	28,504
Hancock, Knox, Lincoln and Waldo Counties (Central Maine Coast) Area	ME	Subpart 1	Waldo Co	P	604
Harrisburg-Lebanon-Carlisle Area	PA	Subpart 1	Cumberland Co	W	213,674
Harrisburg-Lebanon-Carlisle Area	PA	Subpart 1	Dauphin Co	W	251,798
Harrisburg-Lebanon-Carlisle Area	PA	Subpart 1	Lebanon Co	W	120,327
Harrisburg-Lebanon-Carlisle Area	PA	Subpart 1	Perry Co	W	43,602
Haywood and Swain Counties (Great Smoky NP) Area	NC	Subpart 1	Haywood Co	P	28
Haywood and Swain Counties (Great Smoky NP) Area	NC	Subpart 1	Swain Co	P	260
Hickory-Morganton-Lenoir Area	NC	Subpart 1 - EAC	Alexander Co	W	33,603
Hickory-Morganton-Lenoir Area	NC	Subpart 1 - EAC	Burke Co	P	69,970
Hickory-Morganton-Lenoir Area	NC	Subpart 1 - EAC	Caldwell Co	P	64,254
Hickory-Morganton-Lenoir Area	NC	Subpart 1 - EAC	Catawba Co	W	141,685
Houston-Galveston-Brazoria Area	TX	Subpart 2/Moderate	Brazoria Co	W	241,767
Houston-Galveston-Brazoria Area	TX	Subpart 2/Moderate	Chambers Co	W	26,031
Houston-Galveston-Brazoria Area	TX	Subpart 2/Moderate	Fort Bend Co	W	354,452
Houston-Galveston-Brazoria Area	TX	Subpart 2/Moderate	Galveston Co	W	250,158
Houston-Galveston-Brazoria Area	TX	Subpart 2/Moderate	Harris Co	W	3,400,578
Houston-Galveston-Brazoria Area	TX	Subpart 2/Moderate	Liberty Co	W	70,154
Houston-Galveston-Brazoria Area	TX	Subpart 2/Moderate	Montgomery Co	W	293,768
Houston-Galveston-Brazoria Area	TX	Subpart 2/Moderate	Waller Co	W	32,663
Huntington-Ashland Area	KY	Subpart 1	Boyd Co	W	49,752
Huron County Area	MI	Subpart 1	Huron Co	W	36,079
Imperial County Area	CA	Subpart 2/Marginal	Imperial Co	W	142,361
Indianapolis Area	IN	Subpart 1	Boone Co	W	46,107
Indianapolis Area	IN	Subpart 1	Hamilton Co	W	182,740
Indianapolis Area	IN	Subpart 1	Hancock Co	W	55,391
Indianapolis Area	IN	Subpart 1	Hendricks Co	W	104,093
Indianapolis Area	IN	Subpart 1	Johnson Co	W	115,209
Indianapolis Area	IN	Subpart 1	Madison Co	W	133,358
Indianapolis Area	IN	Subpart 1	Marion Co	W	860,454
Indianapolis Area	IN	Subpart 1	Morgan Co	W	66,689
Indianapolis Area	IN	Subpart 1	Shelby Co	W	43,445

Jamestown Area	NY	Subpart 1	Chautauqua Co	W	139,750
Jefferson County Area	NY	Subpart 2/Moderate	Jefferson Co	W	111,738
Johnson City-Kingsport-Bristol Area	TN	Subpart 1 - EAC	Hawkins Co	W	53,563
Johnson City-Kingsport-Bristol Area	TN	Subpart 1 - EAC	Sullivan Co	W	153,048
Johnstown Area	PA	Subpart 1	Cambria Co	W	152,598
Kalamazoo-Battle Creek Area	MI	Subpart 1	Calhoun Co	W	137,985
Kalamazoo-Battle Creek Area	MI	Subpart 1	Kalamazoo Co	W	238,603
Kalamazoo-Battle Creek Area	MI	Subpart 1	Van Buren Co	W	76,263
Kent and Queen Anne's Counties Area	MD	Subpart 2/Marginal	Kent Co	W	19,197
Kent and Queen Anne's Counties Area	MD	Subpart 2/Marginal	Queen Annes Co	W	40,563
Kern County (Eastern Kern) Area	CA	Subpart 1	Kern Co	P	99,251
Kewaunee County Area	WI	Subpart 1	Kewaunee Co	W	20,187
Knoxville Area	TN	Subpart 1	Anderson Co	W	71,330
Knoxville Area	TN	Subpart 1	Blount Co	W	105,823
Knoxville Area	TN	Subpart 1	Cocke Co	P	20
Knoxville Area	TN	Subpart 1	Jefferson Co	W	44,294
Knoxville Area	TN	Subpart 1	Knox Co	W	382,032
Knoxville Area	TN	Subpart 1	Loudon Co	W	39,086
Knoxville Area	TN	Subpart 1	Sevier Co	W	71,170
La Porte County Area	IN	Subpart 2/Marginal	La Porte Co	W	110,106
Lancaster Area	PA	Subpart 2/Marginal	Lancaster Co	W	470,658
Lansing-East Lansing Area	MI	Subpart 1	Clinton Co	W	64,753
Lansing-East Lansing Area	MI	Subpart 1	Eaton Co	W	103,655
Lansing-East Lansing Area	MI	Subpart 1	Ingham Co	W	279,320
Las Vegas Area	NV	Subpart 1	Clark Co	P	1,348,864
Lima Area	OH	Subpart 1	Allen Co	W	108,473
Los Angeles and San Bernardino Counties (W Mojave Desert) Area	CA	Subpart 2/Moderate	Los Angeles Co	P	297,058
Los Angeles and San Bernardino Counties (W Mojave Desert) Area	CA	Subpart 2/Moderate	San Bernardino Co	P	359,350
Los Angeles-South Coast Air Basin Area	CA	Subpart 2/Severe 17	Los Angeles Co	P	9,222,280
Los Angeles-South Coast Air Basin Area	CA	Subpart 2/Severe 17	Orange Co	W	2,846,289
Los Angeles-South Coast Air Basin Area	CA	Subpart 2/Severe 17	Riverside Co	P	1,194,859
Los Angeles-South Coast Air Basin Area	CA	Subpart 2/Severe 17	San Bernardino Co	P	1,330,159
Louisville Area	IN	Subpart 1	Clark Co	W	96,472
Louisville Area	IN	Subpart 1	Floyd Co	W	70,823
Louisville Area	KY	Subpart 1	Bullitt Co	W	61,236
Louisville Area	KY	Subpart 1	Jefferson Co	W	693,604
Louisville Area	KY	Subpart 1	Oldham Co	W	46,178
Macon Area	GA	Subpart 1	Bibb Co	W	153,887
Macon Area	GA	Subpart 1	Monroe Co	P	50
Manitowoc County Area	WI	Subpart 1	Manitowoc Co	W	82,887

Mariposa and Tuolumne Counties (Southern Mountain Counties) Area	CA	Subpart 1	Mariposa Co	W	17,130
Mariposa and Tuolumne Counties (Southern Mountain Counties) Area	CA	Subpart 1	Tuolumne Co	W	54,501
Mason County Area	MI	Subpart 1	Mason Co	W	28,274
Memphis Area	AR	Subpart 2/Marginal	Crittenden Co	W	50,866
Memphis Area	TN	Subpart 2/Marginal	Shelby Co	W	897,472
Milwaukee-Racine Area	WI	Subpart 2/Moderate	Kenosha Co	W	149,577
Milwaukee-Racine Area	WI	Subpart 2/Moderate	Milwaukee Co	W	940,164
Milwaukee-Racine Area	WI	Subpart 2/Moderate	Ozaukee Co	W	82,317
Milwaukee-Racine Area	WI	Subpart 2/Moderate	Racine Co	W	188,831
Milwaukee-Racine Area	WI	Subpart 2/Moderate	Washington Co	W	117,493
Milwaukee-Racine Area	WI	Subpart 2/Moderate	Waukesha Co	W	360,767
Murray County (Chattahoochee Nat Forest) Area	GA	Subpart 1	Murray Co	P	1,000
Muskegon Area	MI	Subpart 2/Marginal	Muskegon Co	W	170,200
Nashville Area	TN	Subpart 1 - EAC	Davidson Co	W	569,891
Nashville Area	TN	Subpart 1 - EAC	Rutherford Co	W	182,023
Nashville Area	TN	Subpart 1 - EAC	Sumner Co	W	130,449
Nashville Area	TN	Subpart 1 - EAC	Williamson Co	W	126,638
Nashville Area	TN	Subpart 1 - EAC	Wilson Co	W	88,809
Nevada County (Western part) Area	CA	Subpart 1	Nevada Co	P	77,735
New York-N. New Jersey-Long Island Area	CT	Subpart 2/Moderate	Fairfield Co	W	882,567
New York-N. New Jersey-Long Island Area	CT	Subpart 2/Moderate	Middlesex Co	W	155,071
New York-N. New Jersey-Long Island Area	CT	Subpart 2/Moderate	New Haven Co	W	824,008
New York-N. New Jersey-Long Island Area	NJ	Subpart 2/Moderate	Bergen Co	W	884,118
New York-N. New Jersey-Long Island Area	NJ	Subpart 2/Moderate	Essex Co	W	793,633
New York-N. New Jersey-Long Island Area	NJ	Subpart 2/Moderate	Hudson Co	W	608,975
New York-N. New Jersey-Long Island Area	NJ	Subpart 2/Moderate	Hunterdon Co	W	121,989
New York-N. New Jersey-Long Island Area	NJ	Subpart 2/Moderate	Middlesex Co	W	750,162
New York-N. New Jersey-Long Island Area	NJ	Subpart 2/Moderate	Monmouth Co	W	615,301
New York-N. New Jersey-Long Island Area	NJ	Subpart 2/Moderate	Morris Co	W	470,212
New York-N. New Jersey-Long Island Area	NJ	Subpart 2/Moderate	Passaic Co	W	489,049

New York-N. New Jersey-Long Island Area	NJ	Subpart 2/Moderate	Somerset Co	W	297,490
New York-N. New Jersey-Long Island Area	NJ	Subpart 2/Moderate	Sussex Co	W	144,166
New York-N. New Jersey-Long Island Area	NJ	Subpart 2/Moderate	Union Co	W	522,541
New York-N. New Jersey-Long Island Area	NJ	Subpart 2/Moderate	Warren Co	W	102,437
New York-N. New Jersey-Long Island Area	NY	Subpart 2/Moderate	Bronx Co	W	1,332,650
New York-N. New Jersey-Long Island Area	NY	Subpart 2/Moderate	Kings Co	W	2,465,326
New York-N. New Jersey-Long Island Area	NY	Subpart 2/Moderate	Nassau Co	W	1,334,544
New York-N. New Jersey-Long Island Area	NY	Subpart 2/Moderate	New York Co	W	1,537,195
New York-N. New Jersey-Long Island Area	NY	Subpart 2/Moderate	Queens Co	W	2,229,379
New York-N. New Jersey-Long Island Area	NY	Subpart 2/Moderate	Richmond Co	W	443,728
New York-N. New Jersey-Long Island Area	NY	Subpart 2/Moderate	Rockland Co	W	286,753
New York-N. New Jersey-Long Island Area	NY	Subpart 2/Moderate	Suffolk Co	W	1,419,369
New York-N. New Jersey-Long Island Area	NY	Subpart 2/Moderate	Westchester Co	W	923,459
Norfolk-Virginia Beach-Newport News (Hampton Roads) Area	VA	Subpart 2/Marginal	Chesapeake	W	199,184
Norfolk-Virginia Beach-Newport News (Hampton Roads) Area	VA	Subpart 2/Marginal	Gloucester Co	W	34,780
Norfolk-Virginia Beach-Newport News (Hampton Roads) Area	VA	Subpart 2/Marginal	Hampton	W	146,437
Norfolk-Virginia Beach-Newport News (Hampton Roads) Area	VA	Subpart 2/Marginal	Isle Of Wight Co	W	29,728
Norfolk-Virginia Beach-Newport News (Hampton Roads) Area	VA	Subpart 2/Marginal	James City Co	W	48,102
Norfolk-Virginia Beach-Newport News (Hampton Roads) Area	VA	Subpart 2/Marginal	Newport News	W	180,150
Norfolk-Virginia Beach-Newport News (Hampton Roads) Area	VA	Subpart 2/Marginal	Norfolk	W	234,403
Norfolk-Virginia Beach-Newport News (Hampton Roads) Area	VA	Subpart 2/Marginal	Poquoson	W	11,566
Norfolk-Virginia Beach-Newport News (Hampton Roads) Area	VA	Subpart 2/Marginal	Portsmouth	W	100,565
Norfolk-Virginia Beach-Newport News (Hampton Roads) Area	VA	Subpart 2/Marginal	Suffolk	W	63,677
Norfolk-Virginia Beach-Newport News (Hampton Roads) Area	VA	Subpart 2/Marginal	Virginia Beach	W	425,257
Norfolk-Virginia Beach-Newport News (Hampton Roads) Area	VA	Subpart 2/Marginal	Williamsburg	W	11,998
Norfolk-Virginia Beach-Newport News (Hampton Roads) Area	VA	Subpart 2/Marginal	York Co	W	56,297
Parkersburg-Marietta Area	OH	Subpart 1	Washington Co	W	63,251
Parkersburg-Marietta Area	WV	Subpart 1	Wood Co	W	87,986

Philadelphia-Wilmington-Atlantic City Area	DE	Subpart 2/Moderate	Kent Co	W	126,697
Philadelphia-Wilmington-Atlantic City Area	DE	Subpart 2/Moderate	New Castle Co	W	500,265
Philadelphia-Wilmington-Atlantic City Area	DE	Subpart 2/Moderate	Sussex Co	W	156,638
Philadelphia-Wilmington-Atlantic City Area	MD	Subpart 2/Moderate	Cecil Co	W	85,951
Philadelphia-Wilmington-Atlantic City Area	NJ	Subpart 2/Moderate	Atlantic Co	W	252,552
Philadelphia-Wilmington-Atlantic City Area	NJ	Subpart 2/Moderate	Burlington Co	W	423,394
Philadelphia-Wilmington-Atlantic City Area	NJ	Subpart 2/Moderate	Camden Co	W	508,932
Philadelphia-Wilmington-Atlantic City Area	NJ	Subpart 2/Moderate	Cape May Co	W	102,326
Philadelphia-Wilmington-Atlantic City Area	NJ	Subpart 2/Moderate	Cumberland Co	W	146,438
Philadelphia-Wilmington-Atlantic City Area	NJ	Subpart 2/Moderate	Gloucester Co	W	254,673
Philadelphia-Wilmington-Atlantic City Area	NJ	Subpart 2/Moderate	Mercer Co	W	350,761
Philadelphia-Wilmington-Atlantic City Area	NJ	Subpart 2/Moderate	Ocean Co	W	510,916
Philadelphia-Wilmington-Atlantic City Area	NJ	Subpart 2/Moderate	Salem Co	W	64,285
Philadelphia-Wilmington-Atlantic City Area	PA	Subpart 2/Moderate	Bucks Co	W	597,635
Philadelphia-Wilmington-Atlantic City Area	PA	Subpart 2/Moderate	Chester Co	W	433,501
Philadelphia-Wilmington-Atlantic City Area	PA	Subpart 2/Moderate	Delaware Co	W	550,864
Philadelphia-Wilmington-Atlantic City Area	PA	Subpart 2/Moderate	Montgomery Co	W	750,097
Philadelphia-Wilmington-Atlantic City Area	PA	Subpart 2/Moderate	Philadelphia Co	W	1,517,550
Phoenix-Mesa Area	AZ	Subpart 1	Maricopa Co	P	3,054,504
Phoenix-Mesa Area	AZ	Subpart 1	Pinal Co	P	31,541
Pittsburgh-Beaver Valley Area	PA	Subpart 1	Allegheny Co	W	1,281,666
Pittsburgh-Beaver Valley Area	PA	Subpart 1	Armstrong Co	W	72,392
Pittsburgh-Beaver Valley Area	PA	Subpart 1	Beaver Co	W	181,412
Pittsburgh-Beaver Valley Area	PA	Subpart 1	Butler Co	W	174,083
Pittsburgh-Beaver Valley Area	PA	Subpart 1	Fayette Co	W	148,644
Pittsburgh-Beaver Valley Area	PA	Subpart 1	Washington Co	W	202,897
Pittsburgh-Beaver Valley Area	PA	Subpart 1	Westmoreland Co	W	369,993
Portland Area	ME	Subpart 2/Marginal	Androscoggin Co	P	3,390
Portland Area	ME	Subpart 2/Marginal	Cumberland Co	P	252,907
Portland Area	ME	Subpart 2/Marginal	Sagadahoc Co	W	35,214
Portland Area	ME	Subpart	York Co	P	164,997

		2/Marginal			
Poughkeepsie Area	NY	Subpart 2/Moderate	Dutchess Co	W	280,150
Poughkeepsie Area	NY	Subpart 2/Moderate	Orange Co	W	341,367
Poughkeepsie Area	NY	Subpart 2/Moderate	Putnam Co	W	95,745
Providence (all of RI) Area	RI	Subpart 2/Moderate	Bristol Co	W	50,648
Providence (all of RI) Area	RI	Subpart 2/Moderate	Kent Co	W	167,090
Providence (all of RI) Area	RI	Subpart 2/Moderate	Newport Co	W	85,433
Providence (all of RI) Area	RI	Subpart 2/Moderate	Providence Co	W	621,602
Providence (all of RI) Area	RI	Subpart 2/Moderate	Washington Co	W	123,546
Raleigh-Durham-Chapel Hill Area	NC	Subpart 1	Chatham Co	P	21,320
Raleigh-Durham-Chapel Hill Area	NC	Subpart 1	Durham Co	W	223,314
Raleigh-Durham-Chapel Hill Area	NC	Subpart 1	Franklin Co	W	47,260
Raleigh-Durham-Chapel Hill Area	NC	Subpart 1	Granville Co	W	48,498
Raleigh-Durham-Chapel Hill Area	NC	Subpart 1	Johnston Co	W	121,965
Raleigh-Durham-Chapel Hill Area	NC	Subpart 1	Orange Co	W	118,227
Raleigh-Durham-Chapel Hill Area	NC	Subpart 1	Person Co	W	35,623
Raleigh-Durham-Chapel Hill Area	NC	Subpart 1	Wake Co	W	627,846
Reading Area	PA	Subpart 1	Berks Co	W	373,638
Richmond-Petersburg Area	VA	Subpart 2/Marginal	Charles City Co	W	6,926
Richmond-Petersburg Area	VA	Subpart 2/Marginal	Chesterfield Co	W	259,903
Richmond-Petersburg Area	VA	Subpart 2/Marginal	Colonial Heights	W	16,897
Richmond-Petersburg Area	VA	Subpart 2/Marginal	Hanover Co	W	86,320
Richmond-Petersburg Area	VA	Subpart 2/Marginal	Henrico Co	W	262,300
Richmond-Petersburg Area	VA	Subpart 2/Marginal	Hopewell	W	22,354
Richmond-Petersburg Area	VA	Subpart 2/Marginal	Petersburg	W	33,740
Richmond-Petersburg Area	VA	Subpart 2/Marginal	Prince George Co	W	33,047
Richmond-Petersburg Area	VA	Subpart 2/Marginal	Richmond	W	197,790
Riverside County (Coachella Valley) Area	CA	Subpart 2/Serious	Riverside Co	P	324,750
Roanoke Area	VA	Subpart 1 - EAC	Botetourt Co	W	30,496
Roanoke Area	VA	Subpart 1 - EAC	Roanoke	W	94,911
Roanoke Area	VA	Subpart 1 - EAC	Roanoke Co	W	85,778
Roanoke Area	VA	Subpart 1 - EAC	Salem	W	24,747
Rochester Area	NY	Subpart 1	Genesee Co	W	60,370
Rochester Area	NY	Subpart 1	Livingston Co	W	64,328

Rochester Area	NY	Subpart 1	Monroe Co	W	735,343
Rochester Area	NY	Subpart 1	Ontario Co	W	100,224
Rochester Area	NY	Subpart 1	Orleans Co	W	44,171
Rochester Area	NY	Subpart 1	Wayne Co	W	93,765
Rocky Mount Area	NC	Subpart 1	Edgecombe Co	W	55,606
Rocky Mount Area	NC	Subpart 1	Nash Co	W	87,420
Sacramento Metro Area	CA	Subpart 2/Serious	El Dorado Co	P	124,164
Sacramento Metro Area	CA	Subpart 2/Serious	Placer Co	P	239,978
Sacramento Metro Area	CA	Subpart 2/Serious	Sacramento Co	W	1,223,499
Sacramento Metro Area	CA	Subpart 2/Serious	Solano Co	P	197,034
Sacramento Metro Area	CA	Subpart 2/Serious	Sutter Co	P	25,013
Sacramento Metro Area	CA	Subpart 2/Serious	Yolo Co	W	168,660
San Antonio Area	TX	Subpart 1 - EAC	Bexar Co	W	1,392,931
San Antonio Area	TX	Subpart 1 - EAC	Comal Co	W	78,021
San Antonio Area	TX	Subpart 1 - EAC	Guadalupe Co	W	89,023
San Diego Area	CA	Subpart 1	San Diego Co	P	2,813,431
San Francisco Bay Area	CA	Subpart 2/Marginal	Alameda Co	W	1,443,741
San Francisco Bay Area	CA	Subpart 2/Marginal	Contra Costa Co	W	948,816
San Francisco Bay Area	CA	Subpart 2/Marginal	Marin Co	W	247,289
San Francisco Bay Area	CA	Subpart 2/Marginal	Napa Co	W	124,279
San Francisco Bay Area	CA	Subpart 2/Marginal	San Francisco Co	W	776,733
San Francisco Bay Area	CA	Subpart 2/Marginal	San Mateo Co	W	707,161
San Francisco Bay Area	CA	Subpart 2/Marginal	Santa Clara Co	W	1,682,585
San Francisco Bay Area	CA	Subpart 2/Marginal	Solano Co	P	197,508
San Francisco Bay Area	CA	Subpart 2/Marginal	Sonoma Co	P	413,716
San Joaquin Valley Area	CA	Subpart 2/Serious	Fresno Co	W	799,407
San Joaquin Valley Area	CA	Subpart 2/Serious	Kern Co	P	550,220
San Joaquin Valley Area	CA	Subpart 2/Serious	Kings Co	W	129,461
San Joaquin Valley Area	CA	Subpart 2/Serious	Madera Co	W	123,109
San Joaquin Valley Area	CA	Subpart 2/Serious	Merced Co	W	210,554
San Joaquin Valley Area	CA	Subpart 2/Serious	San Joaquin Co	W	563,598
San Joaquin Valley Area	CA	Subpart	Stanislaus Co	W	446,997

		2/Serious			
San Joaquin Valley Area	CA	Subpart 2/Serious	Tulare Co	W	368,021
Scranton-Wilkes-Barre Area	PA	Subpart 1	Lackawanna Co	W	213,295
Scranton-Wilkes-Barre Area	PA	Subpart 1	Luzerne Co	W	319,250
Scranton-Wilkes-Barre Area	PA	Subpart 1	Monroe Co	W	138,687
Scranton-Wilkes-Barre Area	PA	Subpart 1	Wyoming Co	W	28,080
Sheboygan Area	WI	Subpart 2/Moderate	Sheboygan Co	W	112,646
South Bend-Elkhart Area	IN	Subpart 1	Elkhart Co	W	182,791
South Bend-Elkhart Area	IN	Subpart 1	St Joseph Co	W	265,559
Springfield (W. Mass) Area	MA	Subpart 2/Moderate	Berkshire Co	W	134,953
Springfield (W. Mass) Area	MA	Subpart 2/Moderate	Franklin Co	W	71,535
Springfield (W. Mass) Area	MA	Subpart 2/Moderate	Hampden Co	W	456,228
Springfield (W. Mass) Area	MA	Subpart 2/Moderate	Hampshire Co	W	152,251
St. Louis Area	IL	Subpart 2/Moderate	Jersey Co	W	21,668
St. Louis Area	IL	Subpart 2/Moderate	Madison Co	W	258,941
St. Louis Area	IL	Subpart 2/Moderate	Monroe Co	W	27,619
St. Louis Area	IL	Subpart 2/Moderate	St Clair Co	W	256,082
St. Louis Area	MO	Subpart 2/Moderate	Franklin Co	W	93,807
St. Louis Area	MO	Subpart 2/Moderate	Jefferson Co	W	198,099
St. Louis Area	MO	Subpart 2/Moderate	St Charles Co	W	283,883
St. Louis Area	MO	Subpart 2/Moderate	St Louis	W	348,189
St. Louis Area	MO	Subpart 2/Moderate	St Louis Co	W	1,016,315
State College Area	PA	Subpart 1	Centre Co	W	135,758
Steubenville-Weirton Area	OH	Subpart 1	Jefferson Co	W	73,894
Steubenville-Weirton Area	WV	Subpart 1	Brooke Co	W	25,447
Steubenville-Weirton Area	WV	Subpart 1	Hancock Co	W	32,667
Sutter County (part) (Sutter Buttes) Area	CA	Subpart 1	Sutter Co	P	1
Tioga County Area	PA	Subpart 1	Tioga Co	W	41,373
Toledo Area	OH	Subpart 1	Lucas Co	W	455,054
Toledo Area	OH	Subpart 1	Wood Co	W	121,065
Ventura County (part) Area	CA	Subpart 2/Moderate	Ventura Co	P	753,197
Washington Area	DC	Subpart 2/Moderate	Entire District	W	572,059
Washington Area	MD	Subpart 2/Moderate	Calvert Co	W	74,563
Washington Area	MD	Subpart	Charles Co	W	120,546

		2/Moderate			
Washington Area	MD	Subpart 2/Moderate	Frederick Co	W	195,277
Washington Area	MD	Subpart 2/Moderate	Montgomery Co	W	873,341
Washington Area	MD	Subpart 2/Moderate	Prince George's Co	W	801,515
Washington Area	VA	Subpart 2/Moderate	Alexandria	W	128,283
Washington Area	VA	Subpart 2/Moderate	Arlington Co	W	189,453
Washington Area	VA	Subpart 2/Moderate	Fairfax	W	21,498
Washington Area	VA	Subpart 2/Moderate	Fairfax Co	W	969,749
Washington Area	VA	Subpart 2/Moderate	Falls Church	W	10,377
Washington Area	VA	Subpart 2/Moderate	Loudoun Co	W	169,599
Washington Area	VA	Subpart 2/Moderate	Manassas	W	35,135
Washington Area	VA	Subpart 2/Moderate	Manassas Park	W	10,290
Washington Area	VA	Subpart 2/Moderate	Prince William Co	W	280,813
Washington County (Hagerstown) Area	MD	Subpart 1 - EAC	Washington Co	W	131,923
Wheeling Area	OH	Subpart 1	Belmont Co	W	70,226
Wheeling Area	WV	Subpart 1	Marshall Co	W	35,519
Wheeling Area	WV	Subpart 1	Ohio Co	W	47,427
York Area	PA	Subpart 1	Adams Co	W	91,292
York Area	PA	Subpart 1	York Co	W	381,751
Youngstown-Warren-Sharon Area	OH	Subpart 1	Columbiana Co	W	112,075
Youngstown-Warren-Sharon Area	OH	Subpart 1	Mahoning Co	W	257,555
Youngstown-Warren-Sharon Area	OH	Subpart 1	Trumbull Co	W	225,116
Youngstown-Warren-Sharon Area	PA	Subpart 1	Mercer Co	W	120,293

a) Under the CAA these nonattainment areas are further classified as subpart 1 or subpart 2 (subpart 2 is further classified as marginal, moderate, serious, severe or extreme) based on their design values. An Early Action Compact (EAC) area is one that has entered into a compact with the EPA and has agreed to reduce ground level ozone pollution earlier than the CAA would require in exchange the EPA will defer the effective date of the nonattainment designation. The severe designation is denoted as severe-15 or severe-17 based on the maximum attainment date associated with the classification.

b) Boston-Manchester-Portsmouth (SE), NH has the same classification as Boston-Lawrence- Worcester (E. MA), MA.

Appendix 3C: PM Nonattainment

Table 3C-1. $PM_{2.5}$ Nonattainment Areas and Populations (data is current through October 2006 and the population numbers are from 2000 census data)

$PM_{2.5}$ Nonattainment Area	Population
Atlanta, GA	4,231,750
Baltimore, MD	2,512,431
Birmingham, AL	807,612
Canton-Massillon, OH	378,098
Charleston, WV	251,662
Chattanooga, AL-TN-GA	423,809
Chicago-Gary-Lake County, IL-IN	8,757,808
Cincinnati-Hamilton, OH-KY-IN	1,850,975
Cleveland-Akron-Lorain, OH	2,775,447
Columbus, OH	1,448,503
Dayton-Springfield, OH	851,690
Detroit-Ann Arbor, MI	4,833,493
Evansville, IN	277,402
Greensboro-Winston Salem-High Point, NC	568,294
Harrisburg-Lebanon-Carlisle, PA	585,799
Hickory, NC	141,685
Huntington-Ashland, WV-KY-OH	340,776
Indianapolis, IN	1,329,185
Johnstown, PA	164,431
Knoxville, TN	599,008
Lancaster, PA	470,658
Libby, MT	2,626
Liberty-Clairton, PA	21,600
Los Angeles-South Coast Air Basin, CA	14,593,587
Louisville, KY-IN	938,905
Macon, GA	154,837
Martinsburg, WV-Hagerstown, MD	207,828
New York-N. New Jersey-Long Island,NY-NJ-CT	19,802,587
Parkersburg-Marietta, WV-OH	152,912
Philadelphia-Wilmington, PA-NJ-DE	5,536,911
Pittsburgh-Beaver Valley, PA	2,195,054
Reading, PA	373,638
Rome, GA	90,565
San Joaquin Valley, CA	3,191,367
St. Louis, MO-IL	2,486,562
Steubenville-Weirton, OH-WV	132,008
Washington, DC-MD-VA	4,377,935
Wheeling, WV-OH	153,172
York, PA	381,751
Total	88,394,361

Table 3C-2. PM_{10} Nonattainment Areas and Populations (data is current through March 2006 and the population numbers are from 2000 census data)

PM10 Nonattainment Areas Listed Alphabetically	Classification	Number of Counties NAA	2000 Population (thousands)	EPA Region	State
Ajo (Pima County), AZ	Moderate	1	8	9	AZ
Anthony, NM	Moderate	1	3	6	NM
Bonner Co (Sandpoint), ID	Moderate	1	37	10	ID
Butte, MT	Moderate	1	35	8	MT
Clark Co, NV	Serious	1	1,376	9	NV
Coachella Valley, CA	Serious	1	182	9	CA
Columbia Falls, MT	Moderate	1	4	8	MT
Coso Junction, CA	Moderate	1	7	9	CA
Douglas (Cochise County), AZ	Moderate	1	16	9	AZ
Eagle River, AK	Moderate	1	195	10	AK
El Paso Co, TX	Moderate	1	564	6	TX
Eugene-Springfield, OR	Moderate	1	179	10	OR
Flathead County; Whitefish and vicinity, MT	Moderate	1	5	8	MT
Fort Hall Reservation, ID	Moderate	2	1	10	ID
Hayden/Miami, AZ	Moderate	2	4	9	AZ
Imperial Valley, CA	Serious	1	120	9	CA
Juneau, AK	Moderate	1	14	10	AK
Kalispell, MT	Moderate	1	15	8	MT
LaGrande, OR	Moderate	1	12	10	OR
Lake Co, OR	Moderate	1	3	10	OR
Lame Deer, MT	Moderate	1	1	8	MT
Lane Co, OR	Moderate	1	3	10	OR
Libby, MT	Moderate	1	3	8	MT
Los Angeles South Coast Air Basin, CA	Serious	4	14,594	9	CA
Medford-Ashland, OR	Moderate	1	78	10	OR
Missoula, MT	Moderate	1	52	8	MT
Mono Basin, CA	Moderate	1	0	9	CA
Mun. of Guaynabo, PR	Moderate	1	92	2	PR
New York Co, NY	Moderate	1	1,537	2	NY
Nogales, AZ	Moderate	1	25	9	AZ
Ogden, UT	Moderate	1	77	8	UT
Owens Valley, CA	Serious	1	7	9	CA
Paul Spur, AZ	Moderate	1	1	9	AZ
Phoenix, AZ	Serious	2	3,112	9	AZ
Pinehurst, ID	Moderate	1	2	10	ID
Polson, MT	Moderate	1	4	8	MT
Portneuf Valley, ID	Moderate	2	66	10	ID
Rillito, AZ	Moderate	1	1	9	AZ
Ronan, MT	Moderate	1	3	8	MT
Sacramento Co, CA	Moderate	1	1,223	9	CA
Salt Lake Co, UT	Moderate	1	898	8	UT
San Bernardino Co, CA	Moderate	1	199	9	CA
San Joaquin Valley, CA	Serious	7	3,080	9	CA

Sanders County (part);Thompson Falls and vicinity, MT	Moderate	1	1	8	MT
Sheridan, WY	Moderate	1	16	8	WY
Shoshone Co, ID	Moderate	1	10	10	ID
Trona, CA	Moderate	1	4	9	CA
Utah Co, UT	Moderate	1	369	8	UT
Washoe Co, NV	Serious	1	339	9	NV
Weirton, WV	Moderate	2	15	3	WV
Yuma, AZ	Moderate	1	82	9	AZ
51 Total Areas		51	28,674		

Appendix 3D: Visibility Tables

Table 3D-1. List of 156 Mandatory Class I Federal Areas Where Visibility is an Important Value (As Listed in 40 CFR 81)*

State	Area Name	Acreage	Federal Land Manager
Alabama	Sipsey Wilderness Area	12,646	USDA-FS
Alaska	Bering Sea Wilderness Area	41,113	USDI-FWS
	Denali NP (formerly Mt. McKinley NP)	1,949,493	USDI-NPS
	Simeonof Wilderness Area	25,141	USDI-FWS
	Tuxedni Wilderness Area	6,402	USDI-FWS
Arizona	Chiricahua National Monument Wilderness Area	9,440	USDI-NPS
	Chiricahua Wilderness Area	18,000	USDA-FS
	Galiuro Wilderness Area	52,717	USDA-FS
	Grand Canyon NP	1,176,913	USDI-NPS
	Mazatzal Wilderness Area	205,137	USDA-FS
	Mount Baldy Wilderness Area	6,975	USDA-FS
	Petrified Forest NP	93,493	USDI-NPS
	Pine Mountain Wilderness Area	20,061	USDA-FS
	Saguaro Wilderness Area	71,400	USDI-FS
	Sierra Ancha Wilderness Area	20,850	USDA-FS
	Superstition Wilderness Area	124,117	USDA-FS
	Sycamore Canyon Wilderness Area	47,757	USDA-FS
Arkansas	Caney Creek Wilderness Area	4,344	USDA-FS
	Upper Buffalo Wilderness Area	9,912	USDA-FS
California	Agua Tibia Wilderness Area	15,934	USDA-FS
	Caribou Wilderness Area	19,080	USDA-FS
	Cucamonga Wilderness Area	9,022	USDA-FS
	Desolation Wilderness Area	63,469	USDA-FS
	Dome Land Wilderness Area	62,206	USDA-FS
	Emigrant Wilderness Area	104,311	USDA-FS
	Hoover Wilderness Area	47,916	USDA-FS
	John Muir Wilderness Area	484,673	USDA-FS
	Joshua Tree Wilderness Area	429,690	USDI-NPS
		36,300	USDI-BLM
	Kaiser Wilderness Area	22,500	USDA-FS
	Kings Canyon NP	459,994	USDI-NPS
	Lassen Volcanic NP	105,800	USDI-NPS
	Lava Beds Wilderness Area	28,640	USDI-NPS
	Marble Mountain Wilderness Area	213,743	USDA-FS
	Minarets Wilderness Area	109,484	USDA-FS
	Mokelumme Wilderness Area	50,400	USDA-FS
	Pinnacles Wilderness Area	12,952	USDI-NPS
	Point Reyes Wilderness Area	25,370	USDI-NPS
	Redwood NP	27,792	USDI-NPS

State	Area Name	Acreage	Federal Land Manager
	San Gabriel Wilderness Area	36,137	USDA-FS
	San Gorgonio Wilderness Area	56,722	USDA-FS
		37,980	USDI-BLM
	San Jacinto Wilderness Area	20,564	USDA-FS
	San Rafael Wilderness Area	142,722	USDA-FS
	Sequoia NP	386,642	USDI-NS
	South Warner Wilderness Area	68,507	USDA-FS
	Thousand Lakes Wilderness Area	15,695	USDA-FS
	Ventana Wilderness Area	95,152	USDA-FS
	Yolla Bolly-Middle Eel Wilderness Area	111,841	USDA-FS
		42,000	USDI-BLM
	Yosemite NP	759,172	USDI-NPS
Colorado	Black Canyon of the Gunnison Wilderness Area	11,180	USDI-NPS
	Eagles Nest Wilderness Area	133,910	USDA-FS
	Flat Tops Wilderness Area	235,230	USDA-FS
	Great Sand Dunes Wilderness Area	33,450	USDI-NPS
	La Garita Wilderness Area	48,486	USDA-FS
	Maroon Bells-Snowmass Wilderness Area	71,060	USDA-FS
	Mesa Verde NP	51,488	USDI-NPS
	Mount Zirkel Wilderness Area	72,472	USDA-FS
	Rawah Wilderness Area	26,674	USDA-FS
	Rocky Mountain NP	263,138	USDI-NPS
	Weminuche Wilderness Area	400,907	USDA-FS
	West Elk Wilderness Area	61,412	USDA-FS
Florida	Chassahowitzka Wilderness Area	23,360	USDI-FWS
	Everglades NP	1,397,429	USDI-NPS
	St. Marks Wilderness Area	17,745	USDI-FWS
Georgia	Cohotta Wilderness Area	33,776	USDA-FS
	Okefenokee Wilderness Area	343,850	USDI-FWS
	Wolf Island Wilderness Area	5,126	USDI-FWS
Hawaii	Haleakala NP	27,208	USDI-NPS
	Hawaii Volcanoes NP	217,029	USDI-NPS
Idaho	Craters of the Moon Wilderness Area[a]	43,243	USDI-NPS
	Hells Canyon Wilderness Area	83,800	USDA-FS
	Sawtooth Wilderness Area	216,383	USDA-FS
	Selway-Bitterroot Wilderness Area[b]	988,770	USDA-FS
	Yellowstone NP[c]	31,488	USDI-NPS
Kentucky	Mammoth Cave NP	51,303	USDI-NPS
Louisiana	Breton Wilderness Area	5,000+	USDI-FWS
Maine	Acadia National Park	37,503	USDI-NPS
	Moosehorn Wilderness Area	7,501	USDI-FWS
	Edmunds Unit	2,706	USDI-FWS
	Baring Unit	4,680	USDI-FWS
Michigan	Isle Royale NP	542,428	USDI-NPS
	Seney Wilderness Area	25,150	USDI-FWS

State	Area Name	Acreage	Federal Land Manager
Minnesota	Boundary Waters Canoe Area Wilderness Area	747,840	USDA-FS
	Voyageurs NP	114,964	USDI-NPS
Missouri	Hercules-Glades Wilderness Area	12,315	USDA-FS
	Mingo Wilderness Area	8,000	USDI-FWS
Montana	Anaconda-Pintlar Wilderness Area	157,803	USDA-FS
	Bob Marshall Wilderness Area	950,000	USDA-FS
	Cabinet Mountains Wilderness Area	94,272	USDA-FS
	Gates of the Mtn Wilderness Area	28,562	USDA-FS
	Glacier NP	1,012,599	USDI-NPS
	Medicine Lake Wilderness Area	11,366	USDI-FWS
	Mission Mountain Wilderness Area	73,877	USDA-FS
	Red Rock Lakes Wilderness Area	32,350	USDI-FWS
	Scapegoat Wilderness Area	239,295	USDA-FS
	Selway-Bitterroot Wilderness Area[d]	251,930	USDA-FS
	U. L. Bend Wilderness Area	20,890	USDI-FWS
	Yellowstone NP[e]	167,624	USDI-NPS
Nevada	Jarbidge Wilderness Area	64,667	USDA-FS
New Hampshire	Great Gulf Wilderness Area	5,552	USDA-FS
	Presidential Range-Dry River Wilderness Area	20,000	USDA-FS
New Jersey	Brigantine Wilderness Area	6,603	USDI-FWS
New Mexico	Bandelier Wilderness Area	23,267	USDI-NPS
	Bosque del Apache Wilderness Area	80,850	USDI-FWS
	Carlsbad Caverns NP	46,435	USDI-NPS
	Gila Wilderness Area	433,690	USDA-FS
	Pecos Wilderness Area	167,416	USDA-FS
	Salt Creek Wilderness Area	8,500	USDI-FWS
	San Pedro Parks Wilderness Area	41,132	USDA-FS
	Wheeler Peak Wilderness Area	6,027	USDA-FS
	White Mountain Wilderness Area	31,171	USDA-FS
North Carolina	Great Smoky Mountains NP[f]	273,551	USDI-NPS
	Joyce Kilmer-Slickrock Wilderness Area[g]	10,201	USDA-FS
	Linville Gorge Wilderness Area	7,575	USDA-FS
	Shining Rock Wilderness Area	13,350	USDA-FS
	Swanquarter Wilderness Area	9,000	USDI-FWS
North Dakota	Lostwood Wilderness	5,557	USDI-FWS
	Theodore Roosevelt NP	69,675	USDI-NPS
Oklahoma	Wichita Mountains Wilderness	8,900	USDI-FWS
Oregon	Crater Lake NP	160,290	USDA-NPS
	Diamond Peak Wilderness	36,637	USDA-FS
	Eagle Cap Wilderness	293,476	USDA-FS
	Gearhart Mountain Wilderness	18,709	USDA-FS
	Hells Canyon Wilderness[a]	108,900	USDA-FS
		22,700	USDI-BLM
	Kalmiopsis Wilderness	76,900	USDA-FS

State	Area Name	Acreage	Federal Land Manager
	Mountain Lakes Wilderness	23,071	USDA-FS
	Mount Hood Wilderness	14,160	USDA-FS
	Mount Jefferson Wilderness	100,208	USDA-FS
	Mount Washington Wilderness	46,116	USDA-FS
	Strawberry Mountain Wilderness	33,003	USDA-FS
	Three Sisters Wilderness	199,902	USDA-FS
South Carolina	Cape Romain Wilderness	28,000	USDI-FWS
South Dakota	Badlands Wilderness	64,250	USDI-NPS
	Wind Cave NP	28,060	USDI-NPS
Tennessee	Great Smoky Mountains NP[f]	241,207	USDI-NPS
	Joyce Kilmer-Slickrock Wilderness[g]	3,832	USDA-FS
Texas	Big Bend NP	708,118	USDI-NPS
	Guadalupe Mountains NP	76,292	USDI-NPS
Utah	Arches NP	65,098	USDI-NPS
	Bryce Canyon NP	35,832	USDI-NPS
	Canyonlands NP	337,570	USDI-NPS
	Capitol Reef NP	221,896	USDI-NPS
	Zion NP	142,462	USDI-NPS
Vermont	Lye Brook Wilderness	12,430	USDA-FS
Virgin Islands	Virgin Islands NP	12,295	USDI-NPS
Virginia	James River Face Wilderness	8,703	USDA-FS
	Shenandoah NP	190,535	USDI-NPS
Washington	Alpine Lakes Wilderness	303,508	USDA-FS
	Glacier Peak Wilderness	464,258	USDA-FS
	Goat Rocks Wilderness	82,680	USDA-FS
	Mount Adams Wilderness	32,356	USDA-FS
	Mount Rainer NP	235,239	USDI-NPS
	North Cascades NP	503,277	USDI-NPS
	Olympic NP	892,578	USDI-NPS
	Pasayten Wilderness	505,524	USDA-FS
West Virginia	Dolly Sods Wilderness	10,215	USDA-FS
	Otter Creek Wilderness	20,000	USDA-FS
Wyoming	Bridger Wilderness	392,160	USDA-FS
	Fitzpatrick Wilderness	191,103	USDA-FS
	Grand Teton NP	305,504	USDI-NPS
	North Absaroka Wilderness	351,104	USDA-FS
	Teton Wilderness	557,311	USDA-FS
	Washakie Wilderness	686,584	USDA-FS
	Yellowstone NP[h]	2,020,625	USDI-NPS
New Brunswick, Canada	Roosevelt Campobello International Park	2,721	i

* U.S. EPA (2001) Visibility in Mandatory Federal Class I Areas (1994-1998): A Report to Congress. EPA-452/R-01-008. This document is available in Docket EPA-HQ-OAR-2005-0036.

a) Hells Canyon Wilderness Area, 192,700 acres overall, of which 108,900 acres are in Oregon and 83,800 acres are in Idaho.

b) Selway Bitterroot Wilderness Area, 1,240,700 acres overall, of which 988,700 acres are in Idaho and 251,930 acres are in Montana.

c) Yellowstone National Park, 2,219,737 acres overall, of which 2,020,625 acres are in Wyoming, 167,624 acres are in Montana, and 31,488 acres are in Idaho

d) Selway-Bitterroot Wilderness Area, 1,240,700 acres overall, of which 988,770 acres are in Idaho and 251,930 acres are in Montana.

e) Yellowstone National Park, 2,219,737 acres overall, of which 2,020,625 acres are in Wyoming, 167,624 acres are in Montana, and 31,488 acres are in Idaho.

f) Great Smoky Mountains National Park, 514,758 acres overall, of which 273,551 acres are in North Carolina, and 241,207 acres are in Tennessee.

g) Joyce Kilmer-Slickrock Wilderness Area, 14,033 acres overall, of which 10,201 acres are in North Carolina, and 3,832 acres are in Tennessee.

h) Yellowstone National Park, 2,219,737 acres overall, of which 2,020,625 acres are in Wyoming, 167,624 acres are in Montana, and 31,488 acres are in Idaho.

i) Chairman, RCIP Commission.

Abbreviations Used in Table:
USDA-FS: U.S. Department of Agriculture, U.S. Forest Service
USDI-BLM: U.S. Department of Interior, Bureau of Land Management
USDI-FWS: U.S. Department of Interior, Fish and Wildlife Service
USDI-NPS: U.S. Department of Interior, National Park Service

Table 3D-2. Current (1998-2002) Visibility, Projected (2015) Visibility, and Natural Background Levels for the 20% Worst Days at 116 IMPROVE Sites

Class I Area Name[a]	State	1998-2002 Baseline Visibility (deciviews)[b]	2015 CAIR Control Case Visibility[c] (deciviews)	Natural Background (deciviews)
Acadia	ME	22.7	21.0	11.5
Agua Tibia	CA	23.2	23.2	7.2
Alpine Lakes	WA	18.0	17.4	7.9
Anaconda - Pintler	MT	12.3	12.2	7.3
Arches	UT	12.0	12.1	7.0
Badlands	SD	17.3	16.8	7.3
Bandelier	NM	13.2	13.2	7.0
Big Bend	TX	18.4	18.3	6.9
Black Canyon of the Gunnison	CO	11.6	11.4	7.1
Bob Marshall	MT	14.2	14.0	7.4
Boundary Waters Canoe Area	MN	20.0	19.0	11.2
Bridger	WY	11.5	11.3	7.1
Brigantine	NJ	27.6	25.4	11.3
Bryce Canyon	UT	12.0	11.9	7.0
Cabinet Mountains	MT	13.8	13.4	7.4
Caney Creek	AR	25.9	24.1	11.3
Canyonlands	UT	12.0	12.0	7.0
Cape Romain	SC	25.9	23.9	11.4
Caribou	CA	14.8	14.6	7.3
Carlsbad Caverns	NM	17.6	17.9	7.0
Chassahowitzka	FL	25.7	23.0	11.5
Chiricahua NM	AZ	13.9	13.9	6.9
Chiricahua W	AZ	13.9	13.9	6.9
Craters of the Moon	ID	14.7	14.7	7.1
Desolation	CA	12.9	12.8	7.1
Dolly Sods	WV	27.6	23.9	11.3
Dome Land	CA	20.3	19.9	7.1
Eagle Cap	OR	19.6	19.0	7.3
Eagles Nest	CO	11.3	11.4	7.1
Emigrant	CA	17.6	17.4	7.1
Everglades	FL	20.3	19.2	11.2
Fitzpatrick	WY	11.5	11.3	7.1
Flat Tops	CO	11.3	11.4	7.1
Galiuro	AZ	13.9	14.1	6.9
Gates of the Mountains	MT	11.2	10.8	7.2
Gila	NM	13.5	13.5	7.0
Glacier	MT	19.5	19.1	7.6
Glacier Peak	WA	14.0	13.8	7.8
Grand Teton	WY	12.1	12.0	7.1
Great Gulf	NH	23.2	21.2	11.3
Great Sand Dunes	CO	13.1	13.0	7.1
Great Smoky Mountains	TN	29.5	26.1	11.4
Guadalupe Mountains	TX	17.6	17.5	7.0
Hells Canyon	OR	18.1	18.0	7.3
Isle Royale	MI	21.1	20.1	11.2

Class I Area Name[a]	State	1998-2002 Baseline Visibility (deciviews)[b]	2015 CAIR Control Case Visibility[c] (deciviews)	Natural Background (deciviews)
James River Face	VA	28.5	25.1	11.2
Jarbidge	NV	12.6	12.8	7.1
Joshua Tree	CA	19.5	20.3	7.1
Joyce Kilmer - Slickrock	NC	29.5	26.1	11.5
Kalmiopsis	OR	14.8	14.4	7.7
Kings Canyon	CA	23.5	24.1	7.1
La Garita	CO	11.6	11.5	7.1
Lassen Volcanic	CA	14.8	14.6	7.3
Lava Beds	CA	16.6	16.5	7.5
Linville Gorge	NC	27.9	24.6	11.4
Lostwood	ND	19.6	18.7	7.3
Lye Brook	VT	23.9	21.1	11.3
Mammoth Cave	KY	30.2	27.0	11.5
Marble Mountain	CA	17.1	16.8	7.7
Maroon Bells - Snowmass	CO	11.3	11.3	7.1
Mazatzal	AZ	13.1	13.5	6.9
Medicine Lake	MT	17.7	17.1	7.3
Mesa Verde	CO	12.8	12.8	7.1
Mingo	MO	27.5	25.9	11.3
Mission Mountains	MT	14.2	14.0	7.4
Mokelumne	CA	12.9	12.8	7.1
Moosehorn	ME	21.4	20.3	11.4
Mount Hood	OR	14.0	13.7	7.8
Mount Jefferson	OR	15.7	15.2	7.8
Mount Rainier	WA	18.9	19.4	7.9
Mount Washington	OR	15.7	15.2	7.9
Mount Zirkel	CO	11.7	11.8	7.1
North Cascades	WA	14.0	14.0	7.8
Okefenokee	GA	26.4	24.7	11.5
Otter Creek	WV	27.6	24.0	11.3
Pasayten	WA	14.7	14.5	7.8
Petrified Forest	AZ	13.5	13.8	7.0
Pine Mountain	AZ	13.1	13.4	6.9
Presidential Range - Dry	NH	23.2	20.9	11.3
Rawah	CO	11.7	11.7	7.1
Red Rock Lakes	WY	12.1	12.1	7.1
Redwood	CA	16.5	16.5	7.8
Rocky Mountain	CO	14.1	14.1	7.1
Roosevelt Campobello	ME	21.4	20.1	11.4
Salt Creek	NM	17.7	17.3	7.0
San Gorgonio	CA	21.5	22.1	7.1
San Jacinto	CA	21.5	21.4	7.1
San Pedro Parks	NM	11.4	11.4	7.0
Sawtooth	ID	13.6	13.5	7.2
Scapegoat	MT	14.2	14.1	7.3
Selway - Bitterroot	MT	12.3	12.1	7.3
Seney	MI	23.8	22.6	11.4
Sequoia	CA	23.5	24.1	7.1
Shenandoah	VA	27.6	23.4	11.3

Class I Area Name[a]	State	1998-2002 Baseline Visibility (deciviews)[b]	2015 CAIR Control Case Visibility[c] (deciviews)	Natural Background (deciviews)
Sierra Ancha	AZ	13.4	13.7	6.9
Sipsey	AL	28.7	26.1	11.4
South Warner	CA	16.6	16.5	7.3
Strawberry Mountain	OR	19.6	19.2	7.5
Superstition	AZ	14.7	15.0	6.9
Swanquarter	NC	24.6	21.9	11.2
Sycamore Canyon	AZ	16.1	16.6	7.0
Teton	WY	12.1	12.1	7.1
Theodore Roosevelt	ND	17.6	16.8	7.3
Thousand Lakes	CA	14.8	14.6	7.3
Three Sisters	OR	15.7	15.2	7.9
UL Bend	MT	14.7	14.1	7.2
Upper Buffalo	AR	25.5	24.3	11.3
Voyageurs	MN	18.4	17.6	11.1
Weminuche	CO	11.6	11.4	7.1
West Elk	CO	11.3	11.3	7.1
Wind Cave	SD	16.0	15.4	7.2
Wolf Island	GA	26.4	24.9	11.4
Yellowstone	WY	12.1	12.1	7.1
Yolla Bolly - Middle Eel	CA	17.1	16.9	7.4
Yosemite	CA	17.6	17.4	7.1
Zion	UT	13.5	13.3	7.0

a) 116 IMPROVE sites represent 155 of the 156 Mandatory Class I Federal Areas. One isolated Mandatory Class I Federal Area (Bering Sea, an uninhabited and infrequently visited island 200 miles from the coast of Alaska), was considered to be so remote from electrical power and people that it would be impractical to collect routine aerosol samples. U.S. EPA (2003) guidance for Tracking Progress Under the Regional Haze Rule. EPA-454/B-03-004. This document is available in Docket EPA-HQ-OAR-2005-0036.

b) The deciview metric describes perceived visual changes in a linear fashion over its entire range, analogous to the decibel scale for sound. A deciview of 0 represents pristine conditions. The higher the deciview value, the worse the visibility, and an improvement in visibility is a decrease in deciview value.

c) The 2015 modeling projections are based on the Clear Air Interstate Rule analyses (EPA, 2005).

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Chapter 4: Table of Contents

Chapter 4: Industry Characterization

An understanding of the nature of the affected industries is useful in assessing the potential impact of the proposed emission control program. Information regarding the structure of the market, including such things as the degree of concentration, entry barriers, and product differentiation, can help explain the pricing and other policies that exist in that market. This chapter describes the light-duty vehicle (LDV) and light-duty truck (LDT) manufacturers, the petroleum refining industry, and the portable fuel container manufacturers.

4.1 Light-Duty Vehicle and Light-Duty Truck Market Structure

The LDV/LDT market is fairly concentrated, with only five of the 19 total generally-recognized manufacturers accounting for almost 82 percent of all sales. LDV/LDT sales numbered more than 16.9 million vehicles in 2004. The top five companies are the so-called "Big Three" (General Motors (GM), Ford, and Daimler-Chrysler) plus Toyota and Honda. The remaining 18 percent of sales are split between the other 14 manufacturers, with none of them achieving more than 2 percent of total sales. The bottom 10 manufacturers in fact account for only about 4.5 percent of total sales. Four of these firms, Ferrari, Maserati, Lamborghini, and Lotus, are considered small-volume manufacturers, since their sales are less than 15,000 vehicles per year.[A] Table 4.1.-1 provides sales figures by manufacturer.

None of the major manufacturers are small businesses. (As discussed later in Chapter 14, the Small Business Administration (SBA) criterion for a small business in the vehicle manufacturing industry is 1,000 employees or less.) This is mainly because of the large outlay of capital and other resources necessary to enter the market. Becoming even a relatively minor player in the industry requires a great deal of manufacturing capacity to achieve the necessary production volumes, as well as an extensive distribution and marketing network. There is also a significant amount of brand loyalty on the part of consumers, because of tradition or perceived differences in the product. These all combine to make market entry difficult, and the industry is basically dominated by the established major manufacturers.

As discussed later in Section 4.1.3, there are also a few smaller, lesser-known LDV/LDT small volume manufacturers, importers and alternative fuel vehicle converters. These have limited product lines, and account for less than one-tenth of one percent of all U.S. sales. They primarily fill niche markets of one kind or another. More than half of these firms are small businesses.

4.1.1 Domestic vs. Foreign Manufacturers

[A] EPA defines small volume manufacturers to be those with total U.S. sales of less than 15,000 vehicles per year. This status allows vehicle models to be certified under a slightly simpler certification process. For certification purposes, small volume manufacturers also include independent commercial importers (ICIs) and alternative fuel vehicle converters since they sell less than 15,000 vehicles per year.

Previously, it has been relatively easy to characterize manufacturers as "domestic" or

Table 4.1-1

LDV AND LDT MANUFACTURERS, SALES VOLUMES AND MARKET SHARES

MANUFACTURER NAME	LDV/LDT SALES	MARKET %	CUM %	LDV SALES	MARKET %	CUM %	LDT SALES	MARKET %	CUM %
GENERAL MOTORS	4,655,459	27.5%	27.5%	1,875,551	24.4%	24.4%	2,779,908	30.1%	30.1%
FORD MOTOR CO.	3,319,767	19.6%	47.2%	1,034,992	13.5%	37.8%	2,284,775	24.8%	54.9%
DAIMLER CHRYSLER	2,427,634	14.4%	61.5%	807,733	10.5%	48.3%	1,619,901	17.6%	72.5%
TOYOTA MOTOR CO.	2,060,049	12.2%	73.7%	1,054,208	13.7%	62.1%	1,005,841	10.9%	83.4%
AMERICAN HONDA	1,394,398	8.2%	81.9%	843,289	11.0%	73.0%	551,109	6.0%	89.4%
NISSAN MOTOR CO.	985,988	5.8%	87.8%	536,756	7.0%	80.0%	449,232	4.9%	94.2%
HYUNDAI GROUP.	688,670	4.1%	91.8%	456,002	5.9%	85.9%	232,668	2.5%	96.8%
VW of AMERICA	336,421	2.0%	93.8%	308,506	4.0%	89.9%	27,915	0.3%	97.1%
BMW GROUP	296,524	1.8%	95.6%	226,695	2.9%	92.9%	69,829	0.8%	97.8%
MAZDA	263,882	1.6%	97.1%	187,678	2.4%	95.3%	76,204	0.8%	98.6%
SUBARU	187,402	1.1%	98.2%	187,402	2.4%	97.8%	0	0.0%	98.6%
MITSUBISHI	161,609	1.0%	99.2%	108,937	1.4%	99.2%	52,672	0.6%	99.2%
SUZUKI	73,946	0.4%	99.6%	47,109	0.6%	99.8%	26,837	0.3%	99.5%
PORSCHE	31,473	0.2%	99.8%	13,356	0.2%	100.0%	18,117	0.2%	99.7%
ISUZU	27,188	0.2%	100.0%	0	0.0%	100.0%	27,188	0.3%	100.0%
FERRARI	1,176	0.0%	100.0%	1,176	0.0%	100.0%	0	0.0%	100.0%
MASERATI	1,055	0.0%	100.0%	1,055	0.0%	100.0%	0	0.0%	100.0%
LAMBORGHINI	653	0.0%	100.0%	653	0.0%	100.0%	0	0.0%	100.0%
LOTUS	84	0.0%	100.0%	84	0.0%	100.0%	0	0.0%	100.0%
TOTAL	16,913,378			7,691,182			9,222,196		

Source: Automotive News, "Market Data Book, 2005" "foreign." However, this is currently much more difficult. For example, the Daimler-Chrysler merger combined the former Chrysler divisions Chrysler, Dodge and Jeep with the imported Mercedes line; but it also includes Maybach, a high-end German luxury car. Ford now includes not only the traditional Ford, Mercury and Lincoln lines, but also the imported marques Jaguar, Volvo, Land Rover and Aston-Martin. GM sales include the Swedish import Saab.

Conversely, Toyota and Honda, as well as the six other Far Eastern manufacturers, all maintain a substantial American manufacturing presence, and the majority of their vehicles sold here, almost 80 percent on average, are manufactured in North America. Sales figures from North American manufacturing facilities for individual firms range from 95 to 98 percent for Toyota and Honda, to 52 to 72 percent for some of the smaller manufacturers. Volkswagen, which now also includes Bentley, is the only European manufacturer with a North American manufacturing operation. About 55 percent of its sales are manufactured here. BMW, which now includes the formerly British Rolls-Royce and Mini lines, is 100 percent imported, as is Porsche.

On the other hand, substantial portions of the Ford and GM "domestic" lines are also imported. Actually, the term "North American-built," meaning “made in the United States, Canada or Mexico,” seems to have replaced the term "domestic" in the sales reports. About 28 percent of all domestic LDVs sold in the U.S. are considered "imports," i.e., not North-American built, as opposed to only about 13 percent of all LDTs.

4.1.2 Light-Duty Vehicles vs. Light-Duty Trucks

In earlier years, light-duty vehicles tended to outsell light-duty trucks by a fairly wide margin. In 1981, for example, LDTs comprised less than 20 percent of total sales, and this had only grown to about 38 percent by 1993. However, in recent years the gap has been closing rapidly. LDTs have made considerable gains in the last decade; by the 2000 model year LDVs outsold LDTs by a margin of only about 52 to 48 percent. By 2001 the split was roughly 50/50, with LDT sales actually moving slightly ahead by about 100,000 units.[1] As shown in Table 4.1-1, for the 2004 model year, LDTs outsold LDVs by a 55 to 45 percent margin. The rise of the Sport-Utility Vehicle (SUV) accounts for much of this change, but stronger sales of the more traditional LDTs account for a substantial amount of the increase as well.

In general, LDTs and LDVs are produced by the same manufacturers, both foreign and domestic. The Big Three plus Toyota and Honda account for almost 90 percent of LDT sales. The Big Three actually account for almost 75 percent of all LDT sales, but only about 45 percent of all LDV sales. All of the Far Eastern manufacturers, except for Isuzu and Subaru, also make LDTs as well as LDVs. Isuzu sells only LDTs, in the U.S. while Subaru sells only LDVs. Three European manufacturers, Volkswagen, BMW, and Porsche, sell both LDTs and LDVs, while the remaining four European manufacturers sell only LDVs. These four are all small-volume, high-end sports car manufacturers (Ferrari, Maserati, Lamborghini and Lotus). Figures 4.1-1 and 4.1-2 show market shares for LDV and LDT manufacturers.

Figure 4.1-1.

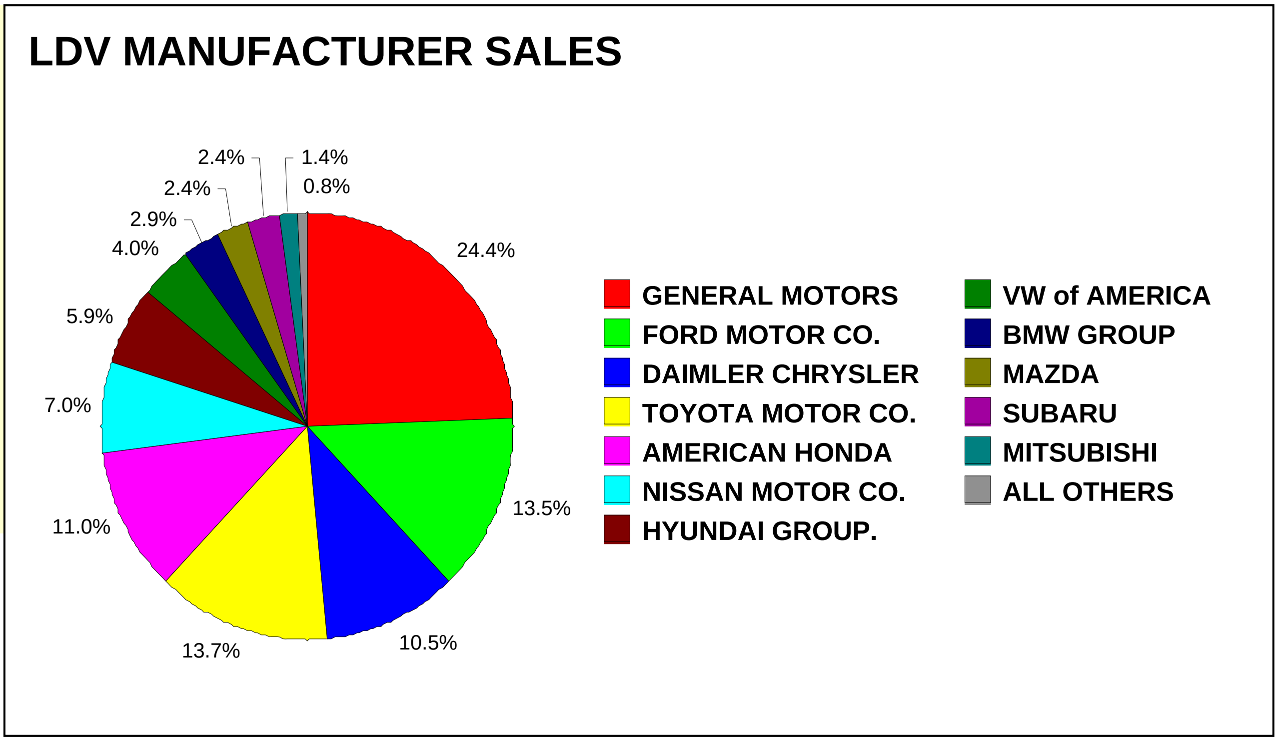
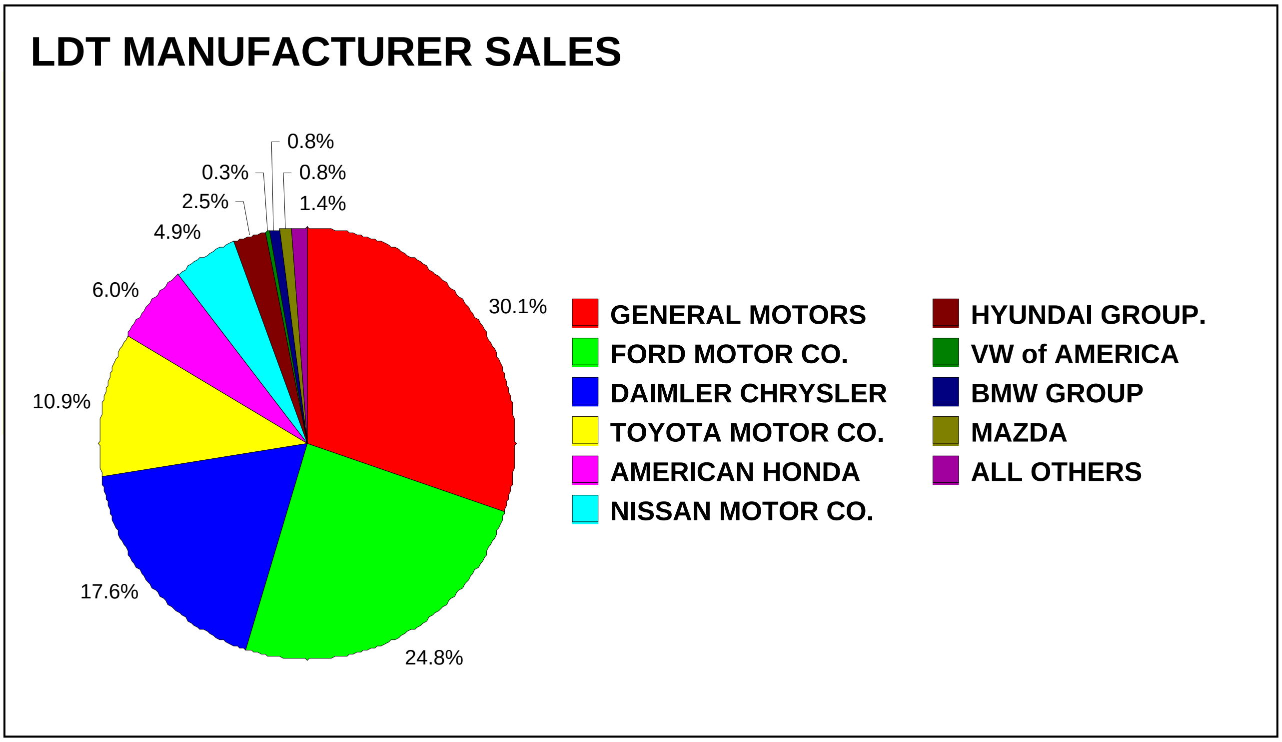


Figure 4.1-2.



For regulatory purposes, LDVs and LDTs are divided into categories based on their gross vehicle weight ratings (GVWR). This distinction was based on the premise that heavier vehicles produce more pollutants than do lighter vehicles, making it more difficult to achieve comparable emission reductions. Standards for the heavier vehicles were therefore less stringent. However, modern emission-control technologies are virtually the same and equally effective for both the lighter and the heavier vehicles. Therefore, the Tier 2 emission standards now make no distinction between weight categories. In addition, Tier 2 applies to medium duty passenger vehicles (MDPVs), i.e. passenger vehicles between 8,500 and 10,000 lbs. GVW. These are primarily the very large SUVs, and passenger vans.

Emission standards were also slightly less stringent for the LDTs than for LDVs, partly because of weight considerations, and partly because of perceived differences in usage patterns. Again, the Tier 2 emission standards now make no distinction between LDVs and LDTs, except for some minor differences in the evaporative emissions standards. In large part this is because LDVs and LDTs share the same basic emission-control technologies and are primarily used for the same purpose, for personal transportation. Thus, there does not appear to be a strong rationale for making distinctions between the two.

4.1.3 Small Volume Manufacturers, Importers, and Alternative Fuel Vehicle Converters

There are a number of lesser-known small volume manufacturers who produce high performance and other specialized vehicles, such as Roush Industries or the Panoz Auto Development Company. These number less than a dozen, and about half are small businesses. In addition to the manufacturers, there are a handful of Independent Commercial Importers (ICIs) who are issued certificates to import a limited number of nonconforming vehicles for racing or other purposes, and to modify these vehicles to meet U.S. standards.[B] These ICIs are almost all considered small businesses, and total sales for all of them are fewer than 500 vehicles per year. There are also a small number of converters who convert conventional gasoline- or diesel-fueled vehicles to operate on alternative fuel (e.g., compressed natural gas and liquefied petroleum gas). These are also few in number, and are almost all small businesses. Altogether, combined sales for these small-volume manufacturers, importers, and converters accounted for less than one-tenth of one percent of total sales of LDVs and LDTs for the 2004 model year.

4.2 Petroleum Refining Industry

Early in this rulemaking process, EPA commissioned an analysis of the U.S. gasoline production and distribution system from RTI International in order to support economic analyses of the proposal. The final report of the analysis, entitled “Characterizing Gasoline Markets: A Profile,” discusses supply and demand issues associated with the refining industry and with gasoline market

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[B] ICIs are not required 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).

behavior.[2] The information contained in the report is summarized below, supplemented by additional information found in this RIA and in other sources.

4.2.1 Gasoline Supply

Detailed descriptions of the refinery processes by which gasoline is produced can be found in the final report mentioned above and in Chapter 6 of this RIA. Gasoline is the dominant product for most refineries, constituting almost half of the total product produced by U.S. refineries in 2002.[3] Federal and state regulations have resulted in a variety of gasoline formulations. These include the RFG and CG designations, oxygenated gasoline, octane-based gasoline grades, and volatility distinctions. Additional variation occurs when different oxygenates are used, though that difference will lessen significantly in the coming years as MTBE use diminishes and the renewable oxygenate requirements of the Energy Policy Act of 2005 cause a substantial increase in ethanol use in gasoline. Some gasoline regulations, such as gasoline sulfur and MSAT1, affect all gasoline and impact refineries and gasoline production, but do not contribute to additional gasoline types.

Gasoline supply is also affected by the types of crude oils available, and the refining industry's ability to process the different crude types to maximize gasoline production while meeting all applicable regulations. Sweet, or low sulfur, crude oils are more easily processed, but this factor increases their cost compared to sour, or high sulfur, crude oils. Some refineries are optimized to run based on a certain type of crude oil, and have little flexibility in processing other types. Crude cost is the largest factor in total refining cost and the price of crude can significantly affect the total cost of production.

Gasoline and other petroleum products are transported from the refineries to intermediate points such as terminals, and to the final market by pipeline, truck and barge. Most product is moved via pipeline, as the cost is extremely low. Pipelines have been able to accommodate the many gasoline formulations that have resulted from federal and state gasoline regulations, but are near their limit in handling additional formulations. Modifying schedules and flow rates in order to get gasoline and non-gasoline products on and off the pipeline contributes to increased costs. The final step for gasoline transport to retail outlets is via truck.

4.2.2 Gasoline Demand

Gasoline demand is affected by gasoline use and factors that influence consumption. The vast majority of gasoline is used for private and commercial highway use. About 3 percent is used in non-highway applications such as lawn and garden or marine use. Light-duty transportation accounts for over 90% of gasoline used, and most of this is attributable to private automobile use. Transportation choices, and thus gasoline use, are affected by many factors, including personal income, geography, gasoline prices and the prices of related goods. Though daily travel increases with household income, average annual expenditures for gasoline, as a percent of income, showed little variation by geography or income class. Consumers can respond to gasoline price increases in many ways, such as reducing the number of miles traveled, or by adjusting their "capital stock," that is, for example, by purchasing a car with better fuel economy.

4.2.3 Industry Organization

The refining industry structure is critical to the implementation and impact of the proposed regulation. Factors such as regional production and shipment patterns and industry concentration can influence market price and product availability. For instance, because of current fuel formulations and distribution patterns, consideration of regional (PADD) gasoline markets, rather than a national gasoline market, may be more appropriate for evaluating certain impacts of the proposed regulatory program.

Market concentration refers to some measure of the market share of competitors in an area. High market concentration may indicate some ability of competitors in an area to influence prices by coordinated action, thus resulting in less competition and higher product prices. A recent Federal Trade Commission analysis has shown that the refining industry is not concentrated or only moderately concentrated. In addition, the possibility of increased gasoline imports, particularly into PADDs I and III, can serve to moderate any attempts to set prices.

Refiners serving the same market may have a wide range of total delivered costs. Cost to the refiner is a function of distance to market, refinery-specific operating costs and gasoline formulation. Gasoline formulation, as discussed, depends on the crude oil, refinery configuration and environmental or other gasoline controls. The market price for gasoline is set by the producers with the highest costs, taking into consideration their full range of products produced.

4.2.4 Gasoline Market Data

An analysis of the impacts of a policy change--in this case, from current gasoline toxics requirements to the proposed fuel benzene standard--requires consideration of the baseline case compared to likely changes expected from the new policy. National and regional (by PADD) consumption and gasoline price, price volatility, international trade, and projected growth (in gasoline consumption) are the primary factors considered in estimating economic impacts of the proposed rule.

Gasoline consumption is estimated to increase by about 1.8 percent annually through 2025. As discussed above, gasoline consumption, primarily influenced by personal light-duty vehicle use, is affected by many factors, including retail gasoline price. Gasoline price is a function of distribution and marketing costs, refining costs, profit, federal and state taxes, and crude oil cost. Crude oil cost accounts for almost half of the retail price of gasoline. Price volatility is primarily due to the magnitude of any supply and demand imbalance, and the speed with which new supply can be provided. These imbalances can be caused by unexpected refinery shutdowns or pipeline disruptions, or even by relatively planned activity, such as seasonal transitions. Isolated markets, or those requiring unique gasoline blends, are likely to be more susceptible to such supply and demand imbalances.

International gasoline trade, that is, imports and exports of gasoline, account for an extremely small part of all gasoline transactions. However, regional activity, at the PADD level, shows significant variation. PADD I received over 90% of all gasoline and gasoline blendstock imports in 2002.[4]

4.3 Portable Fuel Container Industry

EPA also contracted with RTI International for a characterization of the PFC industry in support of our economic analyses of the proposal. The final analysis report, entitled "Characterizing Gas Can Markets: A Profile," discusses production and distribution issues associated with gas cans.[5,6] This report is also summarized below, and is again supplemented by additional information found in this RIA and in other sources. PFCs include gasoline, kerosene, and diesel containers.

4.3.1 Manufacture and Distribution

PFCs are designed to transport, store and dispense fuel, normally for refueling vehicles when they run out of gas, or for home applications such as refueling lawnmowers, trimmers, etc. PFCs include utility jugs that are marketed for use with fuels, which are often used to refuel recreational products such as personal watercraft and all-terrain vehicles. PFCs range in capacity from a gallon or less to over 6 gallons. Standard PFCs have three main components: a spout for pouring fuel, a tank with a fill port to hold the gasoline, and a vent to make pouring the fuel easier. About 98 percent of all containers are made of high-density polyethylene (HDPE) plastic, chosen mainly because of its fuel-resistant properties. Two main manufacturing processes are used: extrusion blow molding, which is used for the bodies, in which a molten tube of plastic is forced into a mold by compressed air; and injection molding, which is used for spouts, caps and other tubes. In injection molding, plastic material is forced through a heated injection chamber and through a nozzle into a cold mold. Because of safety regulations in most states, gas cans are colored red during the manufacturing process. Diesel containers are colored yellow and kerosene containers are colored blue to help consumers avoid misfueling of equipment. Industry and other sources indicate that gas cans and diesel and kerosene containers are distributed by manufacturers through their distribution centers to major retail establishments. Utility jugs are sold in several colors and are more often sold through online retailers.

4.3.2 Container Use

PFCs allow people to refuel a wide variety of equipment without the inconvenience of taking it to a retail gasoline station. This equipment can range from lawn and garden equipment such as tractors, lawnmowers, trimmers and chainsaws to recreational vehicles such as motorcycles, ATVs and golf carts. We estimate that there are about 80 million gas cans in the U.S., which is similar to other such estimates.[7] Although publicly-available data on gas can usage are scarce, a California Air Resources Board (CARB) study performed in 1999 indicated that 94 percent of all gas cans in California were used in households. The remaining 6 percent were used for such commercial applications as farming, logging, construction, lawn care, and automotive applications such as repair shops and gasoline stations. State surveys in California and Texas indicated that between 46 and 72 percent of all households owned gas cans, and that 14 percent of those surveyed had bought one during the past year. The average number of gas cans ranged from 1.4 per household in Texas to 1.8 per household in California. A typical plastic PFC will have a life expectancy of 3 to 5 years before it needs to be replaced.

The demand for fuel containers reflects the demand for other goods and services. The gas can industry has suggested that the sales of gas cans are linked to the sales of gasoline-powered equipment such as lawn and garden equipment or recreational vehicles. Therefore, factors that influence the sales of these types of equipment will also influence the sales of gas cans. These factors can include such things as price, population growth, or changes in personal income.

Gasoline container sales for 2002, the latest year for which we were able to develop data, were about 24.4 million units (including utility jug sales which were estimated to be about 2.4 million units). Diesel and kerosene container annual sales are estimated to be about 620,000 and 1 million units, respectively. Although the PFC manufacturing industry has become fairly concentrated, with one firm accounting for more than half of all U.S. container sales, that firm does not exert significant influence over market prices. This is because there are few barriers to market entry by other companies, and the products are substantially the same, making for very limited brand loyalty. Other firms could enter or re-enter the market should the economic conditions seem right. Imports from Canada, which amount to about 10 percent of annual sales, would also tend to limit arbitrary pricing practices.

4.3.3 Market Structure

As noted above, the PFC market is fairly concentrated, with only five firms accounting for the vast majority of sales. These are Blitz USA, Midwest Can, Scepter Manufacturing, Ltd. (Canadian), No-Spill Research, and Wedco Molded Products, which is owned by the Plastics Group. All of these companies, except for the parent company Plastics Group, meet the primary Small Business Administration (SBA) criterion for small businesses (i.e., less than 500 employees). Data for utility jug manufacturers was scarce, but we believe that there are likely about 5 manufacturers of these containers, including Scribner Plastics. There are other gasoline container manufacturers, but they have a very limited market share. Most of their products are designed for industrial use or to fill a niche market (e.g., racing or safety cans used in an industrial setting), which are not be covered by the standards. These companies include Eagle Manufacturing and Protectoseal Company. Table 4.3-1 provides relevant data about these firms.

4.3.4 Market Entry

There are very few barriers to entering the PFC market. Only about 2 percent of the containers sold in the U. S. in 2002 were of metal construction; the vast majority were plastic. These are produced by a fairly straightforward molding process in much the same manner as hundreds if not thousands of other plastic products. Plastic PFCs are in fact classified in the U.S. Economic

Census as "All other plastics product manufacturing." Since manufacturing such PFCs is similar to manufacturing most other molded plastic products, any firm with that capability could freely enter the market with a relatively low initial investment, if the economic conditions should appear advantageous to do so. Since most consumers tend to view gas cans as more or less all the same, there is not a well-developed brand loyalty to one brand or other, so competition in the industry is based primarily on price. Finally, safety regulations in most states prevent consumers from using old paint thinner cans or other such containers as substitutes for gas cans, thus eliminating any potential reduction in sales from that quarter.

Table 4.3-1. Manufacturers*

Ultimate Parent	**Company name**	**Sales ($million)**	**Employment**	**Comments**
Blitz USA	Blitz USA	20-50	200	Consumer market
Eagle Manufacturing	Eagle Manufacturing	50-100	100-249	Primarily Metal Safety Cans
Midwest Can	Midwest Can	20-50	45	Consumer market
No-spill Research Inc.	No-spill Research Inc.	2.5-5	5	Limited Distribution
Protectoseal Co.	Protectoseal Co.	20-50	100-249	Primarily Industrial
Scepter Mfg., Ltd.	Scepter Mfg., Ltd.	10-20	200	Canadian-Consumer
Scribner Plastics	Scribner Plastics	5-10	20-49	Specialty Containers
The Plastics Group	Wedco Molded Prod.	20-50	600	Consumer Market

* Businesses Engaged In NAICS Code 326119, All Other Plastic Product Manufacturing, Or NAICS Code 332431, Metal Can Manufacturing

Source: Characterizing Gas Can Markets, a Profile,” RTI International, Final Report, EPA Contract 68-D-99-024.

References for Chapter 4

[1] Source: Ward's "World Motor Vehicle Data, 2004."

[2] “Characterizing Gasoline Markets: A Profile," **Final Report**. EPA Contract Number 68-D-99-024, prepared for Robert Johnson, USEPA, Office of Transportation and Air Quality, Ann Arbor, MI by Brooks Depro, et al, RTI International, Research Triangle Park, NC, August 2004.

[3] Table 1-1 in **Final Report**. Data Source: DOE, EIA Petroleum Supply Annual 2002.

[4] Table 4-4. **Final Report**. Source DOE EIA Petroleum Supply Annual 2002.

[5] “Characterizing Gas Can Markets: A Profile." Final Report, EPA Contract Number 68-D-99-024, prepared for Robert Johnson, USEPA, Office of Transportation and Air Quality, Ann Arbor, MI by Brooks Depro, et al, RTI International, Research Triangle Park, NC, August 2004.

[6] “Gas Can Industry Profile Updates”, memorandum from RTI to EPA, January 4, 2007.

[7] Memorandum from Terrance R. Karels, Consumer Product Safety Commission, January 3, 2003.

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Chapter 5: Vehicle Technological Feasibility

5.1 Feasibility of Cold Exhaust Emission Standards for Vehicles

5.1.1 NMHC Emissions Control Technologies on Tier 2 Gasoline-Fueled Vehicles

Emission control technology has evolved rapidly since the passage of the CAA Amendments of 1990. Emission standards applicable to 1990 model year vehicles required roughly 90 percent reduction in exhaust non-methane hydrocarbon (NMHC) emissions compared to uncontrolled emission levels. The Tier 2 program and before that, the National Low Emission Vehicle (NLEV) program, contain stringent standards for light-duty vehicles that have resulted in additional NMHC reductions. Tier 2 vehicles currently in production show overall reductions in NMHC of more than 98 percent compared to uncontrolled emissions levels. These emission standards for NMHC are measured under the EPA Federal Test Procedure (FTP), which measures exhaust emissions from vehicles operating only in the ambient temperature range of 68˚ F to 86˚ F.

Table 5.1-1 below lists specific types of NMHC emission controls that EPA projected in the Tier 2 technological feasibility assessment could be used in order to meet the final Tier 2 standards. It is important to point out that all of the following technologies have not necessarily been needed to meet the Tier 2 standards. The choices and combinations of technologies have depended on several factors, such as current engine-out emission levels, effectiveness of existing emission control systems, and individual manufacturer preferences. In some cases, no additional hardware from the NLEV level of hardware was needed. Instead, many manufacturers focused their efforts in the software and calibration controls to achieve stringent emission levels.

Table 5.1-1. Tier 2 Projected Emission Control Hardware and Technologies

Emission Control Technologies	
Fast Light-off Exhaust Oxygen Sensors	Secondary Air Injection into Exhaust
Retarded Spark Timing at Start-up	Heat Optimized/Insulated Exhaust Pipe
More Precise Fuel Control	Close-coupled Catalyst
Individual Cylinder Control	Improved Catalyst Washcoats/Substrates
Manifold with Low Thermal Capacity	Increased Catalyst Volume and Loading
Air Assisted Fuel Injection	Engine Modifications
Faster Microprocessor	Universal Exhaust Oxygen Sensor

A number of technological advances and breakthroughs have allowed these significant emission reductions to occur without the need for expensive emission control equipment. For example, the California Air Resources Board (ARB) originally projected that many vehicles would require electrically-heated catalysts to meet their Low Emission Vehicle I (LEV I) program requirements. Today, with even more stringent standards than LEV I, no manufacturer needs to use these devices to comply with program requirements. Similarly, the Tier 2 and Low Emission Vehicle II (LEV II) programs, currently being phased-in, have projected that some additional emission control hardware and techniques may be required. However, initial indications from the Tier 2 vehicles already certified indicate that increases in emission control hardware have been kept to a minimum, likely to minimize cost.

The Tier 2 program requires reductions in all regulated pollutants, but the largest reductions are required for oxides of nitrogen (NOx) emissions. To achieve these NOx reductions, significant improvements in catalyst technologies have been employed, largely in improved catalyst substrates and washcoats containing the precious metals. In fact, some manufacturers have even been able to reduce precious metal loadings as compared to previous generation catalysts because of the new substrate and washcoat improvements developed in response to Tier 2. These catalyst technologies have generally also resulted in better emission performance of all regulated pollutants, largely because of improved catalyst light-off times.

The Tier 2 program also includes new tighter non-methane organic gases (NMOG) standards. Unlike tight NOx controls, manufacturers had significant experience in non-methane hydrocarbons (NMHC) controls from the stringent NMOG standards (NMOG consists primarily of NMHC) under the NLEV and LEV I programs. In fact, the NMOG standards for a Tier 2 Bin 5 package are the same for the passenger car and light-duty truck as those established under the NLEV program. One of the largest challenges manufacturers have encountered under the Tier 2 program is the program's weight neutral standards for all vehicles up to 8500 lbs. gross vehicle weight rating (GVWR) and medium-duty passenger vehicles (MDPV) up to 10,000 lbs. GVWR. These heavier vehicles may be where new hardware will more likely be required to meet Tier 2 weight neutral standards as they fully phase in to Tier 2.

Some of the most significant technological advances that have facilitated low NMHC emission levels have occurred in calibration and software-based controls. These controls have been carefully designed to both minimize exhaust emissions before exhaust aftertreatment has reached operational temperature and accelerate the usage of the aftertreatment earlier in the operation of the engine. Additionally, fuel metering controls during the critical period prior to aftertreatment reaching operating temperature is more precise than previous systems, largely due to advances in software controls. While some improvements also have been made to base engine designs, which have resulted in lower overall operating engine-out emissions, controls aimed at minimizing emissions during the critical period before exhaust aftertreatment readiness have been accomplished almost exclusively with software based controls. Even with base engine and exhaust hardware improvements, calibration and software controls of the emission control hardware remain the most important and powerful emission control technique used by manufacturers. Calibrations and software controls will continue to become more refined and sophisticated as manufacturers learn new ways to better utilize existing hardware, particularly in the remaining Tier 2 phase-in vehicle models.

Today, these emission control strategies are utilized at 75˚ F to meet stringent Tier 2 and LEV II NMOG standards. The potential exists for these same software and calibration controls to be utilized at 20˚ F and all other cold start temperatures to control NMHC emissions. Most of these controls are feasible and available today in Tier 2 and LEV II vehicles. With the implementation of these controls at the colder start temperatures, significant reductions in NMHC emissions (and therefore air toxics) can be realized. The following sections provide details on these software and calibration control strategies, supporting certification results, and feasibility studies utilizing these existing emission control opportunities.

5.1.1.1 Calibration and Software Control Technologies

Tier 2 vehicles are equipped with very sophisticated emissions control systems. Table 5.1-1 above lists some of the technologies manufacturers have successfully used to meet stringent Tier 2 emission standards. In addition to hardware technologies, manufacturers have developed calibration and software control strategies to meet Tier 2 emission standards that also can be effectively used at 20˚ F to achieve significant reductions in NMHC and other emissions. We expect manufacturers will expand the use of these same emission control strategies already in place on Tier 2 vehicles at 75˚ F to control NMHC emissions at 20˚ F. The following descriptions provide an overview of the calibration and software technologies capable of reducing exhaust emissions at 20˚ F.

5.1.1.1.1 Idle Speed and Air Flow Control

Idle speed and air flow control have been utilized very successfully to both reduce emissions before the catalyst aftertreatment is considered active and to accelerate the activity of the catalyst. Elevated idle speeds immediately following the start of a vehicle, particularly in park and neutral, will result in more stable combustion resulting from the improved air and fuel mixture motion. This is largely due to the higher air velocity entering the combustion chamber which generally results in a more homogeneous mixture, and therefore, a more fully combustible air-fuel mixture. The higher engine speed may also increase heat created from piston to cylinder wall friction, further assisting in transforming fuel droplets to burnable mixtures. The higher engine speeds cause additional combustion events, in which contribute to the rapid heating of the combustion chamber. The higher combustion stability can generally result in the ability to run leaner air-fuel ratios, which reduces the percentage of unburned fuel that would be exhausted from the engine.

Air flow through the engine, exhausted after combustion, provides the heat required for the catalyst to become active. Increased air flow through the engine, mainly through elevated idle speeds, provides the catalyst with supplemental heat. Additionally, this extra exhaust heat is carried to the catalyst at higher exhaust flow velocities, further shortening the amount of time the catalyst is inactive. The higher combustion stability from the increased air flow results in less hydrocarbons from unburned fuel, which can actually quench a catalyst and slow its warming. The ability to run leaner mixtures can provide the catalyst with the necessary oxygen for the catalyst to begin oxidation of NMHC and carbon monoxide (CO).

Elevated air flow used off-idle can also produce significant emission benefits. This elevated air flow is achieved by allowing extra air flow primarily when the throttle is closed, but also during the transient period when the throttle is in the process of closing. This momentary air flow increase has been referred to as “dashpot” effect. It typically has been used only for short durations following a throttle closing to help provide additional air flow, and usually only during the first few minutes of cold start engine operation. Elevated air flow has also been used to provide slightly more closed throttle engine torque to overcome additional loads only encountered following a cold start. This reduces risk of idle undershoots and stalling.

5.1.1.1.2 Spark Control

Spark control has evolved with modern electronic controls to a highly precise tool to carefully control when the combustion event is initiated in a spark ignition engine. Retarding the spark delivery immediately after the start has been highly effective at reducing exhaust emissions. Retarding the spark, particularly after a cold start, generally reduces engine-out emissions. This is generally believed to be a result of the longer period of time that the fuel is under compression and absorbing combustion chamber heat. This assists in more complete combustion when the fuel is finally spark-ignited. It also is believed that the retarded spark timing results in lower cylinder peak pressures during the combustion of the air-fuel mixture, reducing the opportunity for hydrocarbons to migrate to crevices and further helping lower engine-out hydrocarbon emissions.

Retarded timing also has been used very effectively to accelerate the early usage of the catalyst by providing supplemental heat, which reduces the time for the catalyst to begin oxidation. The retarded timing results in peak combustion of the air-fuel mixture occurring later in the engine operating cycle, leading to significant thermal energy being transferred into the exhaust. This thermal energy very effectively provides a boost to the catalyst warm-up, particularly at colder temperatures and for large mass catalyst systems or catalyst systems that are further from the engine.

The effectiveness of retarded timing can be enhanced significantly when used in conjunction with elevated idle speeds and/or air flow control. The simultaneous use of the two features generally results in greater emission reductions than when either feature is used independently. Additionally, utilizing elevated idle speeds while retarding the timing can offset any engine vacuum level concerns encountered when only retarded timing is used.

5.1.1.1.3 Secondary Air Injection Control

Many Tier 2 vehicles produced today contain secondary air injection systems to comply with stringent Tier 2 and LEV II standards. These systems reduce vehicle emissions by injecting ambient air into the rich engine exhaust upstream of the catalyst for a short period of time immediately after a start. This reduces emissions in two ways. First, the oxygen in the ambient air being pumped into the exhaust assists in oxidizing HC and CO prior to reaching the catalyst. Second, this oxidation can generate large amounts of heat that help bring the catalyst to effective temperatures much sooner. As the catalyst reaches effective temperature, the secondary air can continue to provide needed oxygen for oxidation in the catalyst until the total system is ready to go “closed loop,” at which time the secondary air injection is ceased.

The secondary air injection technology for controlling emissions is not new. For many years, manufacturers used secondary air injection systems that ran continuously from a mechanical belt-driven pump to oxidize HC and CO emissions produced from a rich exhaust mixture during all modes of operation. With the advent of the three-way catalyst, manufacturers began to use engine control modules to activate electric air pumps to only reduce start emissions at 75˚ F, typically on vehicle packages with specific cold start emission challenges. For example, vehicles that have large mass catalysts or catalyst systems located relatively far from the engine have utilized secondary injection to assist catalyst light-off. Further, many Tier 2 and LEV II packages certified to the cleanest emission levels utilize secondary air injection to achieve these results. Some Tier 2 packages that appear to have relatively high engine-out emissions, possibly due to engine design limitations, also have implemented secondary injection to allow compliance with Tier 2 emission standards.

Many manufacturers that have equipped some of their Tier 2 vehicles with secondary air injection systems do not appear to consistently utilize this emission control strategy across start temperature ranges outside of the currently regulated cold start temperature (75˚ F for Tier 2 and 50˚ F for LEV II). However, many identical vehicle models that are sold in both Europe and the U.S. are equipped with secondary air injection that does appear to be used at 20˚ F on the U.S. model, based on our analysis of the certification data. This is attributable to shared emission control technologies with the European market vehicles, where manufacturers are already required to meet a 20˚ F NMHC standard.

The activation of the secondary air system is a feasible and effective emission control technology for 20˚ F as well as all other interim start temperatures. The use of secondary air injection technology at 20˚ F is well proven as an emission control technology, as observed in the European vehicles. Certain design criteria must be taken into account for the system to operate robustly at these colder temperatures, but there appears to be no technological challenge that would prevent these vehicles already equipped with secondary air injection from activating this emission control technology at 20˚ F.

Some manufacturers, who do not use secondary air injection systems at 20˚ F but do include the systems on some of their U.S.-only models, have expressed concerns with freezing water in the system. We have investigated this concern with the manufacturers of the secondary air injection components and found this to be a system design issue that has been addressed by guidelines on the location and plumbing of the individual secondary air injection components.[1]

5.1.1.1.4 Cold Fuel Enrichment

Gasoline-fueled spark ignition engines generally require rich air-fuel mixtures (i.e., a larger amount of fuel for a given amount of air) for some amount of time immediately following a cold start. Under normal operating conditions, the amount of required enrichment always increases as start temperature decreases. This is largely because low in-cylinder temperatures for some period of time following the cold start lead to a lower percentage of liquid fuel vaporizing to a burnable mixture. The level of enrichment and its duration following the start will vary with many factors, including base engine hardware design and fuel properties. Fuel property interactions with engine combustion chamber dynamics are quite complex and can vary with fuel composition, but typical gasoline fuel available in the U.S. during the cold weather (e.g., 20˚ F) is properly formulated for robust cold start operation.

The level of enrichment should be calibrated to closely match the “winter”-grade fuel properties that the overwhelming majority of vehicles will be experiencing during the colder start conditions. Winter-grade fuel is formulated to have a higher Reid vapor pressure (RVP), specifically to allow the fuel to vaporize at lower cold start temperatures and minimize the need for additional enrichment. Any fuel enrichment beyond the minimum required level results in proportional increases in cold start emissions, primarily NMHC and CO. Additionally, over-fueling can hamper earlier use of the exhaust aftertreatment by quenching the catalyst with the unburned fuel, effectively cooling the catalyst. This retards the warm-up rate of the catalyst and also reduces the availability of any excess oxygen that would be used by the catalyst to oxidize the NMHC and CO.

The amount of required enrichment also can be reduced when used in conjunction with the previously mentioned elevated idle speed emission control technology. As stated earlier, elevated idle speeds will result in a more homogeneous mixture which supports more stable combustion. The improvements in the mixture will allow the enrichment levels to be reduced accordingly.

5.1.1.1.5 Closed Loop Delay

“Closed loop” operation refers to operation that allows the exhaust oxygen sensor to feed back to the engine control module and control the air-fuel mixture to an exhaust stoichiometric ratio. Following start-up of a modern gasoline fueled engine, operation in closed loop is delayed for some amount of time based on a combination of engine and oxygen sensor readiness criteria. As stated in the previous section, gasoline-fueled engines require rich air-fuel mixtures for some amount of time immediately following a start. The amount of time requiring the rich operation and, therefore, the delay of exhaust stoichiometric operation, will vary with the gasoline engine’s ability to operate smoothly at these air-fuel ratios.

The delay also will be determined by the exhaust oxygen sensor’s ability to properly function. Modern exhaust oxygen sensors, including both conventional switching and universal linear sensors, contain heating elements to allow them to maintain proper operating sensor temperatures and also to be used sooner following a cold start. These internal heating elements require careful control to prevent any potential thermal shock from water or fuel in the exhaust stream. The water is generated from the combustion process but also can be present in the exhaust pipe from condensation of water, particularly during certain ambient temperature and humidity operating conditions. Generally, cold starts at 20˚ F only require a short delay to allow the initial heating of the exhaust manifold to vaporize any combustion water. This period is followed by an electronically controlled and monitored heating of the sensor. Exhaust oxygen sensors have been designed to have significant protection from water and are typically fully operational well before the engine is prepared to use their information.

Generally, within approximately one minute of 20˚ F cold start operation, combustion chamber temperatures are at levels that vaporize sufficient amounts of the gasoline fuel to command exhaust stoichiometric operation of the engine. Also within that minute, exhaust oxygen sensors should have sufficient time to reach operating temperature with any thermal issues mitigated, allowing closed loop stoichiometric operation. As stated earlier, operating a gasoline-fueled engine at stoichiometry provides the exhaust aftertreatment with oxygen required for oxidation of HC and CO. Therefore, the amount of time requiring enrichment should be minimized and closed loop operation of the emission control system should be able to occur as soon as physically possible.

5.1.1.1.6 Transient Fuel Control

The control of the air-fuel ratio during transient maneuvers (i.e., operator-induced throttle movement) has dramatically improved with modern hardware and software controls. This is largely due to the improved accuracy of both the measurement sensors and the fuel delivery devices, but also refined software modeling of both air flow and physical fuel characteristics. Tier 2 vehicles have highly accurate sensors that measure changes in air flow to predict and deliver the appropriate amount of metered fuel. Additionally, the software that interprets these sensor signals has evolved to predict transient behaviors with much higher accuracy than ever before. Many of these improvements were necessitated by increases in emission stringency in the recent Tier 2 and LEV II programs, which were much less tolerant of transient errors that were acceptable in past emission control systems.

With the recent widespread penetration of electronic throttle controls (ETC), partially in response to the stringent Tier 2 and LEV II 75˚ F standards, manufacturers have been able to further reduce variability of transient errors. ETC applications remove the direct mechanical connection from the accelerator pedal to the engine. Instead, the pedal is simply a sensor that reports pedal movement to the engine control module (ECM). The ECM interprets the pedal movement and provides a corresponding controlled movement of the engine throttle.

Transient air-fuel errors can be minimized through advanced approaches to ETC usage. This is possible because the electronic controls can better synchronize the introduction of the transient maneuver and closely match required air and fuel amounts. The controls can be designed and programmed to prevent most of the transient errors experienced with older cable-driven mechanical systems. The older mechanical systems resulted in reactionary response to throttle movements, making it significantly more difficult to deliver precise dynamic air-fuel control. Since the ETC systems control the actual movement of the throttle, they have the ability to essentially eliminate transient errors by preceding the throttle movement with appropriate fuel metering amounts. This is particularly important at colder temperatures (i.e., 20˚ F cold start) where transient errors can be exaggerated when the engine is operating rich of stoichiometry.

5.1.1.1.7 Fuel Volatility Recognition

Improved modeling of the effect of fuel properties on engine and emission performance has eliminated the need for a new sensor. For instance, some manufacturers have successfully designed software models that can determine the percentage of ethanol in the fuel on which the vehicle is operating. These “virtual sensor” models take into account information from sources such as existing sensors and use historical data for the determinations. The models use this information to adjust many outputs including fuel metering and spark ignition control.

Currently, manufacturers have active software features that are designed to recognize and recover from a lean condition that can be a precursor to an engine stall. These features use different input criteria to identify and actively change the air-fuel ratio when an excessively lean condition may be occurring. These features may look at control parameters such as engine speed (RPM), engine manifold absolute pressure (MAP), engine mass air flow (MAF), and even engine misfire-related information to determine if a fuel metering change should occur.

The approaches described above exemplify possible software-based control designs that can achieve the desired emission and engine performance characteristics. Manufacturers have extensive experience designing and implementing software features to identify and react to specific fuel parameters that are deemed important to engine operation. The ability to recognize fuel volatility and actively adjust the fuel metering accordingly would allow the gasoline-fueled engine to operate at the lean limit, reducing engine-out emissions, particularly NMHC and CO. Much like the "virtual sensor" model described above for ethanol content, this model would take existing sensor information and other information available from the ECM and determine the fuel volatility characteristics at any given cold start temperature. The modern engine controllers have the ability to maintain significant historical data that can help predict fuel properties. The items of importance for fuel volatility may include ambient temperature exposure of fuel, amount of time since previous start, and other related items.

5.1.1.1.8 Fuel Injection Timing

Fuel injection timing control is another emission control technology that has evolved as a result of increased computing power of the engine. Depending on the engine design and the thermal characteristics of the intake port design, significant opportunity may exist for optimizing fuel preparation prior to combustion.

Generally, there are two fuel injection timing approaches used to optimize fuel preparation: closed-valve injection and open-valve injection. Closed valve injection is the traditional method of injecting fuel into the cylinder head intake port. As the name indicates, the intake valve is closed during the injection time period. This approach allows the fuel to have residence time in the intake port prior to ingestion into the cylinder. Usually, the fuel injector is targeted to spray the fuel on the back of the closed intake valve in order to allow the fuel to absorb any heat conducted through the valve from the combustion events occurring inside the cylinder chamber. The heat absorbed by the fuel potentially allows more of the fuel to vaporize either in the port or in the chamber, resulting in higher percentage of vaporized fuel that can be combusted. If the higher percentage of vaporized fuel burns, less liquid fuel will be exhausted, effectively reducing the engine-out NMHC levels.

Open-valve injection involves carefully coordinating the fuel injection timing in order to inject fuel while the intake valve is in some state of opening. This approach attempts to take advantage of the incoming air velocity as the air is drawn through the port and also the intake air pressure depression. The mixture motion and depression can help vaporize the fuel and assist in better mixing of the air and fuel prior to combustion, resulting in improved fuel burn. This approach is dependent on many aspects, including injector spray design, injector targeting, intake valve timing, and intake valve lift. Open-valve timing may be used initially after engine start followed by a closed-valve approach, described previously, once the intake valve is heated. Many similar approaches which can be implemented at any cold start temperature are detailed in past Society of Automotive Engineers (SAE) papers.[2]

5.1.1.1.9 Spark Delivery Control

With the increases in the computing power of the engine controller, opportunities have been created for new spark delivery related emission control features. Separate from the retarded timing benefits described previously, there are other potential controls that may help reduce engine-out emissions. Many new engines contain individual cylinder ignition coils. With these individual coils comes the opportunity for individual cylinder-based spark control features designed to promote more complete combustion. Additionally, some new engines have dual spark plugs (i.e., two plugs for each cylinder). These dual spark plug systems may have opportunities for new concepts targeted at emission reductions, particularly following cold start operation.

Spark energy, the amount of energy delivered to the spark plug that is used to ignite the air-fuel mixture, can be carefully controlled by modifying the dwell time delivered to the ignition coil. The dwell time is the amount of time that the ignition coil is allowed to be charged with electrical energy. An increase in dwell time will generally result in an increase in spark energy delivered to the spark plug. Higher spark energy typically results in a higher burn rate particularly in air-fuel mixtures that are not optimized, which is typical of mixtures at start-up.

Other new concepts may include such ideas as multiple spark events on a single engine cycle. The concept of delivering redundant spark events has been used in the past, primarily for engine performance. While we do not currently know if redundant spark events are beneficial in reducing emissions, it could be explored for emissions control. Similarly, dual spark plug engines or engines with individual cylinder ignition coils can explore other spark delivery related concepts that may prove to be effective emission control tools. All of these concepts are equally feasible at cold temperatures since they are not temperature dependent.

5.1.1.1.10 Universal Oxygen Sensor

As listed in Table 5.1-1 above, universal oxygen sensors were projected to be an emission control hardware that could be used to meet Tier 2 vehicle standards. Several manufacturers did in fact decide to replace their conventional switching oxygen sensors with these universal oxygen sensors. Universal oxygen sensors have certain benefits over conventional switching sensors that should prove substantially beneficial at 20˚ F. While these sensors require a similar delay to reach operating temperature following a start, universal oxygen sensors can accurately control the air-fuel ratio during rich operating conditions prior to commanded closed loop operation. Conventional switching sensors cannot indicate the actual air-fuel ratio during rich conditions, therefore preventing them from being used as a control sensor during critical rich operation. Additionally, universal oxygen sensors can be used to more accurately recover from air-fuel transient errors during the warm-up due to their ability to measure the magnitude of the error.

5.1.1.2 Tier 2 Engine and Exhaust Control Technologies

The Tier 2 technological feasibility assessment described several engine and exhaust hardware control technologies that could be used to meet stringent Tier 2 emission standards.[3] These technologies continue to be very effective emission control strategies to meet Tier 2 standards. We believe that manufacturers will use these same Tier 2 technologies in order to meet the 20˚ F NMHC standard. We do not expect that manufacturers will need to utilize additional emission control hardware. However, if a manufacturer chose to do so, most of these same Tier 2 technologies can also be used to meet the 20˚ F NMHC standard.

5.1.2 Data Supporting Cold NMHC Standard Technical Feasibility

Data to support the feasibility of complying with the 20˚ F NMHC standard are presented in the following two sections. The first section includes evidence from recent model year certification emissions data submitted to EPA. Certification data are required to include cold temperature carbon monoxide emissions data, and some manufacturers have also included associated cold temperature total hydrocarbon emissions data. The second section provides evidence from a feasibility evaluation program recently undertaken by EPA. This program examined the effects of making only calibration modifications to vehicles with 20˚ F NMHC levels that were significantly higher than the standards we are finalizing today.

When considering the supporting data, it should be noted that manufacturers generally design vehicles to incorporate a compliance margin in their exhaust emissions controls systems to account for operational variability. For example, manufacturers design controls to meet emissions targets below the standard when using catalytic converters thermally aged to the full useful life. By ensuring that emission targets are met when testing on artificially aged converters, manufacturers reduce the probability that in-use vehicles will exceed the relevant standard throughout the useful life of the vehicles. Put another way, this design attempts to account for maximum normal operating variability.

However, the data presented in the following sections do not explicitly incorporate a compliance margin since the cold temperature NMHC data, at the time they were submitted to or tested by the EPA, were not subject to cold NMHC standards. The data represent the cold NMHC emissions as tested, and suggest that a significant number of vehicles are within reach of the standards we are finalizing today.

5.1.2.1 Certification Emission Level

Currently, manufacturers are required to report carbon monoxide (CO) exhaust emissions test results for compliance with cold temperature CO standards (i.e., the 20˚ F FTP test) for light-duty vehicles and light-duty trucks. (Cold CO requirements for medium-duty passenger vehicles do not begin until model year 2008.[4]) Many manufacturers have included total hydrocarbon (THC) cold temperature exhaust emission data that are collected along with cold CO data. In addition, several of these manufacturers also reported test results for both the THC emission data and the matching NMHC emission data. Based on these data from manufacturers who have included both THC and NMHC cold temperature data, non-methane hydrocarbons (NMHCs) account for approximately 95% of total hydrocarbon emissions at cold temperatures. Therefore, a review of the more abundant THC data provides a reasonable means of assessing manufacturers' cold NMHC emissions performance.

EPA analyzed 2004-2007 model year full useful life certification data for vehicles certified to nationwide Tier 2 standards, interim non-Tier 2 standards, and California program standards. Lists were compiled from certification data submissions that reported unrounded cold THC results and for which an associated FTP full useful life deterioration factor (DF) was available. The DF was incorporated into the emissions result to estimate emissions at the full useful life of the vehicle. The DF was applied to the unrounded test result, and that result was rounded to one decimal point. This calculation was then compared to the cold temperature NMHC standards of 0.3 g/mi for LDV/LLDTs, and 0.5 g/mi for HLDT/MDPVs.

Table 5.1-2 shows the number of car lines for which the resulting calculation for total hydrocarbons was at or below the 0.3 g/mi NMHC standard for LDV/LLDTs, and at or below the 0.5 g/mi NMHC standard for HLDT/MDPVs. Again, these data only reflect an analysis of those car lines for which manufacturers voluntarily provide cold THC data.

Tables 5.1-3 through 5.1-6 show, by model year, the total hydrocarbon emission levels (calculated according to the method described above) for LDV/LLDTs at or below 0.3 g/mi, and HLDT/MDPVs at or below 0.5 g/mi. For each manufacturer, the data were grouped according to car lines with the same calculated cold THC emission result. Where a range is shown for the emission level, tests on multiple configurations within the car line yielded a range of results.

Table 5.1-2. Number of Car Lines with one or more Engine Families whose Certification Data for Total Hydrocarbons was at or below the Proposed Cold NMHC Standards

Year	LDV/LLDTs	HLDT/MDPVs [(a)]	Total Car Lines
2004	41	13	54
2005	42	16	58
2006	44	22	68
2007	39	16	55

(a) No data for MDPVs were submitted in the HLDT/MDPV weight category. MDPVs are subject to the cold CO standard beginning in model years 2008 and 2009.

As the tables suggest, there are already a significant number of vehicle configurations, across a wide range of vehicle types and manufacturers, within reach of the cold temperature NMHC standards. Though the number of LDV/LLDT configurations at or near the cold NMHC standards significantly outnumber the heavier HLDT/MDPVs, EPA is finalizing as proposed a later phase-in for HLDT/MDPVs due to the unique challenges related to these heavier vehicles, as discussed in section V of the preamble to the final rule.

This analysis does not necessarily imply that manufacturers could have certified these vehicles to meet the new cold NMHC standards. But the data do support the feasibility of meeting such standard levels. This analysis is conservative given that actual NMHC emissions would be slightly less than that of the total hydrocarbon emissions, and given that not all of the vehicles included here were certified to the more stringent Tier 2 standards. That is, some vehicles in the certification data are interim non-Tier 2 vehicles. We would expect hydrocarbon levels to be somewhat lower as these vehicles fully phase-in to Tier 2.

Table 5.1-3. 2004 Model Year Vehicles with Certification Data for Total Hydrocarbons at or below the Cold NMHC Standard

MANUFACTURER	CAR LINE	COLD TOTAL HC LEVEL
LDV/LLDTs		
ACURA	1.7EL, TL	0.1
ACURA	MDX 4WD	0.2
ACURA	RSX	0.3
AUDI	A4 QUATTRO	0.3
BMW	325I SPORT WAGON, 330CI CONVERT.	0.1
BMW	X3	0.2
CADILLAC	CTS	0.2
CHEVROLET	CORVETTE	0.2
HONDA	ACCORD	0.1 - 0.3
HONDA	CIVIC	0.1 - 0.2
HONDA	CIVIC HYBRID, INSIGHT	0 - 0.1
HONDA	CR-V 4WD, ELEMENT 4WD, S2000	0.2
HONDA	ODYSSEY 2WD	0.3
HONDA	PILOT 4WD	0.2 - 0.3
HYUNDAI	XD-5DR	0.3
MAZDA	MAZDA 3	0.2 - 0.3
MAZDA	MAZDA 6, MAZDA 6 SPORT WAGON, MPV	0.3
MERCEDES-BENZ	C240 (WAGON), C-CLASS SEDAN/WAGON, S-CLASS	0.3
MERCEDES-BENZ	E320 4MATIC (WAGON), S500 (GUARD)	0.2
MITSUBISHI	GALANT	0.1 - 0.2
MITSUBISHI	LANCER SPORTBACK	0.3
NISSAN	ALTIMA	0.3
NISSAN	SENTRA	0.2 - 0.3
SATURN	VUE AWD	0.2
TOYOTA	CAMRY	0.3
TOYOTA	PRIUS, RAV4 4WD	0.2
VOLKSWAGEN	JETTA, JETTA WAGON, BEETLE CONVERT.	0.2
VOLVO	V70	0.2 - 0.3
HLDT/MDPVs		
BENTLEY	CONTINENTAL GT	0.3
BMW	X5	0.3
CHEVROLET	ASTRO AWD(C) CONV	0.5
CHEVROLET	K15 SLV HYBRID 4WD	0.4
GMC	K1500 SIERRA AWD	0.4
HIREUS	RR01	0.3
MERCEDES-BENZ	G500, ML350	0.4
PORSCHE	CAYENNE, CAYENNE S	0.3
ROLLS-ROYCE	PHANTOM	0.3
VOLKSWAGEN	TOUAREG	0.4
VOLVO	XC 90	0.3, 0.5

Table 5.1-4. 2005 Model Year Vehicles with Certification Data for Total Hydrocarbons at or below the Cold NMHC Standard

MANUFACTURER	CAR LINE	COLD TOTAL HC LEVEL
LDV/LLDTs		
ACURA	1.7EL, MDX 4WD	0.1
ACURA	RL, RSX	0.2
AUDI	A4 QUATTRO	0.3
BMW	325I SPORT WAGON, 330CI CONVERTIBLE	0.1
BMW	X3	0.2
BUICK	LACROSSE/ALLURE	0.3
CADILLAC	CTS	0.2
HONDA	ACCORD	0.1 - 0.2
HONDA	ACCORD HYBRID	0.2
HONDA	CIVIC	0.1 - 0.2
HONDA	CIVIC HYBRID	0 - 0.1
HONDA	CR-V 4WD, ODYSSEY 2WD, S2000	0.2
HYUNDAI	JM(2WD)	0.3
HYUNDAI	JM(4WD)	0.2
HYUNDAI	XD-5DR	0.3
MAZDA	MAZDA 3	0.2 - 0.3
MAZDA	MPV	0.2
MERCEDES-BENZ	C240 (WAGON), C32 AMG, E320 4MATIC (WAGON), S55 AMG	0.3
MERCEDES-BENZ	C320	0.2
MERCEDES-BENZ	S430 4MATIC	0.1
MITSUBISHI	GALANT	0.2 - 0.3
MITSUBISHI	LANCER, LANCER SPORTBACK	0.3
NISSAN	SENTRA	0.2
SATURN	RELAY AWD	0.3
SATURN	VUE AWD	0.2
TOYOTA	CAMRY, SCION XB	0.3
TOYOTA	PRIUS, RAV4 4WD	0.2
VOLKSWAGEN	JETTA, JETTA WAGON, BEETLE CONVERT., V70	0.2
HLDT/MDPVs		
BENTLEY	CONTINENTAL GT	0.3
BMW	X5	0.3
CHEVROLET	ASTRO AWD(C) CONV, C2500 SLVRADO 2WD, K1500 SUB'N 4WD	0.5
CHEVROLET	K15SLV HYBRID 4WD	0.4
GMC	G3500 SAVANA(P), K1500 SIERRA AWD	0.4
LAND ROVER LTD	LR3	0.4
LEXUS	GX 470	0.4
MERCEDES-BENZ	G500, ML350	0.4
MERCEDES-BENZ	G55 AMG	0.2
PORSCHE	CAYENNE	0.3
ROLLS-ROYCE	PHANTOM	0.3
TOYOTA	TOYOTA TUNDRA 4WD	0.5
VOLVO	XC 90	0.3

Table 5.1-5. 2006 Model Year Vehicles with Certification Data for Total Hydrocarbons at or below the Cold NMHC Standard

MANUFACTURER	CAR LINE	COLD TOTAL HC LEVEL
LDV/LLDTs		
ACURA	MDX 4WD	0.1
ACURA	RL, RSX	0.2
AUDI	A4 QUATTRO	0.3
BUICK	LACROSSE/ALLURE	0.3
CADILLAC	CTS	0.3
CHEVROLET	COBALT, IMPALA	0.3
CHRYSLER	TOWN & COUNTRY 2WD	0.3
HONDA	ACCORD	0.1 - 0.2
HONDA	CIVIC, CR-V 4WD, ODYSSEY 2WD	0.2
HONDA	CIVIC HYBRID	0.1
HONDA	INSIGHT	0 - 0.1
HONDA	S2000	0.3
HYUNDAI	JM(2WD), XD-4DR/5DR	0.3
HYUNDAI	JM(4WD)	0.2
LEXUS	GS 300 4WD, RX 400H 4WD	0.3
MAZDA	MAZDA 3, MAZDA 5, MPV	0.2
MAZDA	MAZDA 6, MAZDA 6 SPORT WAGON	0.3
MERCEDES-BENZ	B200 TURBO, S350	0.2
MERCEDES-BENZ	S430 4MATIC	0.1
MERCEDES-BENZ	S55 AMG	0.3
MITSUBISHI	GALANT	0.2 - 0.3
MITSUBISHI	LANCER, LANCER SPORTBACK	0.3
NISSAN	ALTIMA, SENTRA	0.3
SATURN	RELAY AWD	0.3
SATURN	VUE AWD	0.2
SUZUKI	FORENZA WAGON	0
TOYOTA	CAMRY, CAMRY SOLARA, YARIS	0.3
VOLKSWAGEN	JETTA WAGON	0.2
VOLKSWAGEN	PASSAT WAGON	0.3
VOLVO	V70	0.2
HLDT/MDPVs		
CADILLAC	FUNERAL COACH/HEARS, SRX AWD	0.5
CHEVROLET	C2500 SLVRADO 2WD	0.5
CHEVROLET	K15SLV HYBRID 4WD	0.3
DODGE	DAKOTA PICKUP 4WD, RAM 1500 PICKUP 2WD	0.5
GMC	ENVOY XUV 4WD, G1525 SAVANA CONV	0.5
GMC	K15 YUKON XL AWD	0.3
HONDA	RIDGELINE 4WD	0.2
JEEP	GRAND CHEROKEE 4WD	0.4
LAND ROVER LTD	LR3	0.5
LEXUS	GX 470	0.4
LEXUS	LX 470	0.5
MERCEDES-BENZ	R500	0.2

PORSCHE	CAYENNE, CAYENNE S	0.3
PORSCHE	CAYENNE TURBO KIT	0.5
ROLLS-ROYCE	PHANTOM	0.3
TOYOTA	TOYOTA TUNDRA 4WD	0.5
VOLKSWAGEN	PHAETON	0.5
VOLVO	XC 90	0.3

Table 5.1-6. 2007 Model Year Vehicles with Certification Data for Total Hydrocarbons at or below the Cold NMHC Standard

MANUFACTURER	CAR LINE	COLD TOTAL HC LEVEL
LDV/LLDTs		
BMW	335XI	0.3
DAIMLER-CHRYSLER	CROSSFIRE ROADSTER	0.2
GENERAL MOTORS	IMPALA, UPLANDER FWD	0.3
GENERAL MOTORS	VUE AWD	0.2
GM/DAEWOO	FORENZA WAGON	0
HONDA	ACCORD HYBRID	0.1
HONDA	ACCORD	0.1 - 0.2
HONDA	CIVIC, CIVIC HYBRID, ELEMENT 4WD, S2000	0.3
HONDA	CR-V 4WD, FIT, MDX 4WD, ODYSSEY 2WD, RDX 4WD, RL, TL	0.2
HYUNDAI	HD-4DR, MC(3/4DR)	0.3
LAMBORGHINI	GALLARDO COUPE, MURCIELAGO	0.1
LOTUS	ELISE/EXIGE	0.3
MAZDA	MAZDA 3	0.2 - 0.3
MAZDA	MAZDA 5	0.2
MAZDA	MAZDA 6, MAZDA 6 SPORT WAGON	0.3
MERCEDES-BENZ	SL55 AMG	0.2
MERCEDES-BENZ	CLK550 (CABRIOLET)	0.3
MITSUBISHI	GALANT	0.2 - 0.3
MITSUBISHI	ECLIPSE SPYDER	0.3
PORSCHE	CAYMAN S	0.2
TOYOTA	CAMRY HYBRID	0.1
TOYOTA	PRIUS	0.2
TOYOTA	YARIS, RX 400H 4WD	0.3
VOLKSWAGEN	PASSAT WAGON	0.3
VOLVO	S40	0.1
HLDT/MDPVs		
BENTLEY MOTORS LTD.	CONTINENTAL GTC	0.3
DAIMLER-CHRYSLER	RAM 1500 PICKUP 2WD	0.4 - 0.5
GENERAL MOTORS	K1500 AVALANCHE 4WD	0.3 - 0.4
GENERAL MOTORS	CHEVY C1500 CLASSIC PICKUP 2WD, ISUZU ASCENDER SUV 4WD, FULL SIZE CONVERSION VAN AWD	0.4
GENERAL MOTORS	ESCALADE EXTAWD	0.5
HONDA	RIDGELINE 4WD	0.2
MERCEDES-BENZ	R500 4MATIC	0.2
MERCEDES-BENZ	MAYBACH 62, GL450	0.5
TOYOTA	GX 470	0.4
TOYOTA	LX 470, TOYOTA TUNDRA 4WD	0.5
VOLKSWAGEN	TOUAREG	0.5
VOLVO	XC 90	0.3, 0.5

5.1.2.2 EPA Test Programs

To further assess the feasibility of meeting the new cold temperature NMHC standards through changes to engine and emission control system calibration, EPA performed a test program involving two Tier 2 vehicles. We considered several key aspects when selecting test vehicles for a feasibility study. First, the vehicles currently produce 20˚ F NMHC levels that are significantly higher than the standards we are finalizing today. Second, since higher vehicle weight poses additional challenge, we considered heavier GVWR vehicles. Finally, the technological approach chosen by the manufacturer to meet stringent 75˚ F Tier 2 standards was also considered. Specifically, we considered secondary air injection technology and close coupled catalyst technology. Specifications for the vehicles included in the test program are provided in Table 5.1-6.

Table 5.1-6. EPA Test Vehicle Specifications

Vehicle	Engine Family	Powertrain	GVWR	Emission Class	Mileage
2004 Chevrolet Trailblazer	4GMXT04.2185	4.2L I6 4-speed auto Rear 2-WD	5550 lbs.	Tier 2 Bin 5	36,500
2006 Chrysler 300C	6CRXV05.7VEO	5.7L V8 5-speed auto Rear 2-WD	5300 lbs.	Tier 2 Bin 5	2,000

The vehicles were tested at 20˚ F following EPA cold FTP test procedures established in 40 CFR 86.230-94. In addition to regulated pollutant measurements, we also measured NMHC, NOx, and direct particulate matter (PM). NMOG analysis also produced measurements of 13 carbonyls. PM measurement was performed following 40 CFR 86.110-94 procedures. A detailed diagram of the emission and PM sampling system can be seen in the docket.[A] The road load force target coefficient settings, contained in Table 5.1-7, are 10% higher than the vehicle's 75˚ F target coefficients as established procedure in EPA guidance letter CD-93-01.[B]

Table 5.1-7. EPA 20˚ F Cold Test Vehicle Settings

Vehicle	Test Weight	20˚ F Target Coefficients
2004 Chevrolet Trailblazer	**5000 lbs.**	**A=38.97** **B=1.2526** **C=.02769**
2006 Chrysler 300C	**4500 lbs.**	**A=61.09** **B=.3105** **C=.0247**

[A] "Cold Chamber Sampling System Diagram," PDF file from test lab.

[B] Available at www.epa.gov/otaq/cert/dearmfr/dearmfr.htm.

5.1.2.2.1 2004 Chevrolet Trailblazer Testing

The 2004 Chevrolet Trailblazer was chosen as a test vehicle for several reasons. First, it is certified as a Tier 2 Bin 5 package, which represents what can be considered the “typical” or average 75˚ F emission level once Tier 2 phase-in is complete. The Bin 5 emission standards represent the required EPA fleet average for NOx, and therefore the hardware used on the Trailblazer to comply with Bin 5 standards represents what we might expect from many manufacturers and vehicle lines. Second, while it was certified to the expected average Tier 2 emission levels, its NMHC emission performance at 20˚ F was substantially worse than the industry averages. Finally, due to its GVWR, it represents vehicles that are very close to 6000 lbs. GVWR (i.e., the HLDT emission category). Different Trailblazer models fall above and below 6000 lbs. GVWR, but have no discernable differences in the emission control hardware.

The Trailblazer engine control system is representative of typical Tier 2 systems. The system includes an electronic engine control module (ECM), individual cylinder fuel injectors, individual cylinder ignition coils, heated exhaust gas oxygen sensors (HEGO) before and after the catalyst, electronic throttle control, variable valve timing and several other necessary supporting sensors. The aftertreatment hardware consists of a single, under-floor catalyst and a secondary air injection system.

The secondary air injection system is composed of an electric air pump and an electric solenoid valve. The air pump is located under the vehicle’s driver-side floor board where it is mounted to a frame bracket. The electric solenoid valve is mounted to the engine cylinder head directly above the exhaust manifold on the passenger side of the vehicle. Clean air is drawn by the air pump from the air cleaner assembly in the engine compartment through a pipe, and then it is pumped back to the electric solenoid valve through a second pipe. The two pipes used to transport the air are fairly long, due primarily to the air pump location.

The secondary air injection system on the Trailblazer appears to operate on cold starts above 40˚ F only. The system operates for approximately 20 to 45 seconds after the start, depending on start-up coolant temperature, and is deactivated when the emission control system goes into closed loop operation. Some manufacturers have indicated that operation of the secondary air injection system is not currently performed on cold start temperatures at and below freezing due to potential ice issues. However, this is not universal across all manufacturers, since several manufacturers do, in fact, operate their secondary air injection system at 20˚ F cold start temperatures and above. They have addressed the issue of water collecting and freezing by design aspects primarily concentrated around system plumbing and location of the components. On some European vehicle models, these manufacturers effectively use the secondary air injection systems to comply with a 20˚ F NMHC standard in Europe.[5]

A key element of the feasibility test program was to imitate software initiated emission control system behaviors which are observed at the currently regulated start temperatures of 75˚ F and 50˚ F (California-only requirement). These software features do not entail any new hardware. In the case of the Trailblazer, while not all behaviors could be demonstrated, several of the most important behaviors were replicated. First, the secondary air injection system was operated during the cold temperature test. Second, elevated idle speeds, similar to what the Trailblazer currently uses after the start at the regulated start temperatures, were also used at cold temperature.

Activation of the secondary air injection was accomplished through circuit overrides of the air pump and solenoid valve control circuits, completely external to the ECM. The air pump and the solenoid valve are each powered by a relay normally only controlled by the ECM output signals. The two relays were forced on to activate the secondary air injection system during the desired period following the cold start. We tested several delay periods from the start of the engine until the secondary air system was activated in order to measure benefits of earlier introduction of the air injection. The secondary air was always run until the ECM induced closed loop operation (approximately 60 seconds after the start). At the completion of the desired period of operation, control of the relays was returned to the ECM.

The elevated idle speed was performed by allowing a manually controlled vacuum leak into the intake manifold during the first 30 to 60 seconds following engine start. The controlled vacuum leak targeted 1550 to1600 RPM idle speed in park/neutral, mimicking the same acceptable idle speed the ECM commands at 50˚ F cold starts. Typically, idle speeds increase with drops in start temperature, but the observed desired idle speeds in the Trailblazer were lower at 20˚ F (1350 RPM) than at the warmer 50˚ F starts (1550 RPM). An On-board Diagnostics 2 (OBD2) dealership diagnostic tool was capable of electronically elevating the idle speed to the equivalent 50˚ F cold start idle speed but internal tool or ECM software prevented this idle speed and air flow for the full 30 to 60 second time period. Hence it was determined that for the purposes of this test program, a vacuum leak would accurately demonstrate the effect of an acceptable idle speed and air flow following a start. Manufacturers today control to a desired idle speed through control of electronic throttle or other air bleed devices.

Table 5.1-8 below contains the weighted test total (3 bags) emission results of the different test configurations attempted on the Trailblazer. Test #7 and #8 also included defroster operation starting at 130 seconds into the test and remaining on for the rest of the test. Since the methods used to control cold start NMHC emissions were used only in the first minute of operation, prior to defroster activation, the NMHC and PM emission results with defroster operation remain representative of emission control opportunities. It is important to note the consistent reductions in NMHC with early activation of the secondary air injection system, as seen in the test sequence from test #3 through test #6, and also in the defroster tests. The tests with defroster operation were included to assess any emission impacts of defroster-on, which is required in the fuel economy rule.[C]

While NOx emissions are not part of the controls investigation, the NOx levels appeared to increase with the NMHC control methods. After some modal investigation, it was determined that the NOx increases were occurring after the NMHC controls had performed the majority of their benefits. The NOx emissions were brought back almost to the baseline levels by shortening the elevated idle speed and air bleed time. This can be observed in the results of test #6 and #7. In fact, test #6 produced the largest NMHC reduction with essentially the same NOx levels as the baseline tests. Manufacturers would be able to better synchronize their controls through their

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[C] Fuel Economy Final Rule, 71 FR 77872, December 27, 2006, Defroster Operation Requirement for Cold FTP.

ECM to control NMHC and NOx emissions simultaneously, as compared to this test program's limitations.

CO and direct PM measurements were also significantly reduced when NMHC controls were activated. CO, the only currently regulated pollutant at 20˚ F, was consistently reduced from baseline levels with each of the control combinations. PM was also generally reduced; however, this is less obvious when reported as test total results. Since the emissions are recorded over the three-phase test with each phase composed of an individual bag measurement, PM reductions can be better evaluated in Table 5.1-9, which contains the emission results for only the first phase (bag 1) of the three-phase emission test.

Table 5.1-8. Trailblazer Test Configuration and 20˚ F FTP Weighted Test Total Results

Test Number	Air Injection	Elevated Idle & air bleed time	NMHC g/mi	CO g/mi	NOx g/mi	PM g/mi	Fuel Economy mi/gallon
Standard ≤ 6000 lbs GVWR			**.3**				
Standard > 6000 lbs GVWR			**.5**				
1-baseline	none	none	1.08	7.8	.05	.024	13.82
2-baseline	none	none	1.03	9.5	.04	.015	13.64
3-controls	5 s delay	60 s	.59	5.2	.15	.025	13.87
4-controls	2 s delay	60 s	.42	5.5	.19	.013	13.56
5-controls	1 s delay	60 s	.35	5.2	.17	.014	13.71
6-controls	0 s delay	30 s	**.29**	5.1	.06	.013	13.64
7-defrost on	1 s delay	30 s	.38	6.9	.08	.012	13.17
8-defrost on	0 s delay	45 s	.32	6.4	.13	.013	13.25

As can be seen in Table 5.1-8, control test #6 provided a NMHC level that would have allowed the Trailblazer to comply with the standard for the ≤ 6000 lbs GVWR class (i.e., 0.3g/mi). While this vehicle was tested as the lower GVWR class at 5000 lbs test weight, the Trailblazer also is sold as an over 6000 lbs. GVWR model that would have been tested at 5500 lbs[D]. We believe that if tested at the higher weight, the emission results likely would not have increased much, reflecting a large margin (.2 g/mi) for this vehicle when certified to the heavier class. We recognize that manufacturers will need to account for a compliance margin, but we believe this vehicle can achieve a comfortable compliance margin for the more stringent standard (i.e., 0.3 g/mi) with some additional minor calibration changes. We also recognize that this feasibility study does not constitute a production calibration and that additional development effort would be needed to achieve manufacturer functional objectives for cold starts. This test program simply demonstrates that in the case of this typical secondary air injection equipped vehicle, additional emission reduction opportunities exist without the requirement for additional hardware.

[D] Tier 2 vehicles are tested (inertia setting) at loaded vehicle weight (LVW). LVW=curb weight + 300 lbs.

Emissions results for the 20˚ F cold CO test are reported as a weighted three-bag average. However, bag one (the first 505 seconds of the test) provides a better indication of emission reductions achieved with controls, because almost all of the emissions at 20˚ F are emitted in the first few minutes of operation, and all control changes were attempted only during the first minute of operation. Table 5.1-9 presents only the bag 1 emission results. This table highlights the emission reductions from the control changes by not diluting the improvements over the second and third phase (bag 2 and 3) of the emission test.

As observed below in Table 5.1-9, the results clearly show NMHC, CO and PM reductions. NMHC and CO reductions occur with all the control attempts, but control tests #6 and #8, in which secondary air injection was activated immediately upon engine cranking, achieve the best results. PM reductions follow similar behavior as NMHC, but they appear to be very sensitive to delayed secondary air injection.

Table 5.1-9. Trailblazer Test Configuration and 20˚ F FTP Phase 1 Only Results

Test Number	Air Injection	Elevated Idle & air bleed time	NMHC g/mi	CO g/mi	NOx g/mi	PM g/mi	Fuel Economy mi/gallon
1-baseline	none	none	5.18	27.3	.22	.055	11.55
2-baseline	none	none	4.92	31.7	.16	.040	11.47
3-controls	5 s delay	60 s	2.81	18.6	.72	.043	11.29
4-controls	2 s delay	60 s	1.96	15.0	.85	.033	11.30
5-controls	1 s delay	60 s	1.63	13.6	.81	.026	11.40
6-controls	0 s delay	30 s	1.34	13.3	.29	.022	11.45
7-defrost on	1 s delay	30 s	1.75	14.8	.35	.010	11.23
8-defrost on	0 s delay	45 s	1.47	13.2	.61	.022	11.27

While the emissions reductions were fairly substantial with the best control combination in test #6, we believe that even greater emission reductions can be achieved with more precise use of the secondary air system and additional control measures described earlier in the calibration and controls technology section. The ability to more precisely provide the ideal air-fuel mixture for the secondary air injection system likely would have resulted in faster catalyst light-off and subsequently even greater reductions in emissions, especially NMHC. Additionally, retarded timing was not tested due to the limited capability to modify engine operation. Typically this would further compound the rate of heating the catalyst, particularly on secondary air injection systems, and thus, would be expected as an additional opportunity to reduce NMHC.

5.1.2.2.2 2006 Chrysler 300C Testing

A second vehicle, a 2006 Chrysler 300C, was chosen because it has specific engine related challenges and a different method of controlling emissions than the first feasibility vehicle. Manufacturers have commented that the higher displacement engines typically used in heavier vehicles pose additional challenges because they require more fuel to start and maintain idle stability at cold temperatures than smaller displacement engines.[6] The 300C is a light-duty vehicle equipped with a large displacement V8 engine (5.7 liter). The same large displacement V8 engine used in the 300C is also found in a broad range of vehicles, including full size trucks and several sport utility vehicles above 6000 lbs. GVWR. Unlike the Trailblazer, it does not use secondary air injection, and instead relies more heavily on controlling fuel in the combustion chamber. Like the Trailblazer, it is certified as a Tier 2 Bin 5 package. This represents what can be considered the "typical" or average 75˚ F emission level once Tier 2 phase-in is complete. The hardware used on the 300C to comply with Tier 2 Bin 5 standards also represents what we might expect from many manufacturers and vehicle lines that do not have secondary air injection.

The 300C emission control system is representative of typical Tier 2 systems. The system includes an electronic engine control module (ECM), individual cylinder fuel injectors, individual cylinder ignition coils, heated exhaust gas oxygen sensors (HEGO) before and after the catalysts, electronic throttle control, and several other necessary supporting sensors. The aftertreatment hardware consists of a dual catalysts (one per bank) located in close proximity to the engine exhaust manifold for optimum catalyst heating. Additionally, the 300C contains several new technologies, including cylinder deactivation and dual spark plugs per cylinder.

The 300C is offered as both a US model (sold in North America) and a European model (sold in Europe) without any discernable differences in the emission control hardware (i.e., catalysts, oxygen sensors, etc.), with the exception of the ECM. Vehicles sold in the European market are required to comply with the European Union (EU) type VI test, which is a cold start test performed at 20˚ F. In addition to CO emission standards, the EU cold temperature test also requires stringent HC and NOx emission control. For this reason, any differences observed in the emissions between a US model and a European model are likely due to software and calibration differences targeted specifically at HC, CO and NOx emission reductions to meet the European cold temperature emissions standards.

These emission controls could be implemented in the US model 300C and other US packages also sharing the same large displacement V8 engine. While all the different applications were not directly tested, the control techniques used in the 300C to reduce cold start emissions for EU compliance should also be applicable to the other vehicle platforms that share the same engine. In fact, some of the other vehicle platforms that share the same V8 engine are also sold in Europe, which indicates that emission control techniques are likely already leveraged across various European models sharing a common engine.

In order to determine any emission control opportunities that exist in the European 300C, an ECM containing the 2006 European software and calibration was purchased and installed in the 300C. No other changes were made to the emission control system. The US and European model configurations were each tested over the 20˚ F FTP. The tests were replicated to ensure that the emissions levels were consistent. The testing was performed with defroster operation as specified in the fuel economy rule[E] to incorporate any potential emission impacts of defroster or

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[E] Fuel Economy Final Rule, 71 FR 77872, December 27, 2006, Defroster Operation Requirement for Cold FTP.

heater-on operation. The 300C utilizes an automatic interior climate control system which, as expected, did not ramp up fan speed until the coolant temperature exceeded a threshold established for driver comfort. Since the methods used to control cold start NMHC emissions are primarily used only in the first minute of operation prior to the ramp-up of the automatically controlled interior fan, the emission results are likely not impacted by defroster operation. However, as with the first feasibility vehicle test program, it was logical that the testing be performed with the defroster usage as specified in the fuel economy rule to include any potential emissions impact.

Table 5.1-10 below contains the weighted test total (3 bags) emission results of the two different test configurations attempted on the 300C. All emissions were significantly reduced when tested in the European configuration. CO, the only currently regulated pollutant at 20˚ F in the US, was consistently reduced below baseline levels with each test of the European calibration. In the European model, NMHC, was reduced 32% reduced when compared to the US model. The European models NMHC levels approached the new fleet average standard of 0.3 g/mi for lighter vehicles under 6000 lbs. GVWR. The 300C is considered a worst-case model in the LDV category due to its large displacement V8 engine and high test weight. With the fleet averaging provision provided in the final rule, this vehicle would likely be certified to a higher FEL. However, we fully expect that with the lead time provided, further calibration improvements to reduce NMHC levels to the 0.3 g/mi level are possible but we did not attempt this capability in the limited test program.

Table 5.1-10. 300C Test Configuration and 20˚ F FTP Weighted Test Total Results

Test Number	NMHC g/mi	CO g/mi	NOx g/mi	PM g/mi	Fuel Economy mi/gallon
Standard ≤ 6000 lbs GVWR	**0.3**				
Standard > 6000 lbs GVWR	**0.5**				
1-US model	0.574	2.25	0.06	0.011	14.90
2-US model	0.540	1.99	0.07	0.009	14.89
Average	**0.557**	**2.12**	**0.07**	**0.010**	**14.90**
1-EU model	0.398	1.26	0.04	0.005	14.24
2-EU model	0.384	1.36	0.05	0.006	14.93
Average	**0.379**	**1.23**	**0.04**	**0.006**	**14.64**
% Change	**-32%**	**-42%**	**-43%**	**-40%**	**-2%**

While this vehicle was tested at 4500 lbs test weight representing the lower GVWR class, as noted above, the same engine configuration is also sold in several over 6000 lbs. GVWR models. Vehicles over 6000 lbs. GVWR are required to test at slightly higher weights (i.e., 5000 lbs. to 6000 lbs.)[F]. We expect that if tested at the higher test weight required for vehicles over 6000 lbs. GVWR, the emission results would likely increase but would maintain an acceptable margin below the 0.5 g/mi standard for heavier vehicles. As indicated previously, we believe this vehicle can likely be brought into compliance with the LDV/LLDT fleetwide standard (i.e., 0.3 g/mi) with some additional calibration changes, given the lead time provided in the program.

Since almost all of the emissions at 20˚ F are emitted in the first few minutes of operation and most NMHC controls are attempted only during the first few minutes of operation, Table 5.1-11 presents only the bag 1 emission results.

Table 5.1-11. 300C Test Configuration and 20˚ F FTP Bag 1 Only Results

Test Number	NMHC g/mi	CO g/mi	NOx g/mi	PM g/mi	Fuel Economy mi/gallon
1-US model	2.75	10.4	0.14	0.037	13.26
2-US model	2.49	9.1	0.20	0.033	13.41
Average	**2.62**	**9.8**	**0.17**	**0.035**	**13.34**
1-EU model	1.897	5.6	0.10	0.016	12.42
2-EU model	1.830	6.0	0.10	0.021	12.74
Average	**1.864**	**5.8**	**0.10**	**0.019**	**12.58**
% Change	**-39%**	**-41%**	**-41%**	**-54%**	**-6%**

As observed above in Table 5.1-11, all measured emissions with the European configuration were significantly reduced in bag 1 of the 20˚ F FTP test. NMHC, CO, NOx and PM reductions can be clearly seen from the bag 1 results. As described earlier, these reductions are attributed entirely to calibration and software changes in the European model as all other emission control hardware remained the same with the US model. These calibration and software changes could easily be adapted to the US model to achieve significant emissions reductions. Additional emission reduction opportunities may exist with further software and calibration refinement. We believe this test program demonstrates that significant emissions reductions are available through only calibration on the most challenging Tier 2 vehicles (i.e., 300C) and that most Tier 2 vehicles can achieve these standards. While the standards will be challenging for some manufacturers across their product lines, we believe the lead time and other program flexibilities provided will allow compliance with the new standards.

5.2 Feasibility of Evaporative Emissions Standards for Vehicles

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[F] Tier 2 vehicles are tested (inertia setting) at loaded vehicle weight (LVW). LVW=curb weight + 300 lbs.

The standards for evaporative emissions, which are equivalent to the California LEV II standards, are technologically feasible now. As discussed in Section V of the preamble for today's rulemaking, the California LEV II program contains numerically more stringent evaporative emissions standards compared to existing EPA Tier 2 standards, but because of differences in testing requirements, we believe the programs are essentially equivalent. This view is supported by manufacturers and current industry practices. (See Section V.C.5 of the preamble for further discussion of such test differences (e.g., test temperatures and fuel volatilities).) A review of recent model year certification results indicates that essentially all manufacturers certify 50-state evaporative emission systems.[7] Therefore, harmonizing with California's LEV-II evaporative emission standards will codify the approach manufacturers have already indicated they are taking for 50-state evaporative systems.

References for Chapter 5

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[1] Memo to docket "Discussions Regarding Secondary Air System Usage at 20˚ F with European Automotive Manufacturers and Suppliers of Secondary Air Systems," December 2005.

[2] Meyer, Robert and John B. Heywood, "Liquid Fuel Transport Mechanisms into the Cylinder of a Firing Port-Injected SI Engine During Start-up," SAE 970865, 1997.

[3] For a more detailed description of these technologies see the Tier 2 final rule at 65 FR 6698-6822, February 10,2000, and Regulatory Impact Analysis Chapter IV: Technical Feasibility.

[4] 40 CFR 86.1811-04, paragraphs (g) and (k).

[5] Memo to docket "Discussions Regarding Secondary Air System Usage at 20˚ F with European Automotive Manufacturers and Suppliers of Secondary Air Systems," December 2005.

[6] Comments submitted by Alliance of Automobile Manufacturers (Alliance), OAR-2005-0036-0881.1

[7] Update for FRM: U.S. EPA, Evaporative Emission Certification Results for Model Years 2004 to 2007, Memorandum to Docket EPA-HQ-OAR-2005-0036 from Bryan Manning, January 4, 2007.

Chapter 6: Table of Contents

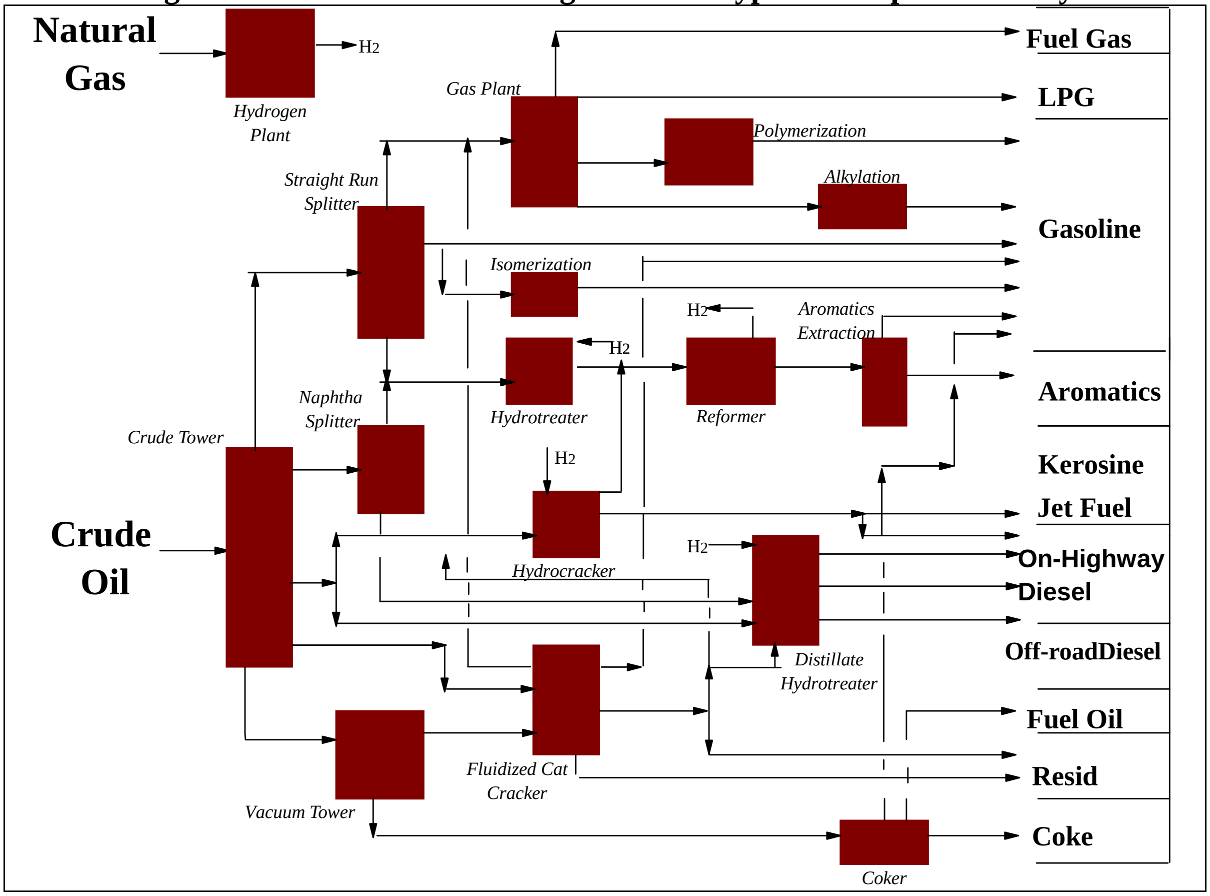
Chapter 6: Feasibility of the Benzene Control Program

This chapter summarizes our assessment of the feasibility of complying with a benzene control standard. It begins with an overview of refining followed by a summary of the benzene levels of gasoline today and where that benzene comes from. The various technologies which reduce benzene levels in gasoline are described along with an assessment of the levels of benzene achievable by the application of these technologies and their potential to be applied by refineries. This assessment of the benzene levels achieved by applying control technologies is used to assess the feasibility of complying with the benzene control program. Next the lead time to apply the various control technologies and to comply with the new standards is evaluated. Finally, the energy and supply impacts of the program are assessed.

6.1 Overview of Refinery Flow

Figure 6.1-1 shows a process flow diagram for a typical complex refinery, capable of making a wide product slate (shown on the right side of the figure) from crude oil (input on the left). Following the figure is a brief description of key units and streams focusing more on the gasoline producing units. It’s important to note that not all refineries have all of these units, which is a key factor in both the variation in their baseline benzene levels as well as their cost of benzene control.

Figure 6.1-1. Process Flow Diagram for a Typical Complex Refinery



Crude Tower

The purpose of the crude tower is to perform a distillation separation of crude oil into different streams for additional processing in the refinery and for the production of specific products. Crude oil is shipped to the refinery via pipeline, ship, barge, rail, or truck, whereupon it is sampled, tested, and approved for processing. The crude oil is heated to between 650° F and 700° F and fed to crude distillation tower. Crude components vaporize and flow upward through the tower. Draw trays are installed at specific locations up the tower from which desired side cuts or fractions are withdrawn. The first side-cut above the flash zone is usually atmospheric gasoil (AGO), then diesel and kerosene/jet fuel are the next side-cuts, in that order The lightest components, referred to here as straight run naphtha, remain in the vapor phase until they exit the tower overhead, following which they are condensed and cooled and sent to the naphtha splitter.[1]

Naphtha Splitter

The purpose of the naphtha splitter is to perform a distillation separation of straight run naphtha into light straight run naphtha and heavy straight run naphtha. The feed can be split between the C_5's and C_6's in order to assure the C_6's and heavier were fed to the reformer.[2]

Isomerization Unit

The purpose for the isomerization unit is to convert the light naphtha from straight chain hydrocarbons to branched chain hydrocarbons, increasing the octane of this stream. The isomerate is sent to gasoline blending.[3]

Reformer

The purpose of the reformer unit is to convert C6 to C8 or C9 hydrocarbons into aromatic and other higher octane compounds (benzene is one of the aromatic compounds produced), typically necessary to produce gasoline with sufficient octane. Heavy straight run naphtha is hydrotreated and fed to the reformer. As the reformer converts the feed hydrocarbons to aromatics, hydrogen and light gases are produced as byproducts. The liquid product, known as reformate, is sent directly to gasoline blending, or to aromatics extraction.[4]

Aromatics Extraction Unit

The purpose of aromatics extraction is to separate the aromatic compounds from the rest of the hydrocarbons in reformate using chemical extraction with a solvent to concentrate the individual aromatic compounds, (mainly xylene and benzene) for sale to the chemicals market.[5]

Vacuum Tower

The purpose of the vacuum distillation tower unit is to enable a refinery to produce more gasoline and diesel fuel out of a barrel of crude oil. It separate the heavy vacuum gasoil (HVGO), which is fed to the FCC unit, from the vacuum tower bottoms (VTB) which is sent to the coker, or in other refineries is made into asphalt.

Fluidized Catalytic Cracker

The purpose of the fluidized catalytic cracker is to convert heavy hydrocarbons, which have very low value, to higher value lighter hydrocarbons. AGO and HVGO are the usual feeds to a fluid catalytic cracker (FCC). The full boiling range cracked product leaves the reactor and is sent to a fractionator. The overhead includes propane, propylene, butane, butylene, fuel gas and FCC naphtha, which contains some benzene. There are two heavy streams; light cycle oil (LCO), which can be hydrotreated and blended into diesel fuel or hydrocracked into gasoline; and heavy cycle oil, sometimes called slurry oil, which can be used for refinery fuel.[6]

Gas Plant

The purpose of the gas plant is to use a series of distillation towers to separate various light hydrocarbons for further processing in the alkylation or polymerization units or for sale.

Alkylation Unit

The purpose of the alkylation unit is to chemically react light hydrocarbons together to produce a high quality, heavy gasoline product. Alkylation uses sulfuric or hydrofluoric acid as catalysts to react butylene or propylene together with isobutane. Following the main reaction and product separation, the finished alkylate is sent to gasoline blending. Alkylate is low in RVP and high in octane.[7]

Polymerization Unit

The purpose of the polymerization unit is to react light hydrocarbons together to form a gasoline blendstock. A polymerization unit, often referred to as a "cat poly" is somewhat similar to an alkylation unit, in that both use light olefins to produce gasoline blendstocks. The feed is generally propylene and/or butylene from the gas plant. The product, called polygas is sent to gasoline blending.

Coker Unit

The purpose of the coker unit is to process vacuum tower bottoms (VTB) to coke and to crack a portion to various lighter hydrocarbons. The hydrocarbons produced by the coker include cracked gases, coker naphtha, coker distillate and gas oil. The gas is fed to the gas plant, the naphtha to the reformer hydrotreater, and the distillate either to distillate hydrotreating or to the hydrocracker.

Hydrocracker

The purpose of the hydrocracker is to crack and "upgrade" the feedstock into higher value products. The feedstock to the hydrocracker is usually light cycle oil (LCO) and coker distillate, poor quality distillate blendstocks, which are upgraded to diesel fuel, or cracked to gasoline. Heavier hydrocarbons such as AGO and HVGO can be feedstocks as well.

A more complete description for reforming is contained in Section 6.3. Other refinery units are described in more detail in the Appendix.

6.2 What are the Benzene Levels in Gasoline Today?

EPA receives information on gasoline quality, including benzene, from each refinery in the U.S. under the reporting requirements of the Reformulated Gasoline and Antidumping Programs. Benzene levels averaged 0.97 volume percent for gasoline produced in and imported into the U.S. in 2004, which is the most recent year for which complete data was available at the time of this analysis. The benzene levels differ depending on different volumes of interest. We assessed the 2004 benzene levels by conventional versus reformulated gasoline, winter versus summer, and with and without California and Imports. Table 6.2-1 contains the benzene levels for these various gasoline types by season and aggregated.

Table 6.2-1. Summary of U.S. Benzene Levels by Gasoline Type and Season for 2004 (vol%)

	U.S. Production (excl. California)	Imports	Production + Imports	California	All Gasoline
CG Summer	1.132	0.949	1.128	-	1.128
CG Winter	1.076	0.756	1.065	-	1.065
Total CG	1.103	0.828	1.095	-	1.095
% total volume	64.3	1.9	66.2	0	66.2
RFG Summer	0.587	0.677	0.594	0.620	0.603
RFG Winter	0.622	0.696	0.629	0.620	0.626
Total RFG	0.606	0.688	0.613	0.620	0.616
% total volume	20.3	2.1	22.4	11.4	33.8
Summer CG & RFG	1.006	0.800	0.998	0.620	0.955
Winter CG & RFG	0.964	0.725	0.952	0.620	0.914
Total CG & RFG	0.984	0.754	0.973	0.620	0.933
% of total volume	84.6	4.0	88.6	11.4	100.0

Individual refinery gasoline benzene levels can vary significantly from the national average with trends forming in specific regions of the country. Therefore, it is useful to understand how the benzene levels vary by individual refinery as well as regionally. Figure 6.2-1 contains a summary of annual average gasoline benzene levels by individual refinery for conventional gasoline and reformulated gasoline versus the cumulative volume of gasoline produced (not including California refineries for which EPA does not receive data).

Figure 6.2-1. Benzene Content of RFG and Conventional Gasoline, 2004.

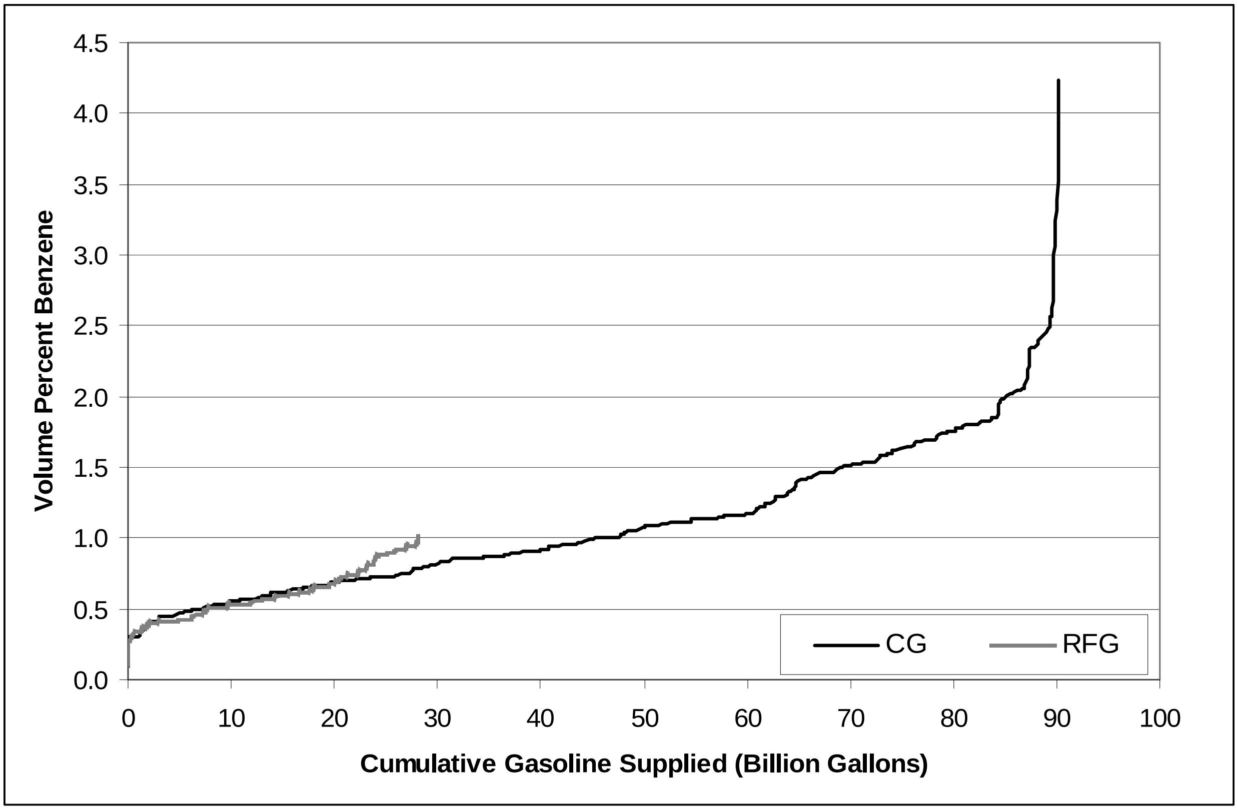


Figure 6.2-1 shows that the annual average benzene levels of conventional gasoline produced by individual refineries varies from 0.3 to 4.2 volume percent. The volume-weighted average is 1.10 volume percent. As expected, the annual average benzene levels of reformulated gasoline as produced by individual refineries are lower ranging from 0.1 to 1.0 volume percent. The volume-weighted average benzene content for U.S. reformulated gasoline (not including California) is 0.61 volume percent.

The information presented for annual average gasoline benzene levels does not indicate the variability in gasoline batches produced by each refinery. We also evaluated the batch-by-batch gasoline benzene levels for individual refineries. This information is obtainable from data provided to EPA under the reporting requirements of the RFG program. To illustrate the degree of variability within different refineries, in Figure 6.1-2 through 6.2-7 we provide the data for 3 different refineries which produce both conventional and reformulated gasoline and 3 refineries which produce solely conventional gasoline. For the RFG producing refineries we summarize the data by gasoline type as these refineries produce both RFG and CG. For the CG refineries we break out the data by premium grade, regular grade and midgrade gasoline, if the refinery produces it. We arbitrarily labeled the refineries in these figures refineries A through F to facilitate the discussion about this data.

Figure 6.2-2. RFG and CG Batch-by-Batch Benzene Levels for Refinery "A" (volume percent benzene in 2003 gasoline)

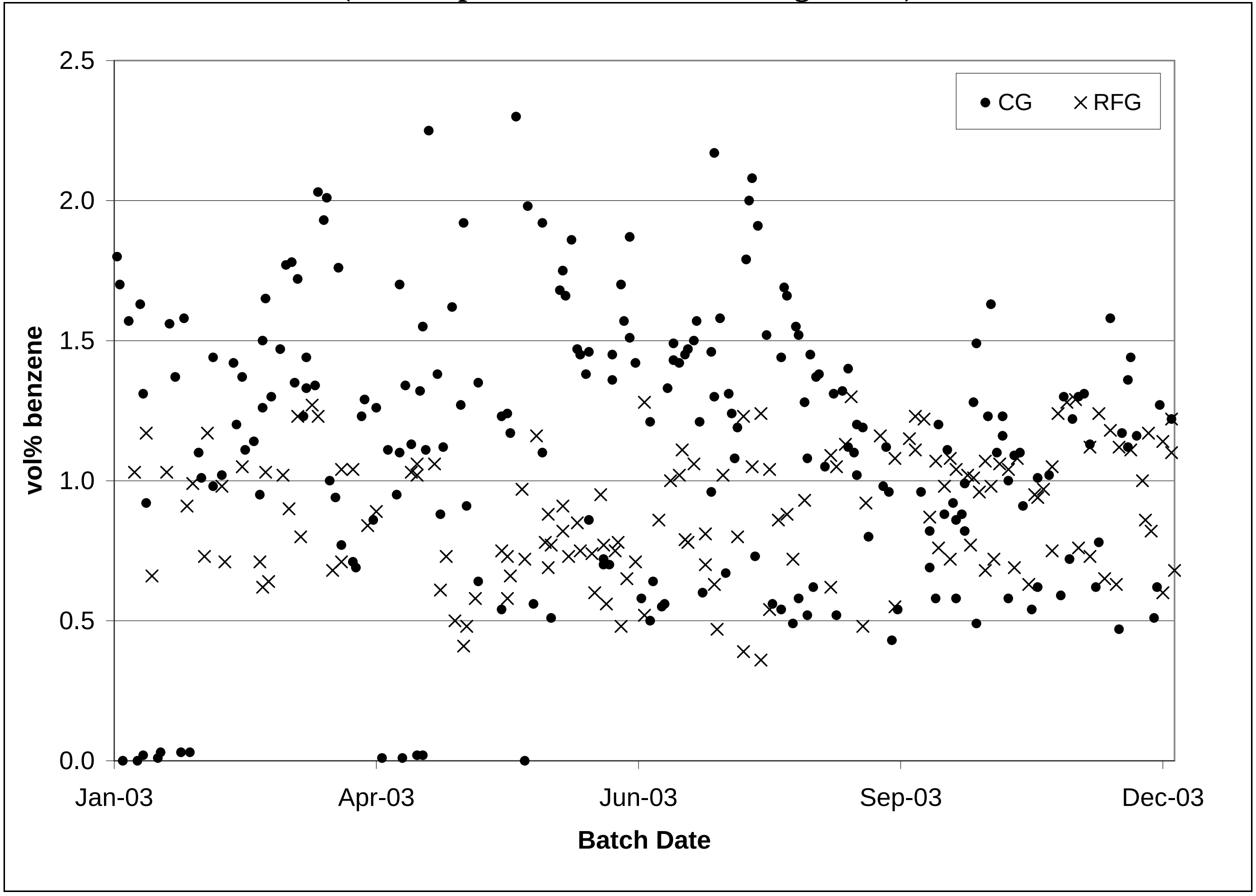


Figure 6.2-3. RFG and CG Batch-by-Batch Benzene Levels for Refinery "B" (volume percent benzene in 2003 gasoline)

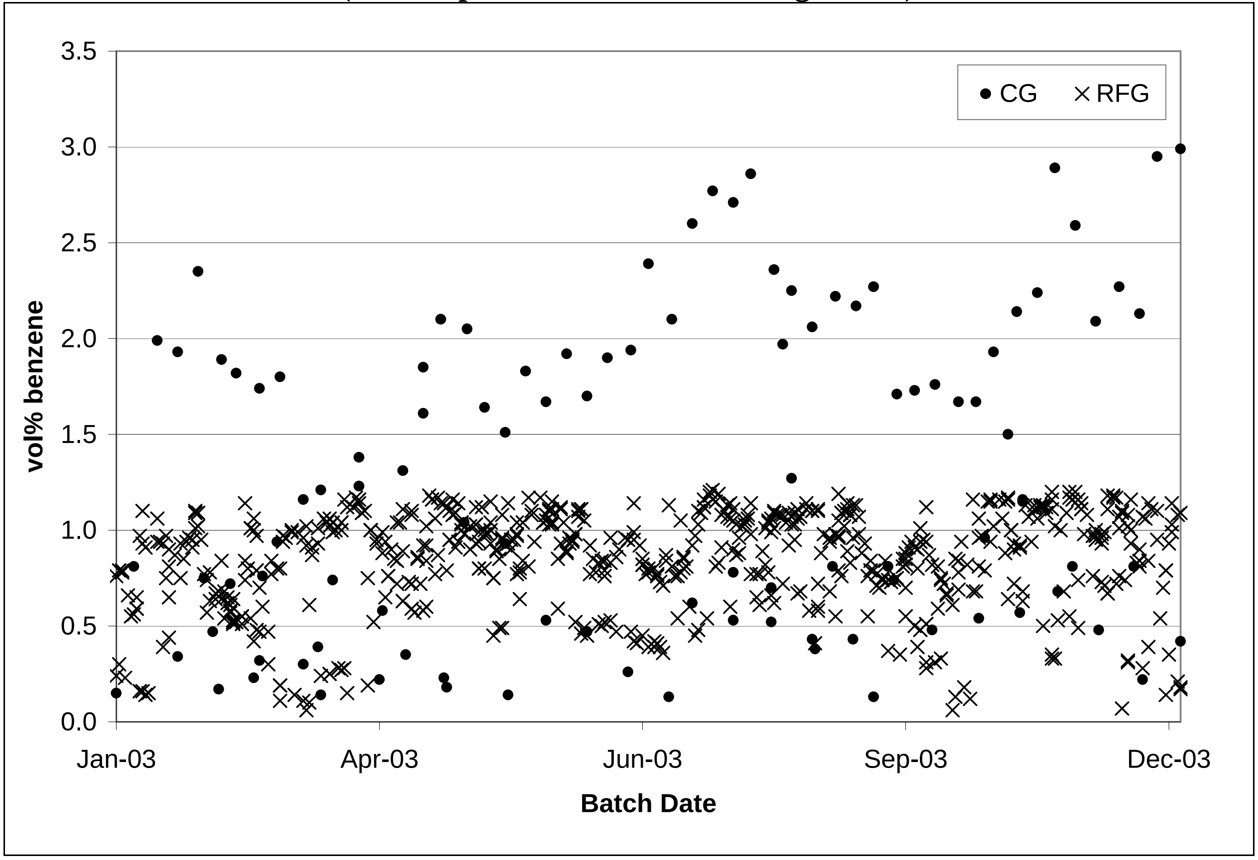


Figure 6.2-4. Batch-by-Batch Benzene Levels for Refinery "C" that Produces both RFG and CG Gasoline (volume percent benzene in 2003 gasoline)

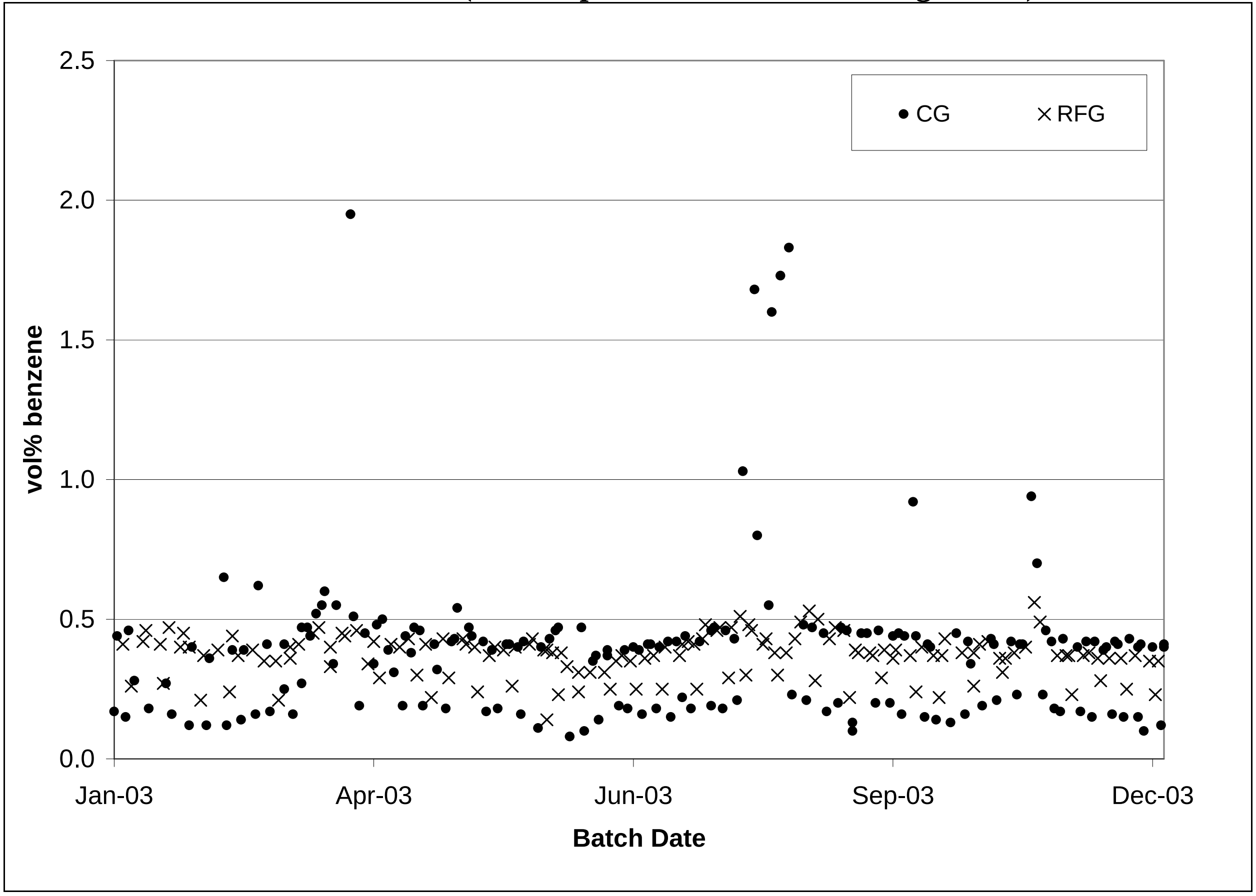


Figure 6.2-5. Premium and Regular Grade Gasoline Batch-by-Batch Benzene Levels for Refinery "D" (volume percent benzene in 2003 gasoline)

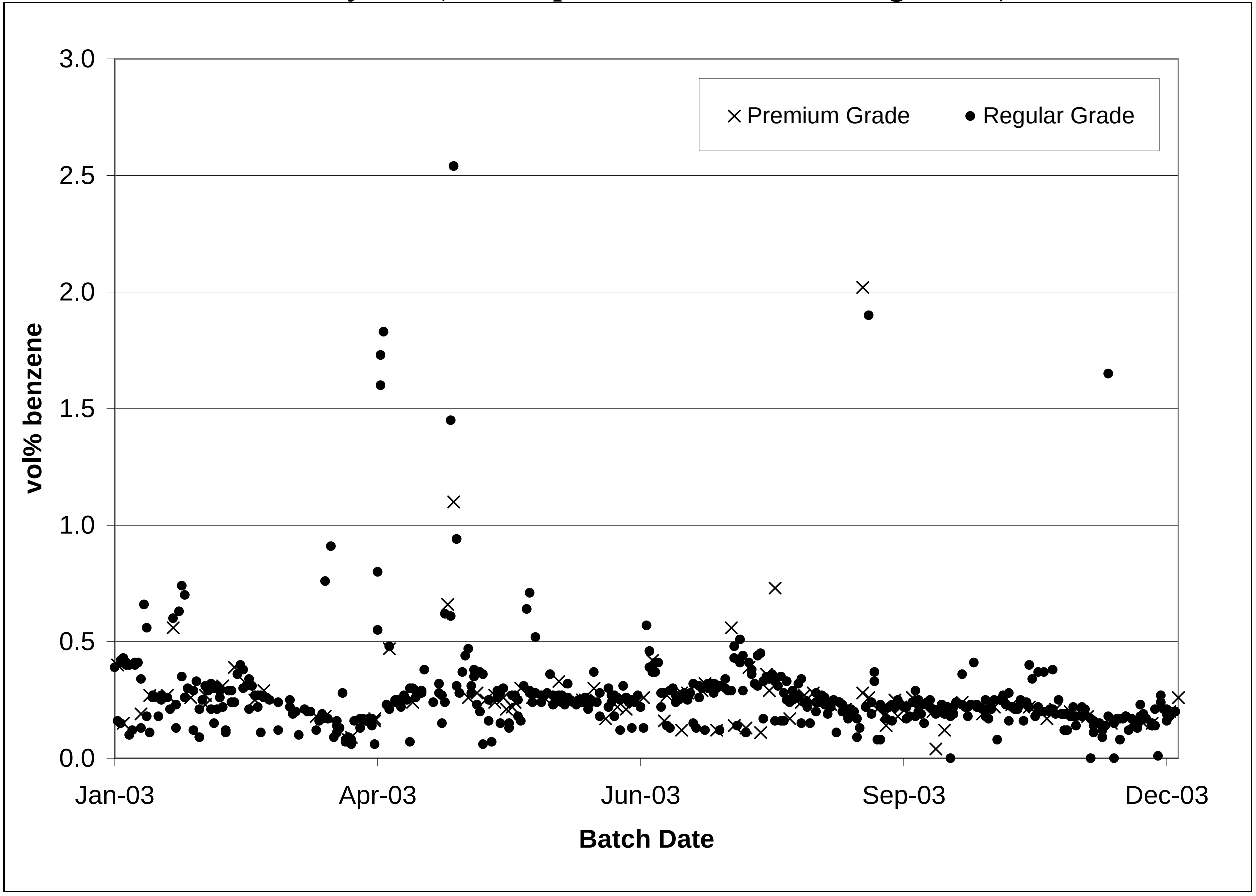


Figure 6.2-6. Premium, Midgrade and Regular Grade Batch-by-Batch Benzene Levels for Refinery "E" (volume percent benzene in 2003 gasoline)

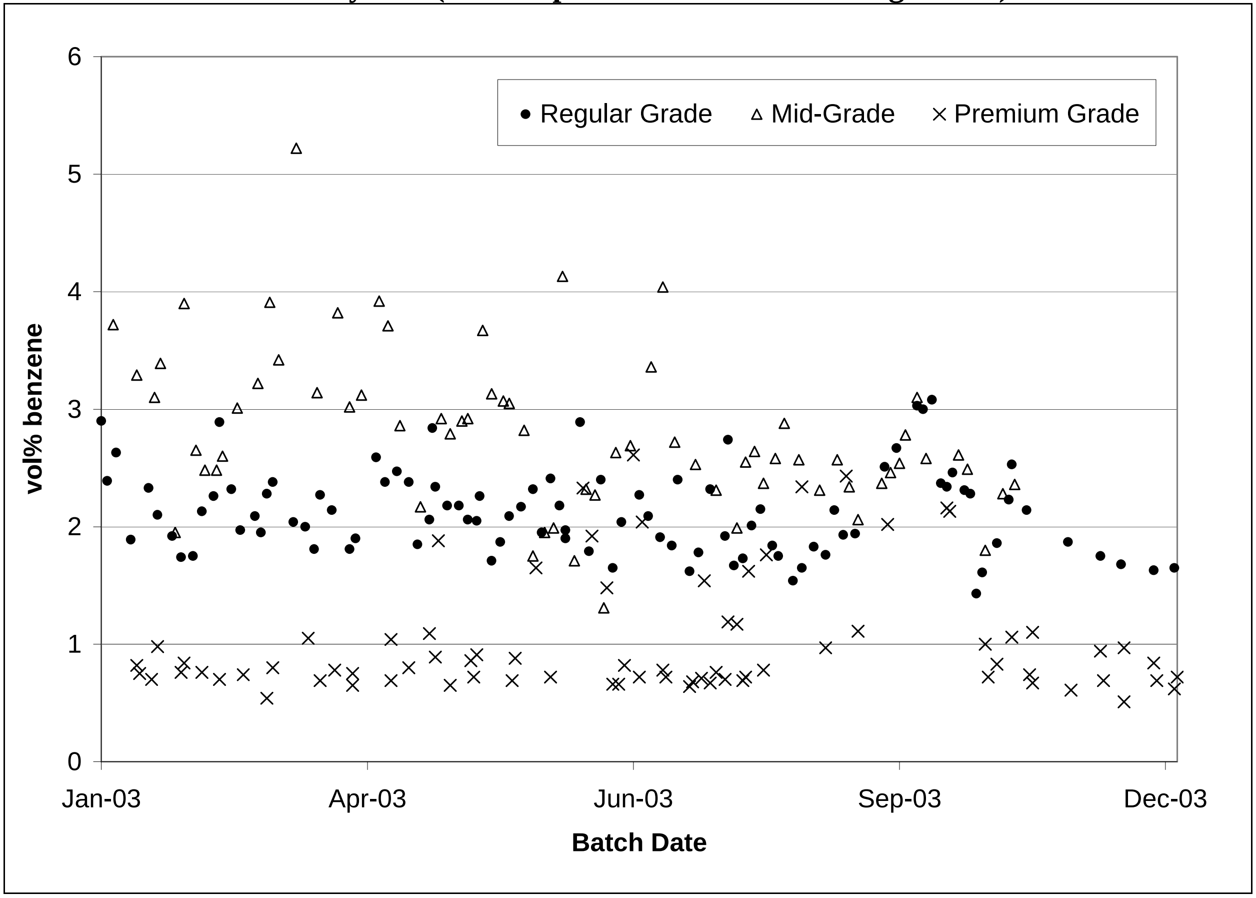
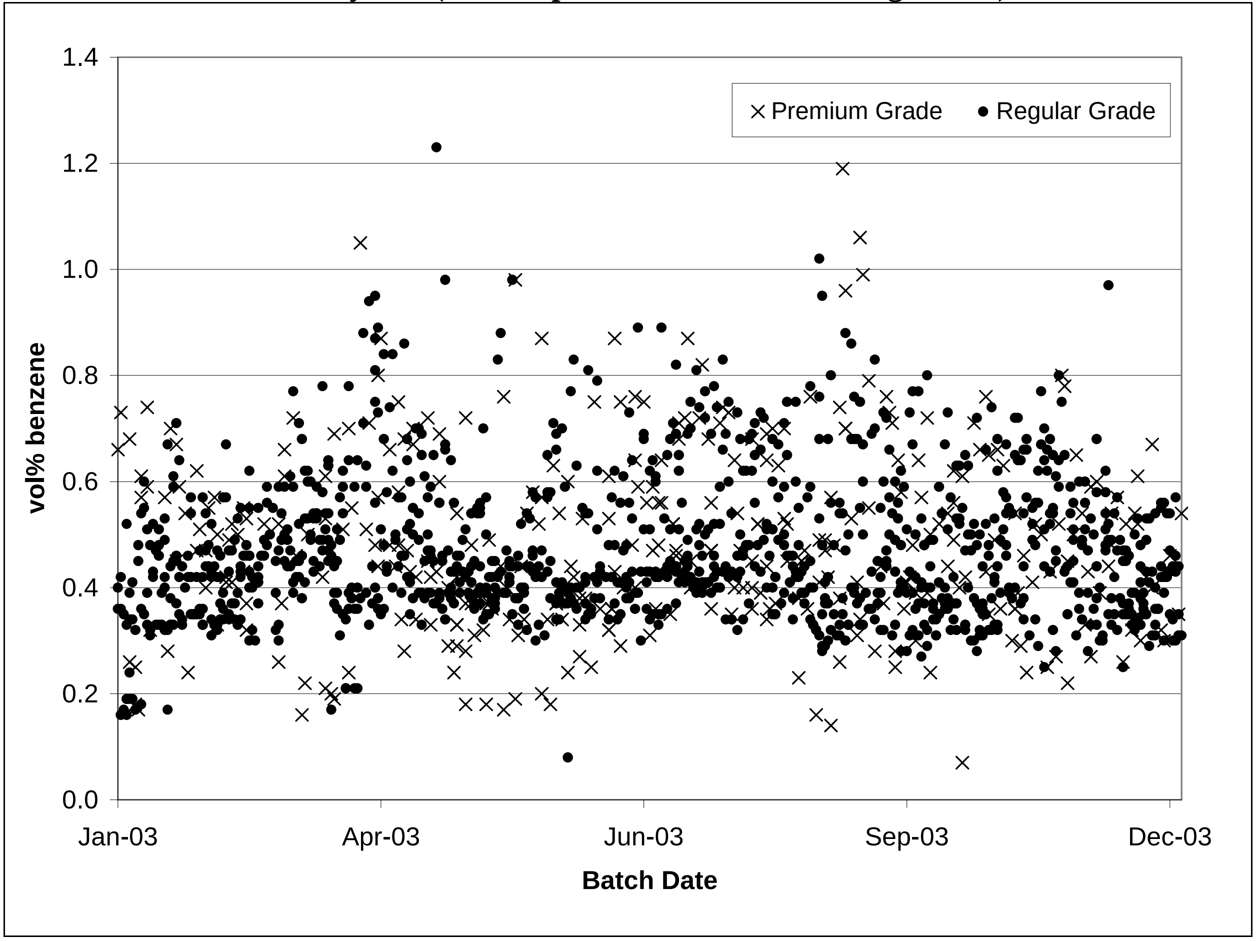


Figure 6.2-7. Premium and Regular Grade Gasoline Batch-by-Batch Benzene Levels for Refinery "F" (volume percent benzene in 2003 gasoline)



Most of the refineries that we studied produced substantially different batch-to-batch benzene levels. As expected, the RFG batches were consistently lower than the CG batches. Two of the RFG producing refineries had a wide variability in benzene levels. The gasoline batch benzene levels for refineries A and B varied by over an order of magnitude. Refinery C's gasoline batch benzene levels varied less than those of refinery A and B. Most all of refinery C's batches were under 0.5 volume percent benzene except for a very few which were much higher and were sold as CG. Also, refinery C's gasoline batches had similar benzene levels for both RFG and CG, a very different trend than refineries A and B.

Of the three CG refineries, refineries labeled E and F have widely varying gasoline batch benzene levels. Refinery E's gasoline batch benzene levels were consistently higher than the rest, ranging from under 1 percent to over 4 percent. Refinery F had no clear trend for either the regular or premium grade of gasoline; the benzene levels varied for both by about an order of magnitude. Refinery E did have an interesting trend for specific refinery grades. Premium grade tended to have lower benzene levels than the other grades, midgrade had the highest benzene levels and regular grade's benzene levels were in between the other two grades. Evaluated all together, the various grades of refinery E also varied by an order of magnitude. The gasoline batch benzene levels for refinery D were consistently under 0.5 volume percent for most of the batches, although a very small fraction of the batches had much higher benzene levels. The lower variability in refinery D's batches was similar for both premium and regular grades of gasoline.

There are several reasons for the variability in refinery gasoline benzene levels across all the refineries. First, crude oil varies greatly in aromatics content. Since benzene is an aromatic compound, its concentration tends to vary consistent with the aromatics content of crude oil. For example Alaskan North Slope (ANS) crude oil contains a high percentage of aromatics. A refiner processing ANS crude oil in their refineries shared with us that their straight run naphtha off the atmospheric crude distillation column contains on the order of 3 volume percent benzene. This is one reason why the gasoline in PADD 5 outside of California is high in benzene. Conversely, refiners with very paraffinic crude oils (low in aromatics) may have benzene levels as low as 0.3 volume percent benzene in their straight run naphtha.

The second reason why benzene levels vary is due to the types of units in their refinery. Different refinery streams contain widely different concentrations of benzene, with reformate typically contributing the most. If a refinery relies on the reformer for virtually all of their octane needs, especially the type which operates at higher pressures and temperatures that tends to produce more benzene, they will likely have a high benzene level in their gasoline. Refineries with a reformer and without an FCC unit are particularly prone to higher benzene levels. However, refineries which can rely on several different units or means for boosting their gasoline octane can usually run their reformers at a lower severity resulting in less benzene in their gasoline pool. Examples of octane-boosting refinery units include the alkylation unit, the isomerization unit, and units which produce oxygenates. Refiners may have these units in their refineries, or in many cases, the gasoline blendstocks produced by these units can be purchased from other refineries or third-party producers. The blending of alkylate, isomerate, and oxygenates into the gasoline pool provides a significant octane contribution which would allow refiners to rely less on the octane from reformate. The variation in gasoline blendstock content across different batches of gasoline is likely the reason for the drastically differing benzene levels between batches of gasoline.

Finally, many refiners may be operating their refinery today to intentionally have less benzene in their gasoline. They could be doing this by operating the refinery with that end in mind such as for the Federal or California RFG programs. Refiners which are currently producing reformulated gasoline are targeting to reduce their gasoline benzene levels to less than 0.95 volume percent for the Federal RFG program or lower for the California RFG program, and are using benzene control technologies to produce gasoline with lower benzene levels. If they are producing conventional gasoline along with the reformulated gasoline, their conventional gasoline is usually lower in benzene as well compared with the conventional gasoline produced by other refineries. Alternatively, some refiners add specific refinery units such as benzene extraction which intentionally removes benzene and concentrates it for the profit it earns. The profit gained by extraction is due to the much higher price that benzene earns on the benzene chemical market compared to the price of gasoline. In most cases, refineries with extraction units are also marketing their low benzene gasoline as RFG.

Table 6.2-2 shows the variations in gasoline benzene levels as produced by refineries in, and as imported into, refining regions called Petroleum Administrative for Defense Districts (PADD) for 2004.[8] The information is presented for both conventional gasoline and reformulated gasoline.

Table 6.2-2. 2004 Benzene Levels by Gasoline Type and by PADD as Supplied in the U.S.

	PADD 1	PADD 2	PADD 3	PADD 4	PADD 5	CA	U.S.
Conventional Gasoline	0.84	1.33	0.94	1.55	1.75	0.62	1.10
Reformulated Gasoline	0.63	0.81	0.54	N/A	N/A	0.61	0.63
Gasoline Average	0.72	1.24	0.87	1.55	1.75	0.62	0.94

Table 6.2-2 shows that benzene levels vary fairly widely across different regions of the country. PADD 1 and 3 benzene levels are lower because the refineries in these regions produce a high percentage of reformulated gasoline for both the Northeast and Gulf Coast. About 60 percent of PADD 1's gasoline is reformulated, while 20 percent of PADD 3's gasoline is reformulated. Reformulated gasoline must meet a 0.95 volume percent average benzene standard, and a 1.3 volume percent cap standard. Another reason why the benzene levels are so low in these two regions is because 35 percent of the refineries in these two regions, are extracting benzene for sale to the petrochemicals market. When refiners are extracting benzene from their gasoline, they extract as much benzene as possible to take maximum advantage of the expensive cost of capital associated with extraction units. This is likely the reason why the CG in PADDs 1 and 3 is low in benzene as well. In other parts of the U.S., where little to no reformulated gasoline is being produced and little extraction exists, the benzene levels are much higher.

6.3 Where Does Gasoline Benzene Come From?

The portion of the crude oil barrel which boils within the gasoline boiling range is called naphtha. There are two principal sources of naphtha. The first principal source of naphtha is straight run naphtha which comes directly off of the crude oil atmospheric tower. The second principal source of naphtha is from the cracking reactions. Each type of naphtha provides a source of benzene to gasoline.

Straight run naphtha which comes directly from the distillation of crude oil contains anywhere from 0.3 to 3 volume percent benzene. While straight run naphtha is in the correct distillation range to be usable as gasoline, its octane value is typically 70 octane numbers which is too low for blending directly into gasoline. Thus, the octane value of this material must be increased to enable it to be sold as gasoline. The primary means for increasing the octane of naphtha is reforming. In the process of increasing the octane of this straight run material, the reformer increases the benzene content of this stream.

There are two primary cracking processes in the refinery. One is called the fluidized catalytic cracking (FCC) unit and the second is called hydrocracking. Other cracking units include cokers and thermal crackers. These various cracked naphthas contain anywhere from 0.5 to 5 volume percent benzene.

The attached table summarizes the range in benzene content and typical percentage of gasoline of the various refinery intermediate streams used to blend up gasoline.

Table 6.3-1. Benzene Content and Typical Gasoline Fraction of Various Gasoline Blendstocks.

Process or Blendstock Name	Benzene Level (volume %)	Typical Volume in Gasoline (volume %)	Estimated Contribution to Gasoline Benzene Content (volume %)
Reformate	3 – 11	30	77
FCC Naphtha	0.5 – 2	36	15
Alkylate	0	12	-
Isomerate	0	4	-
Hydrocrackate	1 – 5	3	4
Butane	0	4	-
Light Straight Run	0.3 – 3	4	2
MTBE/Ethanol	0.05	3	-
Natural Gasoline	0.3 – 3	3	1
Coker Naphtha	3	1	1

Table 6.3-1 shows that the principal contributor of benzene to gasoline is reformate. This is due both to the high benzene content of reformate and the relatively large gasoline fraction that it comprises of the gasoline pool. For this reason, reducing the benzene in reformate is the focus for the various benzene reduction technologies available to refiners.

6.3.1 How Do Reformers work?

Reformers have been the dominant gasoline high octane producing units since they first came into operation in the 1940's.[9] An indication of their importance in refining is that every U.S. refinery except one has a reformer. Prior to the lead phase-down in the early 1980's reformers operated at fairly moderate severities and produced product octane numbers around 85 RON (see the Appendix for a discussion of octane). After the phase-down and eventual phase-out of lead from gasoline, and as the demand for high-octane premium fuel grew, octane numbers for reformate increased to a range from a RON in the low 90s to 104. The reforming process works by rearranging, e.g., "reforming" the chemical structure of straight-chain and cycloparaffin molecules in a given feedstock, to produce a variety of high-octane benzene, substituted aromatic, and isoparaffinic molecules. The reforming process uses a combination of heat, pressure, and catalyst, to produce high octane, high-value finished blendstocks from a low-octane, (about 50 RON in some cases) low-value feedstock.

Reformer Chemical Reactions

The chief means by which reformers increase octane is through the formation of aromatic compounds, including benzene. Aromatic compounds are distinguished from other hydrocarbon compounds by their structure which cannot be described without at least a very rudimentary discussion of organic chemistry. All hydrocarbons can be categorized into two groups, saturated and unsaturated. Saturated compounds have single bonds between carbons with the other bonds to carbon being made with hydrogen. Unsaturated hydrocarbons contain a double bond between one or more carbon atoms thus, there are fewer hydrogen atoms attached to the carbons. Aromatic compounds are unsaturated ring hydrocarbons with six carbons forming the ring. Benzene is the most basic of the aromatic compounds having a structure of C_6H_6. Other aromatic compounds are variants of the benzene ring. Toluene has a methyl group replacing one hydrogen molecule attached to the six carbon ring of benzene. Xylenes have two methyl groups replacing two of the hydrogens of the benzene ring.

Five reactions take place in a reformer: 1) The dehydrogenation (hydrogen removal) of naphthenes; 2) The dehydroisomerization (hydrogen removal and conversation of hydrocarbons from straight chain to branched chain) of alkyl cyclopentanes; 3) The isomerization (conversion of hydrocarbons from straight chain to branched chain) of paraffins and aromatics; 4) The dehydrocyclization (hydrogen removal and conversion of hydrocarbons from straight chain to cyclic) of paraffins; and 5) The hydrocracking (conversion of hydrocarbons to smaller molecules with hydrogen as a reactant) of paraffins and naphthenes. Reactions numbered 1, 2 and 4 form aromatic compounds, while reaction number 3 can alter aromatic types. There are two very important reactions which result in the formation of benzene. Reaction number 1 forms benzene from cyclohexane. Reaction number 2 forms benzene from methyl cyclopentane. Reactions numbered 1, 2, & 4 produce hydrogen as a by-product. Reaction number 3 neither produces nor consumes hydrogen. Reaction number 5 consumes hydrogen.[10],[11]

Reformer Feed and Operations

The feed to the reformer comes from the splitter bottom as we described previously; in some cases, the feed may come directly from the crude tower. Until recently, the reformer feed boiling point range was about 180° F to 370° F. The 180° F initial boiling point temperature sets the cut between the hexanes and pentanes in the crude tower overhead. If the initial boiling point of the feed is lower than 180° F, pentanes that are normally not considered good feed will be pulled into the reformer. The 180° F temperature has varied somewhat according to the crude from which the feed comes and also according to a particular refiner’s economics.

Feed boiling point (FBP) adjustments often have to do with economics. The maximum FBP for reformer feed is about 390° F to 400° F. The catalyst will coke (accumulate carbon) at 370° F, but as the feed FBP’s rise above 370° F the coking rate rises increasingly more rapidly, until at the 390° F to 400° F range, the catalyst cycle length is far to short to even be considered. On the other hand, the reformer feed portion that boils above about 340° F could be cut into kerosene, jet fuel, or diesel. In other words, the price-spread between gasoline and diesel may warrant cutting some of the heavy straight run into diesel. Under other economics, it may pay to run the reformer feed FBP up as high as possible in order to maximize gasoline make. During summer months the demand for gasoline grows while the demand for diesel fuel drops. To stay in balance, a refiner may raise the FBP of the HSR to as high as 390° F. This move would increase the reformer feed volume and at the same time reduce the kerosene and ultimately the diesel make. If the refiner has a jet fuel contract, he may not be able to make such a change. Increasing the initial boiling point can reduce the benzene make in the reformer. This is covered in the next section discussing the technologies for reducing gasoline benzene levels.

Different crude oil types affect the quality and volume of feed to the reformer. Light, sweet crude, such as that produced in southwestern Wyoming, is reported to have had as much as 35% to 45% by volume of heavy straight run (HSR) naphtha that is high naphthenes and aromatics and consequently a fairly rich feed. By contrast, there are heavy asphaltic crudes produced from off the California coast with almost no HSR.[A] Reformer feed often includes intermediate streams from hydrocrackers and cokers. Coker naphtha ordinarily must be hydrotreated at conditions well beyond the severity of the common reformer hydrotreater before it is fed to a reformer. HSR from a hydrocracker is usually very clean with regard to most critical contaminants, but as a rule must be reformed because it has a very low octane. Occasionally a refiner must consider reforming a poorer feed (e.g., feed from paraffinic crude). In such cases, the refiner may need to load two or three different catalysts into his reactors in stacked-beds in order to provide for all the necessary reactions. Paraffinic feedstocks are ordinarily difficult to reform.

A reformer consists of essentially three separate components: the naphtha hydrotreater section, the reformer section, and the product stabilization section. The reformer section contains a catalyst which is usually bi-metallic; platinum and rhenium are two that are often used. Consequently, the catalyst is quite expensive.

The feed to the reformer is hydrotreated to reduce contaminants, such as sulfur, nitrogen, and arsenic. Arsenic poisons the catalyst, from which the catalyst activity cannot be recovered; sulfur and nitrogen deactivate the catalyst and to some degree activity can be regained through regeneration. The process conditions of the hydrotreater are ordinarily not severe; using common hydrotreating catalysts, temperatures around 600° F and pressures of around 400 psi.

The hydrotreater reactor effluent is fed to a stabilizer/splitter to remove light products and gaseous contaminants, such as hydrogen sulfide formed in the hydrotreating process. The stabilizer bottoms are heated against reformer reactor effluent in feed/effluent exchangers, and subsequently fed to the first pass of the reformer feed furnace. There are typically four reactors IA & IB, II, and III, in series. The feed is heated to a feed temperature of about 930° F in the first pass and fed down-flow to reactors IA & IB, where several endothermic reactions take place; the reactor effluent is then fed to the second furnace pass and reheated to the same reactor inlet temperature as for the first set of reactors. It is subsequently fed to reactor II. The effluent is heated once again, and fed to the third furnace to be reheated and fed to the third reactor.

Effluent from the third reactor is cooled against first-pass furnace feed in the

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[A] Internal document.

feed/effluent exchangers and fed to the high pressure separator. One of the principal byproducts of the reforming reactions is hydrogen. Volumes in excess of 1000 scf per barrel of feed have been reported. The high pressure separator is used to separate the hydrogen from the cooled reactor effluent liquid. Part of the hydrogen is recycled back to the reformer; mole ratios of five moles of hydrogen to one mole of feed are usually required to suppress catalyst coking. Some of the excess hydrogen is fed to the naphtha hydrotreater and the balance is available for other units in the refinery that may need it; e.g., cat feed hydrotreaters or distillate hydrotreaters are examples. The liquid reactor effluent is reheated and fed to a stabilizer to control the Reid Vapor Pressure (RVP) of the final reformate. The stabilizer is ordinarily a total-reflux unit, the pressure of which is controlled by a gas controller on the tower overhead drum. Light hydrocarbons in the off-gas, released to maintain pressure control, are sent to either the gas plant or to fuel gas. The light hydrocarbons in the off-gas includes methane, ethane, propane and butanes in small volumes.

Different reformer operating conditions result in the production of different qualities of reformate, different hydrogen production levels and can change the reformer cycle length (time between catalyst replacements or regeneration). For example, low reactor pressure increases yield and octane but increases the production of coke. Increased hydrogen partial pressure, that is the ratio of hydrogen to hydrocarbon, suppresses coke formation, it promotes hydrogen yield and product octane, but it also promotes hydrocracking. Reducing the space-velocity, that is the rate at which the reactor volume of the hydrocarbon changes per unit time, favors aromatic production, but also promotes cracking. Higher activity catalysts increase cycle lengths and usually yields, but sometimes they are more expensive.[12]

Certain tools are available to refiners to tailor the reforming process to their needs. There are several proprietary processes, including catalysts, from which refiners can choose to treat the specific qualities of their heavy naphtha. In most cases, a few laboratory tests allow vendors to estimate, with reasonable accuracy, how well their processes can reform a given feedstock. However, in some cases, vendors insist on running pilot plant tests before they will guarantee their process's performance. A common lab test, known as a PONA, is used to determine paraffin, olefin, aromatic, and naphthene content; API gravity, sulfur, nitrogen, and metals are also important. From these test results, most vendors have computer-based process simulators that, for a given RON, can estimate the finished product and hydrogen yield, off-gas composition at several different Reid Vapor Pressures (RVP), reformate octanes, and catalyst cycle lengths, if a unit already exists with suitable reactors and compressors in place. In nearly all cases, vendors supply the above test results for a range of RON's. For example, the lowest RON a refiner may decide to produce might be 85 RON. A vendor could provide process design services to determine the cycle length requested by that refiner for a set of specified equipment design criteria. This, of course, is based on, among other criteria, the type of reformer.

Types of Reformers

There are two types of reformers in use today, the semi-regenerative reformer, and the continuous reformer. The predominant operating differences between the two are the pressure and the means for regenerating the catalyst.

The semi-regenerative reformer gets its name from the need to periodically shut down the unit to regenerate and reactivate the catalyst. The catalyst, usually carrying a specific weight percent platinum and rhenium on a common base material, is loaded in a series of down-flow reactors. The process pressure is higher in this type of reformer, at around 200 psi to 350 psi. Reactor inlet temperatures begin at around 930° F. This start-of-run inlet temperature may vary from process to process, as will the final end-of-run temperature. A delta temperature from start to end of about 40° F is common. Over time, as a result of some of the reforming/hydrocracking reactions, coke builds up on the surface and the catalyst deactivates. As coke is gradually deposited on the catalyst, the reforming reactions slow down somewhat and the reformate or product octane begins to drop a little below the desired set point. To compensate, the feed temperature is raised until the desired octane is reached again. These steps are repeated periodically over the cycle length of the particular catalyst. Contaminants such as sulfur can speed up the deactivation, as can other problems. When the maximum allowable feed temperature is reached, the refiner must shut the unit down and regenerate the catalyst.

Regeneration may take place “in situ” or the catalyst may be removed from the unit and sent to a regeneration contractor for regeneration. Briefly, regeneration involves carefully burning the coke off of the catalyst surface, and then chemically treating the clean catalyst to reactivate it. Regeneration is a fairly delicate operation, in that, for example, if too much oxygen is allowed into the process, the temperature may get high enough to damage the catalyst and prevent it from being reused. Regeneration, whether in situ or away from the refinery, is generally done the same way. The one significant difference is that the catalyst is not reduced with hydrogen directly following the burn phase at the off site plant. If carried out in situ, the process can go forward without interruption. Some refiners insist on burning in situ. Regardless, the catalyst still must periodically be dumped, screened to remove fines, and reloaded. The burn phase also usually takes place before the unit is shutdown for other maintenance. Startup following a regeneration period also requires patience and may take several days before a specified product octane can be reached. An important step is to dry out the catalyst before attempting to raise the reactor inlet temperatures to achieve the desired octane. As the catalyst “life” shortens, the start-of-run temperature will gradually increase, so that the usual delta T will gradually become narrower and eventually the catalyst cycle length becomes too short to be economical.

This regeneration process can be burdensome on refiners. For this reason, refiners choose to operate this unit at a higher operating pressure to reduce the frequency of regeneration cycles. The higher operating pressure reduces the formation of coke on the catalyst which extends the cycles between regeneration. Higher pressure also reduces hydrogen make and increases the cracking of heavier aromatics to benzene.

The second type of reformer uses continuous catalyst regeneration, wherein the catalyst is continuously withdrawn from the process, the coke burned off, the catalyst is reduced, and fed back into the process without shutting the unit down for long operating periods. In some ways, the process is similar to the FCC. The reactors are stacked rather than lined up separately in series so that the catalyst can flow under gravity. From the bottom of the reactor stack, the 'spent' catalyst is 'lifted' by nitrogen to the top of the regenerator stack. In the regenerator, the above mentioned “regeneration” steps of coke burning, chlorination and drying are done in different sections, separated by a system of valves, screens, and other equipment. From the bottom of the regenerator stack, catalyst is lifted by hydrogen to the top of the reactor stack, in a special area called the reduction zone, where once heated is brought into contact with hydrogen, which reduces (changes the valence) the catalyst surface to restore its activity. A continuous regeneration process can be maintained without unit shutdown for run lengths of about 4 to 5 years.

The continuous reformer's regeneration process is much more streamlined than the semi-regenerative reformer. For this reason, the continuous reformers are operated at a considerably lower pressure, from as low as 90 to 120 psi, than the semi-regen process and the hydrogen make is considerably higher. For the same reason, the severity of continuous reformers can be higher and product octane in the range of 104 RON is not uncommon. The lower pressure of the continuous reformer also causes less benzene make from the cracking of heavy aromatic compounds.

6.3.2 How Can Benzene Levels be Reduced in Gasoline?

There are several ways available to refiners to reduce the benzene in their finished gasoline.[B] One way is to pre-fractionate the feed, and prevent the benzene precursors from entering the reformer. The other way is to post-fractionate reformate into light and heavy cuts, and either saturate the benzene in the light cut or extract it for sale in the chemical feed market.

6.3.2.1 Pre-Fractionation to Reroute Benzene Precursors

The heavy straight run naphtha can be cut differently to reduce gasoline benzene levels. As discussed earlier, the heavy straight run naphtha is cut to prevent the C5s from being sent to the reformer. This means that most of the C6s are sent to the reformer along with the C7s, C8s and sometimes the C9s. The cut-point could be changed from between the C_5's and C_6's to between the C_6's and C_7's; in so doing the benzene precursors are also cut out of the reformer. To assure that most of the C_6's are cut out of the reformer feed, the initial boiling point of the feed would need to be raised from 180° F to around 215° F to 220° F by changing the draw temperatures on the units. The cut adjustments can be made in the pre-flash column (a simple unit before the crude tower which removes the lightest compounds before entering the crude tower), the crude tower overhead, or the naphtha splitter. These various distillation columns are usually designed to make a fairly imprecise cut between the C6s and C7s, which would also cut some C_7's out of the reformer feed. Cutting some of the C7s out of the heavy straight run going to the reformer would, of course, reduce the production of C7 aromatics (toluene), and further reduce the make of hydrogen. This would be costly to the refiner, so the refiner pursuing this strategy would be expected to increase the ability to make a sharper cut between the C6s and

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[B] The benzene reduction technologies are discussed here in the context of the feasibility for reducing the benzene levels of gasoline to meet a gasoline benzene content standard. However, this section could also substitute for a feasibility discussion of complying with a total air toxics standard since benzene control would be the means refiners would choose for complying with such a standard.

C7s. They would accomplish this by adding a naphtha splitter column, or adding height or adding trays to their existing naphtha splitter. In many cases, the refinery would replace the existing naphtha splitter with a new taller tower. The naphtha splitter in some refineries would already be outfitted to make such a cut.

Refiners have recently routed a gasoline substream differently that will affect the content of their heavy straight run naphtha and ability to reduce their benzene levels. Many U.S. refiners, especially in PADDs 4 and 5, and to a lesser extent in PADDs 2 and 3, blend some light gasoline-like material, which is a by-product of natural gas wells, into their gasoline. Previously, natural gasoline was almost exclusively blended directly into the gasoline pool by each refinery in each PADD where natural gasoline is a feedstock for refineries. The benzene concentration in this stream is estimated to be 1.3 volume percent which, because it is not high, would be costly to treat by itself for reducing its benzene content. However, we believe that refiners will already be routing natural gasoline differently in their refinery for other reasons. To comply with the 30 ppm Tier 2 sulfur standard, refiners may be treating this stream in a way to reduce its sulfur. Because natural gasoline is fairly low in octane, most refiners will be blending it into crude oil where it would be distilled so that the heavy portion of it will go to the straight run hydrotreater and then sent to the reformer. This will lower the sulfur in the heavy portion of the natural gasoline and improve its octane. Also, as the naphtha streams are routed to reduce benzene levels, the natural gasoline benzene will be treated along with the rest of naturally occurring benzene.

A few other concerns would need to be addressed as a result of removing the benzene precursors. Benzene has a fairly high octane blending value; well in excess of 100 RON. Simple arithmetic demonstrates that for each one-percent benzene removed, the reformate octane is reduced by at least one number. Most refiners can’t tolerate this, particularly if other high octane blendstocks are not readily available. An obvious means to recover the lost octane would be to increase reformer severity; while this seems reasonable, there are generally additional consequences. Increased severity will likely convert more of the C_7’s, C_8’s, and C_9’s into compounds that could finally end up as benzene. For example, methyheptane can also be converted into benzene, through paraffin dehydrocyclizaion (the methylated paraffin is converted into a cycloparaffin and dehydrogenated) and demethylization (the methyl group is removed) the possibility of which is more likely in semi-regen reformers. Similar reactions can be predicted for other C_8 and C_9 alkanes, all of which reduces the net effect of the original reduction. Even so, the benzene content will be lower than prior to pre-fractionation. Addressing the octane loss due to benzene precursor rerouting can be addressed through other means described below in Section 6.6. Other potential problems are that hydrogen production will be reduced and that the increased severity naturally shortens the catalyst cycle length; this is particularly important for semi-regeneration units, but also affects the continuous regeneration units.

Cutting the benzene precursors out of the reformer feed would definitely reduce the benzene content in gasoline, but it would not completely eliminate it. As discussed above, some of the benzene in reformate is formed by the cracking of heavy aromatics, thus some benzene would remain in reformate. Also the naturally occurring benzene present with the benzene precursors would still be present in the rerouted C6 stream.

6.3.2.2 Benzene Saturation via Isomerization

The rerouted benzene precursor stream contains the naturally occurring benzene from crude oil. An existing isomerization unit could be used to saturate this naturally occurring benzene in the rerouted C6 stream. The role of the isomerization unit is to convert straight chain compounds to branched chain compounds using a catalyst and in the presence of hydrogen, which increases the octane of the treated stream. The isomerization reactor saturates benzene using the hydrogen present in the reactor for the isomerization reactions. However, isomerate has a fairly high RVP (in the range of 13 psi to 15 psi) which could make it difficult for the refiner to add more isomerization capacity in that refinery while still meeting the RVP requirement that applies to its gasoline. As such, a safe assumption could be made that the refinery would be capable to use the existing isomerization unit up to the listed capacity of the unit. The refiner presumably sized the isomerization unit to be able to use that capacity in the first place. Treating the benzene in the rerouted benzene precursor stream could be accomplished by giving a higher priority to treating the rerouted C6 stream in the isomerization unit. If the isomerization unit's capacity is reached before it can treat all the C5 and C6s, then the original C5 stream could be backed out until all the C6s are treated. Even so, adding an isomerization unit may be possible, which also may require the refiner to add some RVP reduction capacity elsewhere in the refinery to compensate for increased isomerate.

A potential drawback to isomerization is that as benzene is saturated, it produces heat (exothermic reaction). Isomerization reactions are all equilibrium reactions. As such, as the temperature in the reactor increases, it changes the equilibrium and shifts the isomerization reactions back, which could lower the product octane. The licenser of the Penex isomerization process has provided a recommendation that the isomerization unit be limited to 6 volume percent benzene in the feed for this reason. The refinery could still treat this C6 stream using this means, it would, however, need an additional reactor installed before the isomerization reactor solely designed for saturating the benzene in this stream. The combined benzene saturation reactor with the isomerization reactor is called a Penex Plus unit.

Another potential drawback to the benzene saturation option is that it requires at least three moles of hydrogen (as H_2) per mole of benzene saturated; this of course would require additional hydrogen production. Providing additional hydrogen would add additional operating cost to supply this hydrogen and could require capital investment.

The naphtha splitter overhead (typically light straight run gasoline, LSR, most of which is C_5's with some C_6's) is routinely fed to an isomerization unit (otherwise it is blended directly into gasoline). Most refiners run the feed through a deisopentanizer to remove isopentane, since it won't need to be treated (it is already a branched chain compound and would only use up existing capacity). The deisopentanizer bottoms are mixed with hydrogen, which helps minimize coke formation on the catalyst; hydrogen is neither generated nor consumed in the isomerization reactions.

The reactor effluent, known as unstabilized isomerate, is fed to a stabilizer where the vapor pressure is controlled. Any light gas produced by minor cracking reactions is typically scrubbed and blended into the refinery fuel gas system. Isomerate, at this point, would probably have a clear octane number 10 points higher than the LSR feed; perhaps 80 to 82 RON.

The overall severity of isomerization process conditions is relative low; the temperature, and the total and hydrogen partial pressures are all relatively low, compared with, say, reforming or some other refinery processes. Isomerization is a vapor-phase process which uses hydrogen to suppress dehydrogenation and coking. The catalyst is ordinarily an alumina type onto which organic chlorides have been deposited. In that the chlorides are sensitive to moisture, the feed must be very dry. Some organic chloride is added to the feed in order to maintain catalyst activity.

Increasing the severity of the isomerization unit will likely increase the product octane but may likewise produce more light ends. Yields are highly dependent on feedstock characteristics, which naturally are closely related to the characteristics of the original crude; paraffinicity, aromaticity, etc. Poor feed quality will usually yield net liquid percent recovered in the mid-80's or less, while good feed quality may yield net liquid percent recovered in the mid- to upper 90's (the rest being cracked to gaseous hydrocarbons). The key control variable is probably the process temperature, in that raising it increases severity and promotes hydrocracking side reactions. Raising the process pressure may increase catalyst life but will also likely promote hydrocracking reactions, which reduce the net liquid yield. While increased hydrogen partial pressure may extend catalyst life, it nevertheless promotes hydrocracking side-reactions that reduce net liquid yield. Run lengths can be extended using as low temperature as possible with moderate hydrogen partial pressure and reduced space velocity. This may or may not seem obvious, but extending run lengths this way has drawbacks as far as product quality and net yield of octane-barrels is concerned.[13]

6.3.2.3 Reformate Post-Fractionation with Benzene Saturation

Another method for reducing reformate benzene is to post-fractionate reformate into heavy and light cuts; the light, $C_{6,}$ cut would contain the reformate benzene which could be treated to remove benzene, while the C7+ stream would be blended directly into gasoline. An important question associated with this methodology is the efficiency that the benzene could be removed from the rest of the reformate, preserving the C7s. Based on vendor information, a typical reformate splitter would be designed to capture about 96 percent of the benzene while only capturing 1 percent of the toluene in the C6 stream. The refinery would design this unit as appropriate for the refinery considering their particular economics and refinery situation. The C6 stream would then be sent to a benzene saturation unit to saturate the benzene into cyclohexane. There are two technologies for doing this. One is named Bensat and is licensed by UOP. The other is named CDHYDRO and is licensed by CDTech,

Bensat

UOP has put their Bensat™ process forward as a way to reduce the benzene content of gasoline. The process was originally developed to reduce to below six percent the benzene concentration in the feedstock to their Penex™ isomerization unit (the Penex unit is capable of saturating the rest). The process saturates the benzene converting it into cyclohexane, which can then be fed to the Penex™ unit.

Although the process was originally designed for Penex™ feed, the vendor has modified it to be used to saturate the benzene in a light reformate cut. UOP reported in a bulletin published on one of their websites[14] that a Bensat™ unit can be designed to handle from 5% to 30% benzene in the feed. Although not stated, it was implied that the benzene content could be reduced to below six percent. We have received personal communications indicating that while the benzene content of light reformate will normally vary, an average range would be about 15% to18%.

The process is carried out in a standalone reactor and according to UOP the process uses a commercially proven noble metal catalyst that is benzene-selective with no side reactions. Since there is essentially no cracking there is also essentially no coke lay-down on the catalyst to cause deactivation. Sulfur in the feed can deactivate the catalyst, but activity can be restored by removing the sulfur. Of course, light reformate would be very low in sulfur; other feedstocks may need to be hydrotreated.

During start-up, hydrogen is mixed with the feed and pumped through feed/effluent exchangers and a start-up preheater. Once the unit is up and running, the heat generated by the process provides heat to the feed via the feed/effluent exchangers. Benzene saturation requires three moles of H_2 per mole of benzene, so makeup hydrogen is continually added to the reactor feed. The reactor effluent is routed to a stabilizer to remove light ends. As noted previously, some octane loss due to benzene saturation can be regained by feeding the resulting cyclohexane to an isomerization unit.[15]

CDHYDRO

Catalytic Distillation Technologies (CDTECH®) has two processes for reducing the benzene content of gasoline by converting it into cyclohexane. Both are referred to as CDHYDRO™ technologies, but one is actually specified for the selective hydrogenation of benzene in the entire reformate to cyclohexane in a catalytic distillation column, while the other is advertised to hydrogenate a benzene-only stream to cyclohexane in a catalytic distillation column.

They advertise both processes online; we note that if a refiner finds it necessary to extract the benzene from his reformate to saturate it, the process advertised to convert benzene to cyclohexane may be of interest[16]. However, we will focus on the process they put forward for reducing the benzene content of reformate, in that they claim it is possible to do without fractionating the reformate prior to the saturation step[17]. This has a clear advantage by combining a splitting column with a benzene saturation reactor which would be expected to reduce the capital cost for this technology.

According to CDTECH® in excess of 90% of the benzene in reformate can be hydrated and the treated C_6's removed from the final product, all in a single catalytic distillation tower; the tower they recommend is a benzene-toluene splitter, either refitted or new. The feed appears to be a mixture of low pressure hydrogen and reformate. The feed is sent to the column and the benzene saturation reaction occurs in the reactor. The overhead stream is condensed, cooled, and collected in a reflux or overhead accumulator drum. The accumulator off gas, mainly unreacted hydrogen, is recycled to feed. There also appears to be an off-gas purge stream. The reflux drum liquid is said to be primarily treated C_6's. Part of the overhead is used for tower reflux while the balance is pumped back into the C_7+ treated reformate tower bottoms. Since this reaction process takes place in a conventionally designed C6/C7 splitter column, this column could presumably be designed to treat the same benzene/ toluene split that a Bensat unit would be designed for.

6.3.2.4 Benzene Extraction

The extraction of benzene from reformate for use as a petrochemical feed can be a useful way to remove the benzene from the gasoline pool. This method is more attractive when the refinery is located near to petrochemical complexes which use benzene as a feedstock.

Benzene extraction involves three different steps. The first step is to separate a C6 stream from the rest of reformate using a reformate splitter. This C6, benzene-rich stream is sent to a liquid/liquid extraction unit where the benzene and any other aromatic compounds, such as any toluene which may captured along with the benzene in the reformate, are extracted from the rest of the hydrocarbons. This aromatic stream is then sent to a very robust distillation process for concentrating the benzene for sale into the chemicals market.

The reformate would be split to separate the C6s from the rest of reformate. This cut would likely be made similar to the splitter unit used for the benzene saturation unit, although since the toluene would only be separated and not be chemically treated, refiners would have more leeway to capture more of the benzene in this case with less effect on the rest of the stream then with benzene saturation.

After separation, the C_6 light reformate cut, containing a fairly complex mixture of paraffins, isoparaffin, and benzene, would be fed to an extraction unit. This type of operation, commonly known as liquid-liquid extraction is one variation on a whole host of extraction processes used in the petrochemical industry.

The essence of the benzene extraction process is to bring the light-reformate cut into intimate contact with a slightly miscible to completely immiscible solvent, into which the benzene may be selectively transferred (absorbed or dissolved) from the light-reformate. Liquid-liquid extraction is applied by several industries, including the pharmaceutical and perfume businesses, in a variety of vessels, such as stirred mixer-settlers, high-speed rotary centrifugal extractors, and various columns, each of which is designed for a particular type of extraction. There are several column types from which an engineer could choose, such as static or agitated, along with spray, sieve plate, and packed columns. For the purposes of this discussion, we will be referring to a static column.

For our general case, the extraction column has essentially two inlet streams and two outlet streams. One inlet stream, fed at the top of the column is the light-reformate from which the benzene aromatic components are to be extracted. The other inlet stream is the lean solvent (solvent with no aromatics in solution) which will extract the aromatics from the light-reformate. The solvent flows upward, while the light-reformate flows downward, during which time the two streams come into intimate contact on the surface of the tower internals.

As designed, the solvent, containing the extracted aromatics, leaves the top of the column as the extract or “aromatic-rich” stream. The light-reformate leaves the column bottom with only a small residual volume of aromatics remaining and may be referred to as the raffinate. It will consist mostly of paraffins and isoparaffins that can be sent to the gasoline blending pool.

The aromatic-rich stream is then separated from the solvent, after which the solvent is recycled back to the extractor for reuse. The benzene, subsequently separated from the other aromatics, can be sold into the chemicals market. The benzene-free aromatics, consisting of toluene and in some cases xylene, which have high octane blending values, can be sent to gasoline blending or to the chemicals market as well.

Despite only being regulated to reduce the benzene content of gasoline, the refiner may choose to also extract toluene and xylenes. Taking such a step would cause a much larger impact on the octane level of the refinery’s gasoline and this octane loss would have to be recovered. This may be possible using the octane recovery technologies summarized below. This may improve the economics for reducing benzene levels, particularly because xylenes are valued more than benzene. Extracting the C6 – C8 aromatics may allow omitting the reformate splitter since refineries omitting the heavy straight run naphtha from the reformer feed (omitting the C9+ fraction) could send all the reformate to the extraction unit. The extraction unit would have to be designed to be much larger and of course the downstream distillation unit would have to be much larger as well.

There are three proprietary extraction processes available. They are the Udex, the Sulfolane, and the Carom processes. The di-, tri-, and tetra-ethylene glycol isomers are used as solvents.

Extractive distillation provides what appears to be a very reasonable alternative to full liquid-liquid aromatics extraction. According to one source, “Liquid-liquid extraction (LLE) was for many years the primary choice for aromatics recovery, because the solvents available during that time were not suitable for separating a wide-boiling range feedstock in the extractive distillation mode of operation. To do so required making narrow boiling feed fractions sent to separate extractive distillation units.” “However, solvent technology has improved, and the availability of new solvent blends makes it feasible and more profitable to employ extractive distillation to aromatics separation.”[18]

In short, when certain mixtures cannot be easily separated by ordinary distillation, either because of low relative volatility or the presence of a homogeneous azeotrope, it may be possible to effect a separation by the use of extractive distillation. According to Perry’s “In extractive distillation, the agent or ‘solvent’ is considerably less volatile than the regular feed components and is added near the top of the column. Because of its low volatility, the agent behaves as a typical heavier-than-heavy key component and is also readily separated from the product streams. A typical extractive distillation might be a unit for separating benzene and cyclohexane using phenol as the separating agent. “Benzene and cyclohexane have nearly identical boiling points and form a homogeneous azeotrope containing about 45 wt.% cyclohexane. However, with the phenol present, the cyclohexane volatility is nearly twice that of benzene.”[19] The benzene/cyclohexane mixture is fed at or near the center of the distillation column, while the phenol separating agent is fed into the tower a few trays below the top. The phenol remains in the liquid phase and flow downward over the trays and out the bottom. The overhead vapor is essentially pure cyclohexane. The bottom phenol/benzene stream is sent to a second tower for separation. Another source suggested using aniline for the benzene/cyclohexane separating agent.[20] A full-boiling range light reformate may be more complicated, but the principles are essentially the same. It appears that the choice of separating agent is critical. As demonstrated by the benzene/cyclohexane example we just described, using two different solvents, it should be clear that there will likely be more than one choice available for any given system. An economic argument for using extractive distillation as opposed to liquid-liquid extraction is that fewer pieces of processing equipment are usually required.

We identified another possible means to remove benzene from reformate which also creates a concentrated benzene stream for sale to the petrochemical market. This process uses steam extraction instead of extractive distillation as the primary unit operation. The first step in this process is similar to conventional benzene extraction – the reformate is distilled to concentrate benzene in a six carbon hydrocarbon stream. However, instead of sending this material to an extraction facility, this six carbon hydrocarbon stream is fed to a stream cracker. The very stable benzene is not cracked in the steam cracker, while other hydrocarbons in that same stream are nearly completely cracked to light olefins, including ethylene, propylene, butylene and butadiene. After the steam cracker, the relative heavy benzene molecules are easily separated from the much lighter cracked olefins using simple distillation. This process creates a benzene stream which is 98% concentrated, as opposed to benzene extraction which creates a benzene stream that is nearly 100% pure. However, many petrochemical manufacturers are satisfied with benzene that is 98% pure. The potential advantage for this process is that the rich benzene stream is created at lower cost, requiring less capital and consuming less in utilities. There has not been any long term commercial demonstrations of this technology, however, six carbon, benzene-rich reformate has temporarily been sent to a steam cracker and it has been demonstrated in practice over the short term.[21] [22]

6.3.2.5 Low-Pressure Reformer Operation

Lowering the pressure at which the reformer operates is another means of controlling the benzene content. Lower pressure operation would provide some benzene reduction by reducing the benzene formed from the hydrodealkylation (cracking) of heavier aromatics to benzene. Beyond retarding the hydrodealkylation reaction, low pressure is an effective means of increasing hydrogen and liquid yields, but can hurt catalyst cycle lengths. Lowering process pressure in a semi-regen unit is reported to provide from 50% to 70% benefits of a continuous catalyst regeneration reformer.

However, it is somewhat difficult to lower the pressure of an early-design semi-regen unit below a certain level. The early generations of reformers were designed for pressures in the range of 350 psi (as an example). Higher pressure usually allowed design engineers to specify small diameter pipe. Lowering the pressure changes the hydraulics, restricts flow, and the reformer simply won't operate. The recycle compressors would also likely need to be changed in order to reduce the pressure. In short, it is not a simple fix to change a unit from high-pressure to low-pressure. Continuous regen reformers already operate at pressures considerably lower than semi-regen units, in the range of say, 90 psi and therefore have little room for improvement.

6.3.2.6 Pre-fractionation Combined with Low-Pressure Reformer Operation

Pre-fractionation of benzene precursors combined with low pressure reformer operation (< 100 psi) will usually produce less than 1 vol% benzene in the reformate regardless of the feed composition. If octane can be obtained through other means, this appears to be a useful approach.

6.4 Experience Using Benzene Control Technologies

All these benzene reduction technologies and octane generating technologies described above have been demonstrated in refineries in the U.S. and abroad. Each of these technologies have been used for compliance purposes for the federal Reformulated Gasoline program, which requires that benzene levels be reduced to an average of 0.95 volume percent or lower starting in 1995. The two primary means used by refiners to produce low benzene gasoline for the RFG program is routing benzene precursors around the reformer and benzene extraction. Benzene saturation is another technology used to achieve benzene reductions for the reformulated gasoline program on a limited basis.

According to the Oil and Gas Journal's worldwide refining capacity report for 2003, there are 27 refineries in the U.S. with extraction units. Those refineries which chose extraction often reduced their benzene to levels well below 0.95 volume percent because the value of benzene as a chemical feedstock is high. The reformulated gasoline program also caused the installation of a couple of benzene saturation units. There are two benzene saturation units in the Midwest installed in refineries there to produce RFG for the markets there. California has its own reformulated gasoline program which also put into place a stringent benzene standard for the gasoline sold there. The Oil and Gas Journal's Worldwide Refining Report shows that four California refineries have benzene saturation units. If we assume that those refineries producing RFG that do not have extraction or saturation units are routing their precursors around their reformer, then there are 28 refineries using benzene precursor rerouting as their means to reduce benzene levels. Personal conversations with several refiners have revealed that some of the refineries which are routing the benzene precursors around the reformer are sending that rerouted stream to their isomerization unit for saturating the benzene and recovering lost octane. Thus, these four technologies have been demonstrated in many refineries since the mid-90s in the U.S. and should be considered by the refining community as commercially proven technologies.

A vendor of benzene control technology has shared with us how the refining companies in other countries have controlled the benzene levels of their gasoline in response to the benzene standards put in place there. In Europe, benzene control is achieved by routing the benzene precursors around the reformer and feeding that rerouted stream to an isomerization unit. In Japan, much of the benzene is extracted from gasoline and sold to the chemicals market. Finally, in Australia and New Zealand, refiners use benzene saturation to reduce the benzene levels in their gasoline.

6.4.1 Benzene Levels Achievable through Reformate Benzene Control

We evaluated the benzene levels achievable by refineries applying benzene control in two different ways. One way was to evaluate the benzene levels of refineries in 2003 which are producing low benzene gasoline to comply with the RFG requirements. The second way was to use the refinery-by-refinery cost model to evaluate the benzene levels achievable by the various benzene control technologies.

Refiners today are producing gasoline with low benzene levels for sale into the RFG market. The RFG program requires that gasoline must meet a 0.95 benzene control standard. While the benzene standard is much less stringent than the benzene control standard, many refiners comply at a much lower level probably because they are using benzene extraction to comply. When extracting benzene from gasoline, the high capital costs associated with extraction provides a strong incentive to maximize the extraction of as much benzene as possible. The low benzene levels achieved by today’s refineries provide an indication of the feasibility of complying with the benzene standard. RFG averages 0.62 volume percent benzene – the same level as the average benzene standard.

There are 17 refineries today producing gasoline which currently averaged 0.62 volume percent benzene or below. Of these 17 refineries with very low benzene levels, 11 are located in PADD 3, four are located in PADD 1, and one each are located in PADDs 2 and 4. The benzene levels for these refineries range from 0.29 to 0.62 volume percent and average of 0.51 volume percent. The average benzene level for these refineries is well below the benzene standard. We reviewed the list of refinery unit capacities from EIA and the Oil and Gas Journal to determine if these refineries have benzene saturation or extraction benzene control technologies. Of the 17 refineries with benzene levels at or below 0.62 volume percent, 14 of these have benzene extraction or saturation units, while two more are assumed to be selling reformate to other refineries with extraction units. While this demonstrates that achieving the benzene standard is feasible for a portion of U.S. refiners, this does not indicate that all U.S. refiners are capable of achieving a 0.62 volume percent benzene level.

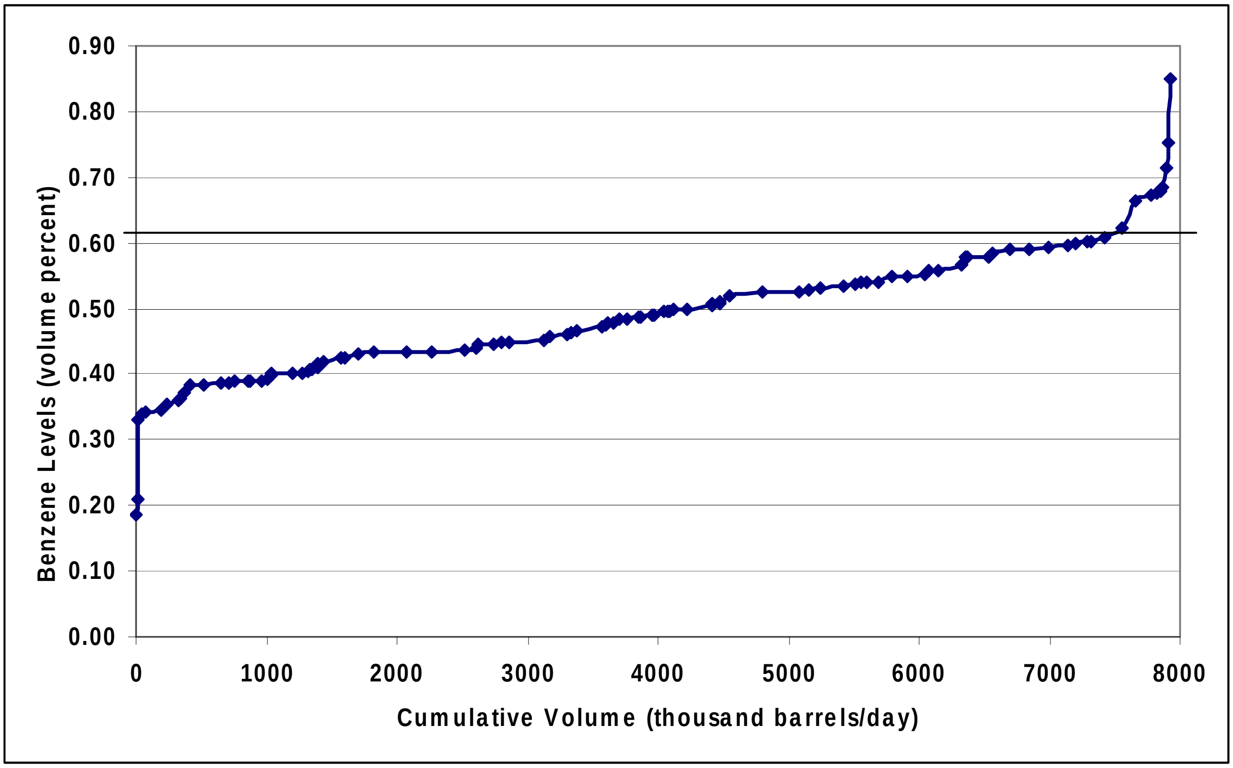
To assess the ability for the rest of the refineries to achieve a benzene level of 0.62 or below, we used the refinery-by-refinery model. For each benzene control technology, we assessed its ability to achieve benzene reductions. Routing the benzene precursors around the reformer is the least severe benzene control technology. The refinery by refinery cost model shows that refineries using this technology can reduce their gasoline benzene levels from an average of about 1.6 volume percent to 1.1 volume percent, a 30 percent reduction. The refinery-by-refinery cost model shows that only two refineries would be able to meet or exceed the new benzene standard using this technology. This technology is clearly insufficient for achieving the required benzene control by itself.

Those refineries with isomerization units would be able to route their rerouted benzene precursors to this unit further reducing their benzene levels by saturating the naturally occurring benzene in this stream. The refinery-by-refinery cost model shows that on average these refineries would be able to reduce their gasoline benzene levels to 0.75 volume percent using this technology combined with benzene precursor rerouting. Of these refineries, 9 would be able to achieve the benzene standard. Averaged across the U.S. refineries, benzene precursor rerouting can achieve about a 60 percent reduction in reformate benzene levels. When benzene precursor rerouting is combined with isomerization, about an 80 percent reduction in reformate benzene levels is possible. While this benzene precursor rerouting combined with isomerization can achieve a significant reduction in refinery benzene levels, the application of further benzene control technologies is still required to enable the U.S. refining industry to achieve the benzene control standard. The reason why these combined benzene control technologies are incapable of achieving a significant enough benzene reduction is because they do not address the benzene formed from reforming the heavy part of reformate.

We assessed the benzene reduction capacity of benzene saturation and benzene extraction. These two technologies are able to achieve a deeper reduction in gasoline benzene levels because they treat all the benzene in reformate – that formed from the six carbon hydrocarbons, that formed from the cracking of heavier aromatics to benzene in heavy reformate, and the naturally occurring benzene which is in the feed to the reformer. Our analysis of these benzene control technologies reveals that they are able to reduce reformate benzene levels by 96 percent. The refinery-by-refinery model shows that for those refineries that were found eligible for using benzene saturation, they were able to reduce their gasoline benzene levels from about 1.6 volume percent to 0.5 volume percent, a 60 percent reduction. For refineries identified as eligible as using benzene extraction, the refinery-by-refinery cost model estimates that they are capable of reducing their gasoline benzene levels from 0.9 volume percent to 0.5 volume percent, a 40 percent reduction. The refineries eligible for benzene extraction are already low in benzene because many of them are using extraction today, or they are selling a benzene-rich reformate stream to a neighboring refinery which is extracting the benzene from this stream. However, the refinery-by-refinery cost model estimates that they are able to achieve further benzene reduction, by revamping their benzene extraction units to do so. While the use of benzene extraction is limited to refineries on the East and Gulf Coasts, where they have access to the petrochemical markets, the use of benzene saturation is not limited. Therefore, each refinery in the U.S. is able to install one of these two benzene control technologies. We assessed the benzene reduction capacity of using these two maximum reformate control technologies.

We found that, on average, U.S. refineries could achieve a benzene level of 0.50 volume percent based on the maximum level of benzene control from reformate, assuming that benzene saturation or extraction was applied in each refinery in the country. However, this average was obtained by averaging refineries with benzene levels both above and below 0.50 volume percent ranging between 0.19 to 0.85 volume percent benzene. To illustrate the benzene levels achievable by the application of benzene extraction and benzene saturation in each refinery in the U.S., we plotted the estimated final benzene level for each refinery against their cumulative gasoline volume from low to highest benzene level in Figure 6.4-1. To provide a perspective for how the gasoline benzene levels for U.S. refineries compare to the benzene standard, we provided a line at 0.62 volume percent benzene.

Figure 6.4-1. Benzene Levels Achievable by U.S. Refineries Applying Benzene Extraction and Saturation



As shown in Figure 6.4-1, the refinery-by-refinery cost model estimates that if reformate were treated with benzene saturation and benzene extraction, 8 refineries would continue to have benzene levels above 0.62 volume percent benzene. Under the ABT program, this would not be an issue since those refineries with benzene levels above 0.62 could purchase credits from refineries with benzene levels below the 0.62 benzene standard. However, credits must always be available for these refineries to show compliance with the new benzene program. While we believe that credits would be available, it is still possible to show that each refinery could attain the benzene standard with additional benzene control options available to them.

6.4.2 Other Benzene Controls

We have identified other means that could be used to reduce gasoline benzene levels in addition to the technologies discussed above and modeled in the refinery-by-refinery cost model.[23][24] Although we have not quantified their costs, they could be more expensive and therefore less attractive for achieving benzene reductions than the reformer-based treating technologies identified above.

We believe that four light gasoline streams are possible candidates for benzene reduction. At some point in most modern refineries, at least one and sometimes all four of these streams can be found. They are light-straight run (LSR) naphtha, light coker naphtha (LCN), light hydrocrackate (LHC), and light cracked gasoline (LCG). The actual distillation composition of each stream varies somewhat from refinery to refinery, and can vary within the same refinery, usually as a function of seasonal changes and crude compositional variations. Upon enquiring of just a few refiners as to an approximate boiling range, we found that currently light naphtha streams vary from a C_5 (80 ^oF-90 ^oF) initial boiling point (IBP) to as high as 340 ^oF final boiling point (FBP). The range for most of the streams was around C_5-200 ^oF. We believe this reflects post-MSAT I operations; a pre-MSAT I nominal boiling range for these streams was around C_5-180 ^oF. The benzene concentration in each of these light streams is, typically: LSR may range from 0.5 vol% to 2.5 vol% (typically 1.1 vol%); LHC from 0.1 vol% to 5.5 vol% (typically 2.4 vol%); and LCN from 0.2 vol% to 2 vol% (typically 2.0 vol%). These may seem quite high, but the relative volume of these streams is quite low.

The following includes a brief description of the units that produce these streams as well as a brief summary of their current disposition (post Tier II) with regard to how they are cut, processed, and blended. We don't intend to discuss all of the operating conditions or product streams associated with the units. Rather, we will focus mainly on the streams we've highlighted and on process conditions in the units or tower sections from which they flow. We then suggest ways refiners may be able to modify the boiling ranges of these streams and perhaps install additional equipment to reduce the overall benzene concentration of their gasoline pool sufficiently to comply with this rule.

Light Straight Run Naphtha (LSR)

LSR is derived from crude oil. Although most crude oils contain at least some benzene, it is seldom reported as a separate crude component. In the past, naturally occurring benzene, regardless of its concentration, was a desirable component, of otherwise little concern, and usually ended up in gasoline. Nevertheless, we believe that in order to comply with this rule, a few refiners may need to consider removing the benzene that comes in with their crude.

In a common crude unit configuration, a preflash tower overhead/topped crude cut point of about 180 ^oF separates the LSR (consisting of mostly C_4 and C_5 isomers) from the whole crude feed. This cut point also fixed the IBP of the topped crude (and subsequently the HSR) at about the same 180 ^oF[25]. A stabilizer or stripper take the C_4's and lighter, overhead, for feed to the saturated gas plant. The stripper bottoms, or C_5's, are either isomerized or blended directly into gasoline. As previously mentioned, the 180 ^oF cut point, leaves most of the benzene and benzene precursors in the topped crude.

Subsequently, the topped crude was fed to the main crude fractionator, from which the HSR, with the benzene and benzene-precursors, are taken overhead, fed to a naphtha hydrotreater, and then to a reformer. If the stabilized LSR requires desulfurization, it will be hydrotreated with the HSR, following which they were split out for isom feed.

As described above, refiners can comply with the MSAT1 benzene restrictions by shifting the preflash LSR/topped crude cut from 180 ^oF to somewhere around 200 ^oF to 210 ^oF, to keep the benzene and benzene precursors in the LSR and out of the reformer. The debutanized LSR, consisting of C_5's and C_6's, could then be blended directly into gasoline, or fed to an isom unit to saturate the benzene and to convert the straight-chained C_5/C_6 paraffins into isoparaffins, in order to recover some of the octane lost to benzene removal.

Alternatively, if refiners are putting in a reformer post-treat benzene treatment unit, either a benzene saturation unit or an extraction unit, they can adjust the endpoint of their LSR higher to route the small amount of benzene in LSR into the heavy straight run naphtha so that it would be sent to the benzene posttreaters. The stabilizer or stripper that most refiners use to separate the LSR from the rest of the naphtha is likely not capable of making a sufficiently hard cut to cut the benzene in LSR into the heavy straight run naphtha without cutting some C5s into heavy straight run as well. Thus refiners would likely have to install a light naphtha splitter to accomplish this.

Light Hydrocrackate (LHC)

Hydrocrackers are designed to use high temperature and high hydrogen partial pressure, in the presence of hydrocracking catalyst, to convert low-value heavy oil into a variety of light products including diesel, jet fuel or kerosene, and gasoline. If process conditions are sufficiently severe, such as when producing primarily diesel, benzene formed during hydrocracking will likely be saturated. Under less severe conditions, such as when producing mostly gasoline, benzene likely won’t be saturated and will end up in the naphtha; olefins are usually saturated under all hydrocracking conditions. In that the hydrocracking process ultimately saturates any olefins produced during cracking, LHC is actually somewhat similar to LSR.

LHC has a nominal boiling range of C_5-180 ^oF, while heavy hydrocrackate (HHC) has a boiling range from around 180 ^oF-390 ^oF. Because the HHC normally has low octane, it is usually mixed with heavy straight run naphtha and fed to a naphtha hydrotreater and reformer. The cut between LHC and HHC is made with a main fractionator unit which also makes the cuts between the HHC and the heavier compounds exiting the hydrocracker unit. There are two means for further reducing the benzene levels of the LHC. A refiner could shift the aforementioned LHC-FBP from 180 ^oF to around 200 ^oF to keep any benzene or benzene precursors in the LHC. The LHC could then be fed with the similar C_5/C_6-LSR stream from the crude unit to an isom unit for benzene saturation and octane improvement. If the refiner does not have an isomerization unit, or if it is of insufficient capacity to treat both the LSR and the LHC, then the refiner would not be able to treat the LHC that way. Alternatively, the refinery could cut the LHC lighter so that all the benzene would end up in the HHC and be treated with the rest of the reformate. However, the fractionation column is not designed to make fine adjustments in distillation temperature, nor is it capable of making hard cuts to cut the benzene into the HHC without also cutting the lighter hydrocarbons into the HHC, which is undesirable for feed to the reformer. Thus, it would likely be necessary to add a naphtha splitter to make the appropriate distillation cut the benzene into the HHC.

Light Cracked (LCG) Gasoline and Heavy Cracked (HCG) Gasoline

To produce gasoline, most fully integrated refineries have FCC’s to catalytically crack heavy atmospheric and vacuum gasoil from the crude and vacuum units. The volume of benzene produced by an average FCC is ordinarily quite low when compared with other “cracking” type units, but can be somewhat higher in severe, high-conversion operations. Prior to Tier II, debutanized or depentanized, full-range FCC cracked gasoline was usually sent directly to gasoline blending. To comply with Tier II sulfur restrictions, many refiners were able to split the full-range stream into LCG, the cut with most of the olefins, and HCG, the cut in with most of the sulfur. The LCG is usually caustic washed (with either a Merox or Merichem unit) to remove mercaptans and sent directly to gasoline blending. Only the HCG was desulfurized, to avoid LCG olefin saturation and the consequent octane loss.

Controlling the benzene in the FCC cracked naphtha presents a different set of issues. If the benzene is cut into the LCG, it would need to be severely hydrotreated to saturate the benzene. This could be quite costly, since under these conditions the olefins would also undoubtedly be saturated, ultimately reducing the finished octane. Many refiners would find this unacceptable, given the contribution LCG usually makes to the gasoline blending pool. Although, currently, there doesn’t appear to be an easy, inexpensive way to remove benzene form LCG, without some reduction in octane, there are a few vendors that claim they can minimize the loss. In some cases, the capital costs are a little higher than those for hydrotreating or isomerization units, but they are reported to be offset by significantly lower operating costs.

The HCG is usually hydrotreated and sent to gasoline blending, once the LCG has been removed. If the benzene is cut into the HCG and it is severely hydrotreated to saturate the benzene, the product would be quite similar to HHC and would likely need to be routed to a reformer. Reformer capacity could easily become an issue. While olefin levels are much lower in HCG, there still are enough olefins in this refinery stream to cause higher octane losses than the straight run naphtha streams.

A possible means for reducing the benzene in FCC naphtha has been hypothesized through the alkylation of the benzene. As proposed, this process would first separate the benzene and other six carbon compounds from the rest of the FCC naphtha. The five carbon and seven carbon and heavier compounds in the rest of the FCC naphtha would continue to be blended into gasoline. This six carbon stream, which is estimated to contain 2 to 5 percent benzene, would be reacted over the appropriate catalysts with FCC offgas, which contains hydrogen, methane, ethane, and ethylene, propane and propylene. The benzene would react with the olefins, which are mainly ethylene and propylene, creating ethylbenzene and cumene (propylbenzene). Since these alkylated benzene compounds are no longer benzene, they are blended into the gasoline pool where they have increased the octane of gasoline slightly over the benzene that they replaced. There are several unknowns with this concept. One unknown is what catalyst would be best for catalyzing this reaction quickly, with few side reactions, in the presence of some residual sulfur and nitrogen containing compounds. The second is identifying the operating conditions that would be best for this reaction. The third is to determine the operation run lengths for this process with the identified catalysts operating conditions. Since these basic processing elements have not yet been answered, this potential FCC unit benzene control technology must be further developed before it is ready for installation in refineries.[26]

Light Coker Naphtha (LCN)

Cokers thermally crack low API Gravity, high-sulfur asphaltic crude, vacuum unit residuum (also usually asphaltic), and, in a few cases, FCC decant or heavy cycle oil to produce, among several valuable products, coker naphtha. Other than having more sulfur, fewer olefins, and a few other contaminants, it also contains some benzene. The LCN cut is ordinarily quite low-volume; thus, prior to Tier II, regardless of sulfur content or the presence of other minor contaminants, it could actually be sent directly to gasoline blending or mixed with isom unit feed, with no real negative effects. The heavy coker naphtha (HCN) is usually sent to a naphtha hydrotreater and, subsequently, to a reformer.

To comply with Tier II, refiners set the LCN-FBP to around 190 ^{o}F-200 ^{o}F to capture the thiophenes (along with the benzene and benzene precursors), and sent it to the FCC naphtha hydrotreater. The relatively mild FCC-hydrotreater conditions allowed the benzene to pass through, unsaturated, into the gasoline blending pool. We also note that while a few olefins may be present, the volume is quite low compared with LCG and they will obviously be saturated in the naphtha hydrotreater.

MSAT II Compliance

Perhaps the single most important factor for this discussion is that the relative volumes of these light naphtha streams is low. On average, the plants size to handle each of these streams separately would be relatively small and consequently capital and operating costs on a per-barrel basis of either feed or benzene produced would most likely be inordinately high. This might not be the case for large refiners though.

The refiners that choose to comply with this rule using the benzene/benzene precursor rerouting and isomerization unit benzene saturation schemes might be able to add one or more of these additional light naphtha streams along with their LSR to feed of the isomerization unit. A potential critical problem is that isomerization unit capacity limitations may become a problem. We acknowledge that the fractionating towers in the other four units we’ve identified, may be able to more efficiently cut the C_6’s from the C_7’s and other heavy ends of the various streams we been discussing, thus reducing the effects of limited isomerization capacity.

The economics of rerouting these light naphtha streams to the isomerization unit to saturate benzene are not favorable, especially given the high cost of building small units as well as the prospects of overall system octane reduction, and hydrogen consumption in the isomerization unit. We estimate that it could cost from $100 to $135 per barrel of benzene to control the benzene in LHC; for LSR, we estimate it could cost from $45 to $222 per barrel of benzene. These costs are at middle and the high end of the marginal costs that would compete with the technologies that our model shows would be used to comply with the final rule benzene control program. These costs would likely be much more attractive for a large refinery with high benzene levels in their LSR and LHC.

For the LSR, LHC, and LCN, we suggest that perhaps the best pathway to compliance may be to return the benzene to the reformer. Then, depending on the specific refinery economics, the benzene could be either saturated and sent to the gasoline pool or extracted for sale in the chemical market. The cut point between each of the light and heavy streams would be set at or even slightly lower than 180 ^{0}F; basically, the opposite of what we previously discussed. While we acknowledge that keeping C_5’s out of the reformer is desirable, depending on the stage efficiencies of the various fractionating towers, some C_5’s may find their way into the feed. If some C5s are sent to the reformer they can be tolerated, and in any case, there is a good chance the C_5’s can be recovered from the naphtha hydrotreater stabilizer overhead, upstream of the reformer. The net stabilizer overhead, usually a gaseous C_3-C_5 stream, could be sent to the gas concentration unit for C_5 recovery, if such isn't already the case. We estimate that benzene controlled by saturation could cost, very roughly, from $70 to $350 per barrel of benzene. To control by extraction could cost from $30 to $900 per barrel of benzene. The re-cut LSR, LHC, and LCN could be sent to isomerization for octane improvement. The great variance in costs is due to the range in light naphtha stream volume and benzene level.

While the cost analysis we conducted for reducing the benzene levels of these light naphtha streams was only preliminary, the cost analysis suggests that the treatment of benzene in LSR, LHC, and LCN could be cost-effective. If and when we reconsider setting more stringent toxics control standards for gasoline, we should revisit whether the benzene standards we set could be more stringent considering the treatment of benzene in these light naphtha streams.

For our feasibility analysis, we discovered that 8 refineries would not be able to comply with the 0.62 average benzene control standard, even when applying maximum reformate benzene control, unless if credits were available. Each refinery should be able to achieve the average standard without relying on credits. Therefore we assessed the benzene levels achievable by applying light naphtha benzene control technologies, as discussed above, or other benzene control means that we identified that would be available to them.

One of these other benzene control opportunities would apply for those refineries using benzene saturation or extraction. They could achieve additional benzene reduction with these units by capturing more of the benzene in the reformate splitter and sending this additional benzene to their saturation or extraction unit. Refiners attempt to optimize the capital and operating costs with the amount of benzene removed when splitting a benzene-rich stream out of the reformate stream for treating in a benzene saturation or extraction unit. To do this, they optimize the distillation cut between benzene and toluene, thus achieving a benzene reduction of about 96 percent in the reformate while preserving all but about 1 percent of the high-octane toluene. However, if a refiner was to be faced with the need for additional benzene reductions, it could change the distillation cut in their existing reformate splitter to send the last 4 percent of the benzene to the saturation or extraction units. This action though would also capture more of the seven carbon hydrocarbons, resulting in the saturation of the toluene contained in the seven carbon hydrocarbons. Refiners using this strategy to capture more of the benzene in the reformate splitter would have to have sufficient capacity downstream in the saturation or extraction units to process this additional volume, although refiners normally design their units with some excess capacity. They could design either their reformate splitter, or their benzene saturation or extraction units with this end in mind. On the one hand, they could design their reformate splitter to be larger to make a "hard cut" thus capturing virtually all the benzene and rejecting virtually all the toluene; sending only the additional volume of benzene to their downstream saturation or extraction unit. This option would entail increased capital and operating costs for their reformate splitter, but only a very slight increase in capital and operating costs for the benzene saturation or extraction unit.

Another means for further reducing the benzene levels for 6 of these 8 refineries is to reduce the benzene content of the LSR naphtha stream. Refiners could use additional distillation equipment to cut the benzene in the LSR naphtha into the heavy straight run naphtha where it would be treated along with the rest of the reformate using benzene saturation or extraction. For each of the 6 refineries which the refinery-by-refinery cost model shows could not achieve 0.62 volume percent benzene, we estimate the extent that benzene levels could be further reduced by addressing the benzene in light straight run naphtha summarize this in Table 6.4-1.

Another means for further reducing the benzene levels for 4 of these 8 refineries which have a hydrocracker is to reduce the benzene content of the LHC and LCN naphtha streams. For each of the 6 refineries with a hydrocracker or coker which the refinery-by-refinery cost model shows could not achieve 0.62 volume percent benzene, we estimate the extent that benzene levels could be further reduced by addressing the benzene in light hydrocrackate and summarize this in Table 6.4-1.

Another possible option for these refineries to further control benzene might be to control the benzene content in naphtha from the fluidized catalytic cracker, or FCC unit. As we discussed above, segregating a benzene-rich stream from FCC naphtha for sending to a benzene saturation unit would saturate the olefins in this stream, in addition to the benzene, causing an unacceptable loss in octane value. We learned that one refinery is operating their FCC unit very severely to produce a high octane (92 octane number) gasoline blendstock. This resulted in this particular FCC naphtha having a benzene content of 1.2 volume percent. This refiner could change the operations of their FCC unit (change the catalyst and operating characteristics) to reduce the severity and produce slightly less benzene and make up the octane loss in other ways, such as blending in ethanol.[27] We do not know if any of the refineries which the refinery-by-refinery cost model has identified as not being able to achieve the 0.62 benzene standard using reformate benzene control are operating their FCC units this way. Thus, we cannot estimate that any of these refineries could reduce their gasoline benzene levels by reducing the severity of their FCC units. Our conclusion after carefully considering treating this stream is that we cannot assume that LCN nor HCN can be treated to lower the benzene contained in this stream.

For each of the 8 refineries which the refinery-by-refinery model shows could not achieve 0.62 vol% benzene using maximum reformate control, we estimate the extent that benzene levels could be further reduced based on the discussion above. Table 6.4-1 summarizes the benzene levels achievable by each of these refineries by capturing some of the remaining benzene and treating it in a saturation unit or extracting it from gasoline.

Table 6.4-1. Additional Benzene Reduction Achievable by non-Reformate Means of Control for Refineries Unable to Achieve the Average Standard using Reformate Control

Refinery Number	Gasoline Benzene Level after Reformate Benzene Control	Treating last 4% of Reformate Benzene	Treating 99.5% of Light Straight Run Naphtha Benzene	Treating 99.6% of Light Hydrocrackate Benzene
1	0.66	-0.04	-0.07	-0.14
2	0.69	-0.07	N/A	N/A
3	0.68	-0.02	-0.18	N/A
4	0.67	-0.01	-0.09	-0.20
5	0.85	-0.09	N/A	-0.71
6	0.71	-0.06	-0.06	N/A
7	0.75	-0.09	-0.24	-0.41
8	0.67	-0.04	-0.16	N/A

6.5 Averaging, Banking, and Trading (ABT) Program

We are finalizing a program where refiners and importers can use benzene credits generated or obtained under the averaging, banking, and trading (ABT) program to meet the 0.62 vol% annual average standard in 2011 and beyond (2015 and beyond for small refiners). We are also finalizing a 1.3 vol% maximum average standard which takes effect in July 2012 (July 2016 for small refiners). The maximum average standard must be met based on actual refinery benzene levels and may not be met through the use of credits.

This regulatory impact analysis begins with a discussion of today's gasoline benzene production levels. From there, we outline the conclusions of the refinery-by-refinery cost model (described in more detail in Chapter 9) including a summary of refiners' projected compliance strategies for meeting the 0.62 and 1.3 vol% gasoline benzene standards. For the ABT analysis, we focus on when the benzene reductions would occur (some likely to occur early while others could lag) and the resulting credit generation/demand scheme. We also describe the gradual phase-in of the 0.62 vol% standard as a result of early credit use and demonstrate how such a program is more cost effective than a program lacking an early credit program or ABT program all together. We provide explanation on how early and standard credits are generated as well as how a refinery would compute their credit demand, if they should choose to rely on benzene credits. Finally, we present our predictions on how the credit generation/trading scheme would work via company to highlight our certainty that credits will likely be available to those in need.

6.5.1 Starting Gasoline Benzene Levels

To begin the ABT analysis, we started by examining current gasoline benzene levels. In 2004, the benzene content of gasoline produced by 113 U.S. refineries located outside of California ranged from 0.34 to 4.04 vol% with an overall volume-weighted average of 1.00 vol%

as shown in Table 6.5-1[C].

Table 6.5-1. 2004 Gasoline Benzene Production Levels

	No. of Refineries by Gasoline Benzene Level (vol%)						Benzene Level (vol%)			
	< 0.5	0.5 to <1	1 to <1.5	1.5 to <2	2 to <2.5	2.5+	Min	Max	Range	Avg
PADD 1	3	4	2	1	2	0	0.39	2.26	1.87	0.67
PADD 2	1	6	8	9	1	1	0.41	2.86	2.46	1.26
PADD 3	4	20	9	6	1	1	0.34	2.86	2.52	0.85
PADD 4	0	1	4	7	2	2	0.88	4.04	3.15	1.56
PADD 5 - CA	1	0	2	2	2	1	0.39	3.66	3.27	1.80
Total	**9**	**31**	**25**	**25**	**8**	**5**	**0.34**	**4.04**	**3.69**	**1.00**

This data, as well as all the data presented from this point forward, includes 16 U.S. refineries that we project will meet the small refiner criteria in § 80.1338[D]. This data includes both reformulated gasoline (RFG) and conventional gasoline (CG), but excludes gasoline produced by terminals as well as gasoline produced by California refineries for use outside of California. It is also worth emphasizing that this data represents gasoline benzene production levels by region. This is not necessarily the same as in-use gasoline benzene levels by region due to the movement of gasoline across the country. For a more detailed discussion on projected in-use levels considering gasoline distribution patterns, refer to section 6.10.

As shown above in Table 6.5-1, there is currently a wide variation in gasoline benzene levels throughout the county. The variation (explained in more detail above in 6.2) is primarily attributed to differences in crude oil quality, use of low-benzene blendstocks, benzene control technology, and refinery operating procedures. PADDs 1 and 3 have the lowest average benzene levels in the country. Refineries in these regions are located in close proximity to the petrochemicals market making benzene extraction a viable strategy for reducing gasoline benzene. Refineries in PADD 2 have the next lowest benzene levels primarily due to the availability of low-benzene blendstocks, i.e. ethanol. PADDs 4 and 5 currently have the highest benzene levels based on the benzene-rich Alaskan crude they process and their distance from the petrochemicals market.

6.5.2 Model-Predicted Refinery Compliance Strategies

To determine how each refinery would behave under the MSAT2 program, we relied on a linear programming (LP) cost model (discussed in more detail in Chapter 9). The LP model considered starting benzene levels, existing benzene-control technology as well as cost and predicted a compliance strategy for each U.S. gasoline refinery. The model assumed that refineries would choose the most economical strategy for complying with the 0.62 and 1.3 vol% standards. The model predicts that 77 of the 103 refineries would make technological

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[C] 2004 gasoline benzene production levels based on batch reports received by EPA under the RFG / Anti-Dumping requirements.

[D] EPA's current assessment is that 14 refiners (owning 16 refineries) meet the small refiner criterion under § 80.1338 of having 1,500 employees or less and a crude capacity of less than or equal to 155,000 bpcd. It should be noted that because of the dynamics in the refining industry (i.e., mergers and acquisitions) and decisions by some refiners to enter or leave the gasoline market, the actual number of refiners that ultimately qualify for small refiner status under the MSAT2 program could be different than these estimates.

improvements to reduce gasoline benzene levels. For some of these refineries, it was economical to reduce benzene levels to ≤ 0.62 vol%, while for others it was more economical to reduce benzene levels to ≤ 1.3 vol% (to meet the maximum average standard) and rely on credits to meet the annual average standard. The model shows that the remaining 26 refineries would simply maintain their current benzene levels – which are ≤ 1.3 vol% on average, or in some cases ≤ 0.62 vol%. A summary the model-predicted refinery compliance strategies is presented in Table 6.5-2.

Table 6.5-2. Predicted Refinery Compliance Strategies

Refinery Compliance Strategy		No. of Refineries by PADD					
Make process improvement to reduce gasoline benzene levels?	**Rely on Credits?**	**PADD 1**	**PADD 2**	**PADD 3**	**PADD 4**	**PADD 5[a]**	**Total**
Yes, reduce Bz levels to 0.62 - 1.3 vol%	Yes	3	12	9	12	4	40
Yes, reduce Bz levels to <= 0.62 vol%	No	4	12	18	1	2	37
No, Bz levels already 0.62 - 1.3 vol%	Yes	1	1	6	3	1	12
No, Bz levels already <= 0.62 vol%	No	4	1	8	0	1	14
Total Number of Refineries		**12**	**26**	**41**	**16**	**8**	**103**

[a]PADD 5 excluding California refineries

Most refiners planning on reducing gasoline benzene levels will focus on reformate control, since the majority of the benzene found in gasoline comes from the reformer as explained in 6.3.1. We predict that most refiners would choose this strategy since it is capable of getting the greatest benzene reductions and the technology is known and readily available. The refinery cost model and this subsequent ABT analysis focuses specifically on the following forms of reformate control: light naphtha splitting, isomerization, benzene extraction and benzene saturation. These technologies are discussed in more detail above in section 6.3.2.

As mentioned above, the refinery cost model predicts which benzene-reducing steps each refinery would take to meet the 0.62 and 1.3 vol% standards at the lowest possible cost. The strategy that a refinery selects will depend on existing equipment, proximity to the petrochemicals market, and technology costs compared to the cost of buying credits. Of the 77 refineries predicted to make technological improvements (from Table 6.5-2), 17 would pursue light naphtha splitting, 4 would pursue isomerization, 24 would implement a combination of light naphtha splitting and isomerization, 16 invest in benzene extraction, and the remaining 16 would invest in benzene saturation. A summary of the predicted benzene reduction strategies by PADD is found below in Table 6.5-3.

Table 6.5-3. Predicted Benzene Reduction Strategies

	No. of Refineries by PADD					
Ultimate Benzene Reduction Strategy	**PADD 1**	**PADD 2**	**PADD 3**	**PADD 4**	**PADD 5[a]**	**Total**
Light naphtha splitting	2	5	3	6	1	17
Isomerization	0	1	3	0	0	4
Light naphtha splitting & isomerization	0	14	6	4	0	24
Benzene extraction	3	1	12	0	0	16
Benzene saturation	2	3	3	3	5	16
Total Number of Refineries	**7**	**21**	**27**	**10**	**1**	**77**

[a] PADD 5 excluding California refineries

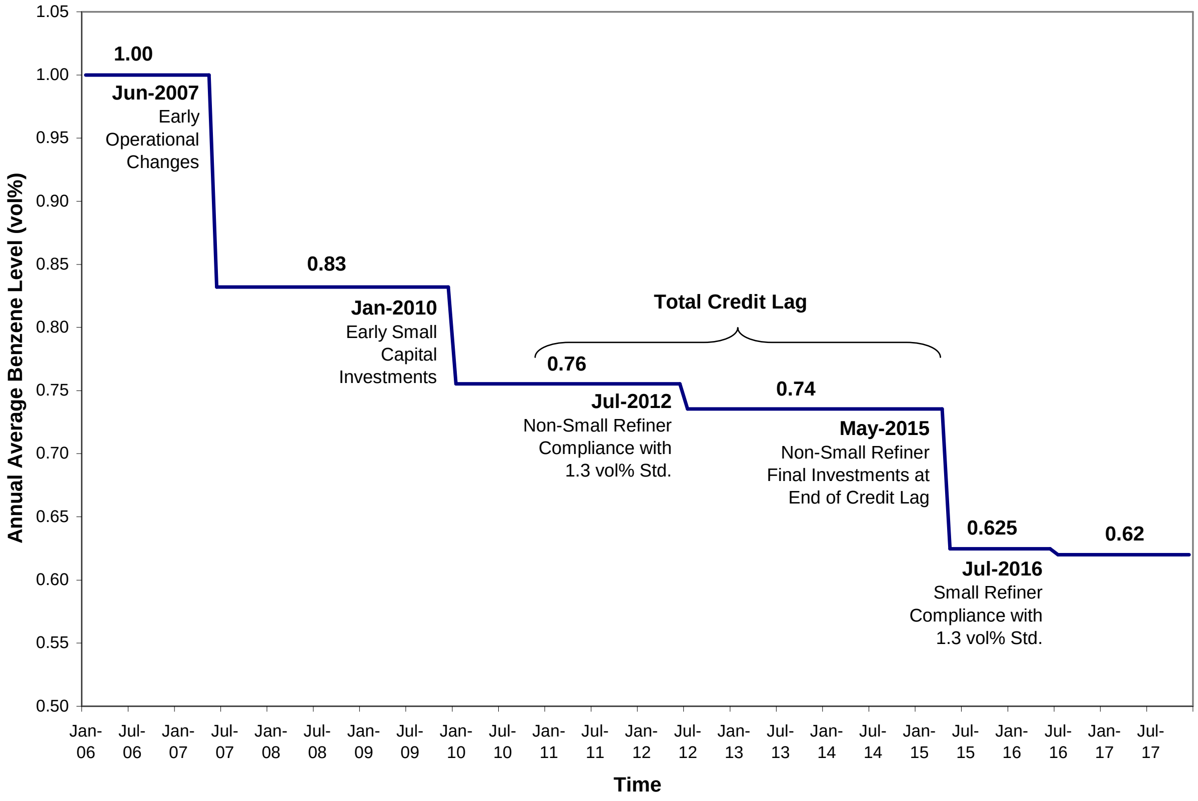
The strategies listed above in Table 6.5-3 are ultimate benzene control strategies. However, refineries may also make additional operational changes (requiring zero cost) that are not necessarily captured in Table 6.5-3. For example, a refinery ultimately pursuing benzene extraction may also make early operational changes (e.g., LNS, isomerization or both) to reduce gasoline benzene levels prior to making their final investment. In this case, only their final control strategy (benzene extraction) has been reflected in Table 6.5-3. Likewise, refineries may complete their process improvement as a series of small steps. For example, a refinery pursuing light naphtha splitting may make early operational changes and postpone their final investment until later. In this case, LNS (the overall strategy) would only be listed once in Table 6.5-3. A refinery's ability to implement their benzene control technology sooner than required is a function of cost and lead time. A more detailed discussion on the implementation of benzene control technologies and the resulting phase-in of the benzene standards is found below.

6.5.3 Predicted Reductions in Gasoline Benzene

Refineries will need lead time to complete refinery modifications and/or invest in new technology for meeting the 0.62 and 1.3 vol% standards. The rule we are finalizing provides nearly four years of lead time for this to occur. However, in many cases there are incremental benzene reductions that can be made earlier than required. To encourage early introduction of benzene control technology, refiners can generate early benzene credits from June 1, 2007 to December 31, 2010 (December 31, 2015 for small refiners) by making qualifying reductions from their 2004-2005 individual refinery baselines. A discussion of how refinery baselines are established and what constitutes a qualifying benzene reduction is found below in section 6.5.4.2.

The early reductions we are predicting to occur would be consistent with each refinery's ultimate benzene control strategy but simply completed sooner than required. The early credits generated can be used to provide the refining industry with additional lead time to make their final (more expensive) investments in benzene control technology. As a result, some benzene reductions will occur prior to the start of the program while others will lag (within the limits of the credit life provisions described below). We anticipate that there will be enough early credits generated to allow refiners to postpone their final investments by three years - the maximum time afforded by the early credit life provisions. In addition, we predict that standard credits generated during this early credit lag period (January 1, 2011 through December 31, 2013) will allow for an additional 16 months of lead time. The result is a gradual phase-in of the 0.62 vol% benzene standard beginning in June 2007 and ending in July 2016 as shown below in Figure 6.5-1.

Figure 6.5-1. Benzene Level vs. Time



As shown in Figure 6.5-1 (and described in more detail below), our modeling assumes a stepwise reduction in gasoline benzene levels over time. However, due to the inputs of many different individual refinery decisions over time, we anticipate that a more continuous benzene reduction pattern will actually occur, but follow the same trend.

The ABT analysis assumed that small refiners would comply with the 1.3 vol% maximum average standard in January 2015 at the same time as the 0.62 vol% annual average standard. However, in actuality, we are finalizing a later maximum average standard implementation date (July 2016) for small refiners. We anticipate that this will have very little effect on the overall credit generation/use picture and therefore have elected not to change our ABT analysis. As a result, the phase-in of benzene control technologies (presented below) and the subsequent credit and cost savings calculations (presented in section 6.5.4) are based on small refiners complying with the 1.3 vol% maximum average standard in January 2015 (instead of July 2016).

6.5.3.1 Early Operational Changes in Benzene Control Technology

We estimate that the first phase of early benzene reductions would occur as early as June 1, 2007. These refinery modifications would consist of operational changes made to the reformer that could be implemented without making a capital investment. The early operational changes we predict to occur are light naphtha splitting and isomerization. For refineries that are already splitting light naphtha in their crude distillation columns (or have the potential to), we assume that operational changes could be made to re-route up to 75% of the benzene precursors around the reformer. If the refinery is equipped with an isomerization unit, we predict that this re-routed light naphtha would also be isomerized. If no isomerization unit exists, we predict that the light naphtha would simply be combined with the light straight run to make gasoline.

Based on the refinery cost model findings, we predict that 46 of the 103 refineries would take advantage of the early credit generation opportunities and make early operational changes. More specifically, 18 refineries would implement light naphtha splitting, 4 would implement isomerization, and 24 would pursue a combination of both. These operational changes would result in a 17% reduction in average gasoline benzene level from 1.00 vol% to 0.83 vol%. The changes would also result in an overall 29% reduction in maximum benzene level from benzene level variation from 4.04 vol% to 2.85 vol%. A summary of these reductions and resulting benzene levels by PADD is found in Table 6.5-4.

Table 6.5-4. Benzene Levels after Early Operational Changes

	No. of Refineries by Gasoline Benzene Level (vol%)						Benzene Level (vol%)			
	< 0.5	0.5 to <1	1 to <1.5	1.5 to <2	2 to <2.5	2.5+	Min	Max	Range	Avg
PADD 1	3	4	3	0	2	0	0.39	2.17	1.78	0.65
PADD 2	1	14	9	0	2	0	0.44	2.49	2.05	0.91
PADD 3	4	23	10	3	0	1	0.35	2.85	2.50	0.77
PADD 4	0	1	12	2	0	1	0.90	2.59	1.69	1.26
PADD 5 - CA	1	1	3	1	2	0	0.39	2.10	1.70	1.21
Total	**9**	**43**	**37**	**6**	**6**	**2**	**0.35**	**2.85**	**2.50**	**0.83**

6.5.3.2 Early Small Capital Investments in Benzene Control Technology

We estimate that a second round of early benzene reductions could occur by January 2010. These refinery modifications would consist of upgrades in reformate benzene control technology requiring a relatively small capital investment. For the purpose of this analysis, we are defining a small capital investment as an investment in technology with an incremental cost of ≤ $60 per barrel of benzene reduced. The early technology changes we predict to occur include light naphtha splitting, isomerization, and benzene extraction. We predict that refineries could invest in dedicated columns for splitting light naphtha that would be capable of re-routing 100% of the benzene precursors around the reformer. As with the operational changes mentioned above, if the refinery is equipped with an isomerization unit, we predict that the re-routed light naphtha would also be isomerized. If no isomerization unit exists, the light naphtha would be combined with the light straight run to make gasoline. .

At this time, we predict that 38 of the 103 refineries would make early technology changes requiring a small capital investment. More specifically, 31 refineries would implement light naphtha splitting and/or isomerization at this time. In addition, we predict that seven refineries currently extracting benzene would make modifications to their existing extraction units (costing up to $60/bbl Bz) to improve benzene separation and in turn reduce the benzene concentration of their finished gasoline. Together these changes would result in an 8% reduction in average gasoline benzene level from 0.83 vol% to 0.76 vol%. There would be no change in the maximum benzene level as a result of this step. A summary of these reductions and resulting benzene levels by PADD is found in Table 6.5-5.

Table 6.5-5. Benzene Levels after Early Small Capital Investments

	No. of Refineries by Gasoline Benzene Level (vol%)						Benzene Level (vol%)			
	< 0.5	0.5 to <1	1 to <1.5	1.5 to <2	2 to <2.5	2.5+	Min	Max	Range	Avg
PADD 1	3	5	2	0	2	0	0.39	2.17	1.78	0.63
PADD 2	4	16	4	0	2	0	0.44	2.49	2.05	0.76
PADD 3	5	24	10	1	0	1	0.35	2.85	2.50	0.72
PADD 4	0	4	9	2	0	1	0.88	2.59	1.71	1.14
PADD 5 - CA	1	2	2	1	2	0	0.39	2.10	1.70	1.16
Total	**13**	**51**	**27**	**4**	**6**	**2**	**0.35**	**2.85**	**2.50**	**0.76**

6.5.3.3 Compliance with the 1.3 vol% Maximum Average Standard

In January 2011, the 0.62 vol% standard becomes effective for refineries that do not meet the small refiner criteria in § 80.1338. However, since these refineries will have a sufficient amount of early credits available to them (described in more detail below in section 6.5.4.3), we estimate that they could maintain their 2010 benzene levels until July 2012 when the 1.3 vol% maximum average standard takes effect.

At this time, we predict that 7 of the 103 refineries would implement benzene saturation to reduce their average benzene levels down to 1.3 vol% to comply with the maximum average standard. At this point in the analysis we also incorporated any outstanding benzene reductions associated with increased ethanol use in response to the Energy Policy Act of 2005.[E] Together these changes would result in a 3% reduction in average gasoline benzene level from 0.76 vol% to 0.74 vol%. The changes would also result in a 14% reduction in maximum benzene level from 2.85 vol% to 2.45 vol%. A summary of these reductions and resulting benzene levels by PADD is found in Table 6.5-6.

[E] The Renewable Fuel Standard proposed on September 22, 2006 (71 FR 55552) would require 7.5 billion gallons of renewable fuel to be blended into gasoline by 2012, the majority of which would likely be satisfied by ethanol use. However, in AEO 2006, EIA projected that ethanol use would be 9.6 billion gallons by 2012, well exceeding the RFS requirement. As a result, for this rulemaking we have elected to incorporate the impacts of blending 9.6 billion gallons of ethanol into gasoline by 2012. For the ABT analysis, as refineries were predicted to make early benzene reductions, the impacts of increased ethanol use were incorporated. For refineries not predicted to make any early process changes, increased ethanol use was incorporated in the 2012 year.

Table 6.5-6. Benzene Levels after 1.3 vol% Standard Becomes Effective

	No. of Refineries by Gasoline Benzene Level (vol%)						Benzene Level (vol%)			
	< 0.5	0.5 to <1	1 to <1.5	1.5 to <2	2 to <2.5	2.5+	Min	Max	Range	Avg
PADD 1	3	5	3	0	1	0	0.39	2.11	1.72	0.61
PADD 2	4	16	5	0	1	0	0.45	2.17	1.72	0.75
PADD 3	5	24	12	0	0	0	0.34	1.30	0.96	0.70
PADD 4	0	6	8	1	1	0	0.81	2.45	1.64	1.05
PADD 5 - CA	1	2	4	1	0	0	0.34	1.75	1.41	1.07
Total	**13**	**53**	**32**	**2**	**3**	**0**	**0.34**	**2.45**	**2.11**	**0.74**

Based on credit availability and the relatively high operational costs associated with benzene saturation, we predict that the seven refineries implementing benzene saturation at this time would postpone running the units to their maximum capacity until May 2015 (end of the credit lag, described in more detail below in section 6.5.4.6). In the interim, these refineries would produce gasoline with 1.3 vol% benzene on average and rely on credits to meet the 0.62 vol% annual average standard.

6.5.3.4 Small Refiner Compliance with the Benzene Standards

As mentioned above, we assumed that in January 2015, both the 0.62 vol% annual average standard and the 1.3 vol% maximum average standard would become effective for refineries meeting the small refiner criteria in § 80.1338. At this time, we predict that two small refineries would implement light naphtha splitting and isomerization to reduce their benzene levels to the maximum extent possible. Additionally, we predict that four small refineries would implement benzene saturation to reduce their average benzene levels to 1.3 vol%. Together these changes would result in a 1% reduction in average gasoline benzene level from 0.74 vol% to 0.73 vol%. These changes would also result in a 47% reduction in maximum benzene level from 2.45 vol% down to the maximum average standard of 1.30 vol%. A summary of these reductions and resulting benzene levels by PADD is found in Table 6.5-7.

Table 6.5-7. Benzene Levels after the 1.3 vol% Standard Becomes Effective for Smalls

	No. of Refineries by Gasoline Benzene Level (vol%)						Benzene Level (vol%)			
	< 0.5	0.5 to <1	1 to <1.5	1.5 to <2	2 to <2.5	2.5+	Min	Max	Range	Avg
PADD 1	3	5	4	0	0	0	0.39	1.30	0.91	0.61
PADD 2	4	17	5	0	0	0	0.45	1.30	0.85	0.74
PADD 3	5	24	12	0	0	0	0.34	1.30	0.96	0.70
PADD 4	0	7	9	0	0	0	0.81	1.30	0.49	1.03
PADD 5 - CA	1	2	5	0	0	0	0.34	1.30	0.96	1.06
Total	**13**	**55**	**35**	**0**	**0**	**0**	**0.34**	**1.30**	**0.96**	**0.73**

Unlike the assumption made above for benzene saturation, we predict that the four small refineries investing in benzene saturation will never run their units to their maximum capacity to minimize operational costs. In the event that they did, the benzene levels in the future could be slightly lower than what is reported here.

6.5.3.5 Full Program Implementation / Ultimate Compliance with the 0.62 vol% Standard

We estimate that the final phase of benzene reductions would occur in May 2015 at the end of the early/standard credit lag (described in more detail below in section 6.5.4.6). At this time we predict that 12 refineries would pursue benzene saturation, 9 refineries would pursue benzene extraction, and 12 refineries would pursue light naphtha splitting and/or isomerization.

Of the 12 refineries predicted to pursue benzene saturation, five would be investing in brand new saturation units and the other seven would be making operational changes to run their new units (installed in July 2012) to their maximum benzene reduction potential. Of the nine refineries predicted to pursue benzene extraction, three would be investing in brand new units and the remaining six would be making modifications to their existing extraction units (costing over $60/bbl Bz). Of the 12 refineries predicted to pursue light naphtha splitting and/or isomerization, nine would be investing in new units and three would be making changes to existing units - steps that could have been completed early but were postponed due to the early credit trigger point (explained in more detail in section 6.5.4.1).

Together the 33 technology changes made at this time would result in a 15% reduction in average gasoline benzene level from 0.73 vol% to 0.62 vol%. There would be no change in the maximum benzene level as a result of this step. However, the program in its entirety would result in a 68% reduction in maximum benzene level from 4.04 vol% to 1.30 vol%. Similarly, the program overall would result in a 38% reduction in average gasoline benzene levels from 1.00 vol% to 0.62 vol%. A summary of resulting benzene levels by PADD is found below in Table 6.5-8.

Table 6.5-8. Benzene Levels after Full Program Implementation

	No. of Refineries by Gasoline Benzene Level (vol%)						**Benzene Level (vol%)**			
	< 0.5	**0.5 to <1**	**1 to <1.5**	**1.5 to <2**	**2 to <2.5**	**2.5+**	**Min**	**Max**	**Range**	**Avg**
PADD 1	6	5	1	0	0	0	0.39	1.30	0.91	0.52
PADD 2	7	15	4	0	0	0	0.41	1.30	0.89	0.63
PADD 3	7	29	5	0	0	0	0.34	1.18	0.84	0.61
PADD 4	0	12	4	0	0	0	0.60	1.30	0.70	0.90
PADD 5 - CA	3	4	1	0	0	0	0.34	1.30	0.96	0.69
Total	**23**	**65**	**15**	**0**	**0**	**0**	**0.34**	**1.30**	**0.96**	**0.62**

6.5.4 Credit Generation/Use Calculations & Considerations

6.5.4.1 What factors impact refiners' decisions to make early process changes?

As mentioned before, a refinery's ability to make early benzene reductions depends on the nature of the improvement(s), required lead time, and associated capital costs. However, a refinery's decision to make early improvements depends on several other factors.

First, an early reduction must be consistent with the refinery's ultimate compliance strategy. Our analysis assumes that refineries will make all model-predicted operational changes requiring zero capital to reduce starting benzene levels regardless of their ultimate strategy for meeting the 0.62 and 1.3 vol% standards. However, we assume that they will only make early technology changes requiring a small capital investment if these changes are consistent with their final control strategy. For example, a refinery would not invest capital in a dedicated light naphtha splitting column (even if it was < $60/bbl Bz to incrementally reduce benzene) to reduce benzene and generate credits if its ultimate strategy for complying with the 1.3 vol% maximum average standard involved investing in a benzene saturation unit.

Second, a refinery would only make a model-predicted early change if the benzene reduction was significant enough to allow them to generate early credits. In other words, a refinery would not make an early benzene reduction if it did not satisfy the 10% reduction trigger point derived in the proposal (EPA420-D-06-004, February 2006). Applying this assumption reduced the number of predicted early refineries predicted to make operational changes from 52 to 47 and the number of refineries predicted to make early small capital investments from 40 to 39.

Third, a refinery would only make a model-predicted early change if the company had a need for early credits, i.e., the company's average starting benzene level was higher than the 0.62 vol% standard. If a company's average benzene level was at or below the standard to begin with, they would not have a need to generate early credits to postpone compliance since they could do nothing and still comply with the standard in 2011 via company averaging. Applying this assumption, one refinery which the model predicted to make both operational and small capital investments was assumed not to do so early. This further reduced the number of refineries predicted to make early operational changes from 47 to 46 and the number of refineries predicted to make early small capital investments from 39 to 38.

It is worth noting that refineries constrained by these last two conditions would go on to make the outlined model-predicted changes, just not earlier than required.

6.5.4.2 How are early credits calculated?

Before we estimate early credit generation, we must first explain how early credit baselines and annual average benzene levels are computed and briefly how the trigger point impacts early credit generation.

As mentioned earlier, refiners are eligible to generate early credits for making qualifying benzene reductions prior to the start of the program. Refiners must first establish individual benzene baselines for each refinery planning on generating early credits. Per § 80.1280, benzene baselines are defined as the annualized volume-weighted benzene content of gasoline produced at a refinery from January 1, 2004 through December 31, 2005. To qualify to generate early credits, refineries must make operational changes and/or improvements in benzene control technology to reduce gasoline benzene levels in accordance with § 80.1275.

Additionally, a refinery must produce gasoline with at least ten percent less benzene (on a volume-weighted annual average basis) than its 2004-2005 baseline. The purpose of setting an early credit generation trigger point is to ensure that changes in benzene level are representative of real process improvements. Without a trigger point, refineries could generate credits based on operational fluctuations in benzene level from year to year. This would compromise the environmental benefits of an ABT program because the early credits generated would have no associated benzene emission reduction value. A more detailed discussion on how we arrived at a 10 percent reduction trigger point is found in the proposal (EPA420-D-06-004, February 2006).

Once the 10% trigger point is met, refineries can generate early credits based on the entire benzene reduction. For example, if in 2008 a refinery reduced its annual benzene level from a baseline of 2.00 vol% to 1.50 vol% (below the trigger of 0.90 x 2.00 = 1.80 vol%), its benzene credits would be determined based on the difference in annual benzene content (2.00 - 1.50 = 0.50 vol%) divided by 100 and multiplied by the gallons of gasoline produced in 2008 (credits expressed in gallons of benzene).

Under the ABT program, the first early credit generation period is from June 1, 2007 through December 31, 2007, and subsequent early credit generation periods are the 2008, 2009, and 2010 calendar years (2008 through 2014 calendar years for small refiners). To estimate the number of early credits that would be generated during these years, we used the 2004 refinery model baseline (derived from benzene levels summarized in Table 6.5-1) to represent early credit baselines. The benzene level from which early credits are calculated is the volume-weighted average benzene concentration of all batches of gasoline produced during a given averaging period. This is referred to as the annual average benzene concentration. To estimate early credits, we used the benzene levels predicted by the refinery cost model to represent annual average benzene levels. For 2007, 2008, and 2009, we have used the post-operational change benzene levels reflected in Table 6.5-4. For 2010, we have used the benzene levels following the early small capital investments reflected in Table 6.5-5.

6.5.4.3 How many early credits do we predict will be generated?

By applying these criteria to the refinery cost model, we estimate that refineries making early operational changes and small capital investments in reformate technology from June 1, 2007 to December 31, 2010 could generate over 765 million gallons (MMgal) of benzene credits. A breakdown of the early credit generation by PADD is found below in Table 6.5-9.

Table 6.5-9. Early Credits Generated by PADD (gal Bz)

	2007	2008	2009	2010	Total
PADD 1	1,387,041	2,399,049	2,420,505	5,932,981	12,139,576
PADD 2	59,878,797	103,978,138	105,326,076	154,049,197	423,232,208
PADD 3	24,796,242	42,909,137	43,314,833	77,511,287	188,531,499
PADD 4	9,601,712	16,726,807	16,998,147	22,877,834	66,204,500
PADD 5 - CA	11,484,773	20,019,372	20,356,434	23,278,019	75,138,597
Total	**107,148,564**	**186,032,503**	**188,415,995**	**283,649,318**	**765,246,381**

In addition to the above-referenced early credits, small refiners are predicted to generate an additional 110 MMgal of credits from January 1, 2011 through December 31, 2014, bringing the total early credit generation to 875 MMgal. These additional early credits generated by small refiners have not been included in Table 6.5-9 to preserve confidential business information.

6.5.4.4 How many early credits will be demanded?

Early credits can be applied to the first three years of the program to comply with the 0.62 vol% annual average standard. This is governed by the three-year early credit life provision described in more detail in section 6.5.4.10. However, credits may not be used to meet the 1.3 vol% maximum average standard which begins July 1, 2012. In other words, refineries whose benzene levels are at or below 1.3 vol% following their early technology changes in 2010 can choose to use early credits to comply with the 0.62 vol% standard and postpone their final investment for up to three years. Refineries predicted to be above the maximum average standard in 2010 will not be able to rely exclusively on early credits. After July 1, 2012, these refineries will need to reduce benzene levels to meet the 1.3 vol% annual average standard. Once this hurdle has been met, they can choose to rely on early credits to meet the 0.62 vol% standard.

For example, consider a refinery whose annual average benzene level was 0.80 vol% in 2010. If the refinery did not make any additional benzene reductions in the first three years of the program, its early credit demand would be computed as follows. In 2011, its early credit demand (expressed in gallons of benzene) would be determined based on the difference between its annual average benzene level and the standard (0.80 – 0.62 = 0.18 vol%) divided by 100 and multiplied by its annual gasoline production volume. The early credit demand would be the same in 2012 and 2013, provided gasoline production did not change.

As another example, consider a refinery whose average benzene concentration was 1.60 vol% until July 1, 2012 when it was reduced to 0.80 vol% to meet the 1.3 vol% maximum average standard. If the refinery did not make any additional reductions in the first three years of the program, its early credit demand would be calculated as follows. In 2011, its early credit demand would be determined based on the difference between its starting annual average benzene level and the standard (1.6 – 0.62 = 0.98 vol%) divided by 100 and multiplied by its annual gasoline production volume. In 2012, its early credit demand would be the difference between the first half of the year’s average benzene level and the standard (1.6 – 0.62 = 0.98 vol%) divided by 100 and multiplied by the first half of the year’s gasoline production volume plus the difference between the second half of the year’s average benzene level and the standard (0.80 – 0.62 = 0.18 vol%) divided by 100 and multiplied by the second half of the year’s gasoline production volume.[F] In 2013, its early credit demand would be determined based on the difference between its final annual average benzene level and the standard (0.80 – 0.62 = 0.18 vol%) divided by 100 and multiplied by its annual gasoline production volume.

Applying this methodology to all 103 refineries, we anticipate that 579 million gallons of early benzene credits would be demanded from January 1, 2011 through December 31, 2013 as shown below in Table 6.5-10. In addition, we predict that small refiners would demand an additional 39 MMgal of credits from January 1, 2015 through December 31, 2017, bringing the total early credit demand to 618 MMgal. These additional early credits demanded by small refiners have not been included in Table 6.5-10 to preserve confidential business information.

[F] This is equivalent to computing the volume-weighted annual average benzene concentration in the second year (e.g., 1.2 vol%) and calculating the credit demand based on this value. However it’s worth noting that since 2012 is a transitional year, a refinery’s computed annual average benzene concentration could feasibly be above 1.3 vol% yet the refinery could still be on track for complying with the 1.3 vol% maximum average standard during the first compliance period (July 1, 2012 through December 31, 2013). The first compliance period is 18 months and subsequent compliance periods are the calendar years beginning with 2014.

Table 6.5-10. Early Credits Demanded by PADD (gal Bz)

	2011	2012	2013	Total
PADD 1	13,647,236	12,992,329	12,412,384	39,051,950
PADD 2	48,090,307	46,403,262	44,756,871	139,250,440
PADD 3	86,828,577	84,978,468	83,351,100	255,158,145
PADD 4	22,394,715	20,380,618	18,259,995	61,035,327
PADD 5 - CA	30,479,498	28,322,111	26,074,485	84,876,094
Total	**201,440,332**	**193,076,789**	**184,854,835**	**579,371,956**

As outlined above, we predict that there will be enough early credits generated to allow for refiners to postpone their final investments for up to three years or through January 2014 - the maximum time afforded by the early credit life provision. In additional, we predict that there will be a 40 percent surplus in early credits (total early credit generation is 875 MMGal, total early credit demand over the first three compliance years is only is 618 MMGal). To the extent that the predictions from the refinery cost model are directionally accurate, there would be a built-in early credit compliance margin which would essentially increase the certainty that early credits would be available to those in need, including small refiners.

6.5.4.5 How are standard credits calculated?

Beginning January 1, 2011, standard benzene credits can be generated by any refinery or importer that overcomplies with the 0.62 vol% gasoline benzene standard on an annual volume-weighted basis in 2011 and beyond. For example, if in 2011 a refinery's annual average benzene level was 0.52, its benzene credits (expressed in gallons of benzene) would be determined based on the margin of overcompliance with the standard (0.62 - 0.52 = 0.10 vol%) divided by 100 and multiplied by the its annual gasoline production volume. Likewise, if in 2012 the same refinery produced the same amount of gasoline with the same benzene content they would earn the same amount of credits. The credit generation opportunities for overcomplying with the standard continue indefinitely.

6.5.4.6 How much additional lead time would be generated by standard credits generated during the early credit "lag"?

From January 1, 2011 through December 31, 2013 while early credits are being used, we predict that standard credits will be generated by refineries that are already below the 0.62 vol% standard or plan to get there by making early technology changes. A summary of the predicted standard credit generation is found below in Table 6.5-11.

Table 6.5-11. Standard Credits Generated during 3-Year Early Credit Lag (gal Bz)

	2011	2012	2013	Total
PADD 1	12,548,070	13,149,182	13,866,802	39,564,053
PADD 2	7,064,755	6,862,297	6,656,029	20,583,080
PADD 3	34,125,185	35,584,771	37,202,521	106,912,477
PADD 4	0	0	0	0
PADD 5 - CA	653,573	748,092	836,160	2,237,825
Total	**54,391,583**	**56,344,342**	**58,561,511**	**169,297,436**

We calculate that enough standard credits will be generated during this period to extend the credit lag by another 16 months, or through May 2015. This will essentially allow refineries to maintain their 2010 post-operational change benzene levels a little longer following a similar credit demand scheme to that described above in Table 6.5-10.

For the above credit generation/demand calculations as well as those presented below, we have made a simplifying assumption that importers will play a negligible role in the overall ABT program. In other words, that beginning in 2011 importers will bring in gasoline that is compliant gasoline with the 0.62 vol% standard and thus will neither generate nor demand credits.

6.5.4.7 How do we estimate ongoing standard credit generation/demand?

Once refineries make their final investments in benzene control technology in (described above in section 6.5.3.5), nationwide gasoline benzene levels will be at 0.62 vol% on average. We predict that this will occur by May 2015 at the end of the total credit lag. At this point, the refinery cost model predicts that 50 refineries will be below the 0.62 vol% standard (generating standard credits) and 53 will be above (demanding standard credits). A summary of the resulting standard credit generation/demand scheme is found below in Table 6.5-12. We have chosen to present 2016 standard generation/demand (based on projected gasoline production levels) since 2015 is a transitional year with two sets of predicted benzene reductions.

Table 6.5-12. Standard Credits Generated/Demanded in 2016 & Beyond (gal/yr)

	Credits Generated by Refineries <0.62 vol%	Credits Demanded by Refineries >0.62 vol%	Net Credit Generation (+) or Demand (-)
PADD 1	20,197,659	3,859,615	16,338,044
PADD 2	20,423,752	22,768,665	-2,344,913
PADD 3	48,151,821	42,522,657	5,629,164
PADD 4	55,477	15,457,960	-15,402,483
PADD 5 - CA	4,478,444	8,698,256	-4,219,812
Total	**93,307,153**	**93,307,153**	**0**

Although, the above table shows credit generation and demand balancing in 2016 and beyond, our refinery cost model actually predicts that there will be a small surplus of standard credits if small refineries rely on early credits (as opposed to standard credits) for the first three years of their program (2015-2017). To the extent that the predictions from the refinery cost model are directionally accurate, there would be a built-in 39 MMgal standard credit surplus that would essentially increase the certainty that standard credits would be available to those in need. This would be an ongoing compliance margin that could effectively carry over from year-to-year (within the 5-year standard credit life provision) provided credits were used in the order they were generated.

6.5.4.8 What are the credit use provisions?

Refineries and importers can use benzene credits generated or purchased under the provisions of the ABT program to comply with the 0.62 vol% gasoline benzene standard in 2011 and beyond. As mentioned earlier, credits may not be used to demonstrate compliance with the 1.3 vol% maximum average standard beginning in July 2012 (July 2016 for small refiners). Refineries must reduce gasoline benzene levels to ≤ 1.3 vol% on average, essentially placing a ceiling on credit use.

All benzene credits are to be used towards compliance on a one-for-one basis, applying each benzene gallon credit to offset the same volume of benzene produced in gasoline above the standard. For example, if in 2011 a refinery’s annual average benzene level was 0.72 vol%, the number of benzene credits needed to comply (expressed in gallons of benzene) would be determined based on the margin of under-compliance with the standard (0.72 - 0.62 = 0.10 vol%) divided by 100 and multiplied by the annual gasoline production volume.

Early credits may be used equally and interchangeably with standard credits to comply with the 0.62 vol% benzene standard in 2011 and beyond. However, based on the credit life provisions described below, we predict that refiners would choose to use early credits first before relying on standard credits. Likewise, we expect that refineries would choose to use standard credits in the order in which they were generated (first in, first out) to avoid the likelihood that they would expire and become worthless.

6.5.4.9 Are there any geographic restrictions on credit trading?

We are not placing any geographic restrictions on where credits may or may not be traded and thus are finalizing a nationwide ABT program. If PADD restrictions were placed on credit trading, there would be an imbalance between the supply and demand of credits. As shown in Table 6.5-12, if there was no inter-PADD trading allowed, PADDs 1 and 3 would have a surplus of standard credits while PADDs 2, 4, and 5 would have a shortage of credits. This would result in surplus credits expiring and becoming worthless in PADDs 1 and 3 while at the same time PADDs 2, 4, and 5 would experience insufficient credit availability. This would force refineries with more expensive benzene technology costs in PADDs 2, 4, and 5 to comply increasing the total compliance costs. Overall, restricting credit trading by PADD would result in a more expensive, less flexible, and less efficient program.

Additionally, we believe that restricting credit trading could reduce refiners' incentive to generate credits and hinder trading essential to this program. In other fuel standard ABT programs (e.g., the highway diesel sulfur program), fuel credit trading restrictions were necessary to ensure there was adequate low-sulfur fuel available in each geographic area to meet the corresponding vehicle standard. Since there is no vehicle emission standard associated with this rulemaking that is dependent on gasoline benzene content, we do not believe there is a crucial need for geographic trading restrictions. We project that under the proposed nationwide ABT program, all areas of the country would still experience large reductions in gasoline benzene levels as shown in Table 6.5-13.

Table 6.5-13. Predicted Reductions in Benzene Level by PADD

	Starting Bz Levels (vol%)[a]	Ending Bz Levels (vol%)[b]	Overall % Bz Reduction
PADD 1	0.67	0.52	22%
PADD 2	1.26	0.63	50%
PADD 3	0.85	0.61	28%
PADD 4	1.56	0.90	42%
PADD 5 - CA	1.80	0.69	62%
Total	1.00	0.62	38%

[a] Based on 2004 gasoline benzene production levels

[b] Based on model-predicted benzene reductions

6.5.4.10 What are the credit life provisions?

Early credits must be used towards compliance within three years of the start of the program; otherwise they will expire and become invalid. In other words, early credits generated or obtained under the ABT program must be applied to the 2011, 2012, or 2013 compliance years. Similarly, early credits generated/obtained and ultimately used by small refiners must be applied to the 2015, 2016, or 2017 compliance years. No early credits may be used towards compliance with the 2014 year. Our intent is that a break in the early credit application period will funnel surplus early credits facing expiration to small refiners in need.

Standard credits must be used within five years from the year they were generated (regardless of when/if they are traded). For example, standard credits generated in 2011 would have to be applied towards the 2012 through 2016 compliance year(s); otherwise they would expire and become invalid. To encourage trading to small refiners, there is a credit life extension for standard credits traded to and ultimately used by small refiners. These credits may be used towards compliance for an additional two years, giving standard credits a maximum seven-year life. For example, the same above-mentioned standard credits generated in 2011, if traded to and ultimately used by a small refiner, would have until 2018 to be applied towards compliance before they would expire.

6.5.4.11 Consideration of credit availability

Our ABT analysis presented here assumes perfect nationwide credit trading. In reality, we recognize that not all credits generated may necessarily be available for sale. Since EPA is not managing the credit market, credit trading will be at the generating parties’ discretion. With such a program, there are usually concerns that credits may not be made available on the market, especially among single refinery refiners. To determine the likelihood of credit availability, we have assessed the model-predicted credit generation and trading by company. To preserve confidentiality, each of the 39 refining companies have been assigned a random/discrete company ID. The resulting early and standard credit generation by company is found in Tables 6.5-14 and 6.5-15, respectively.

Table 6.5-14. Early Credit Trading by Company

Company	Early Credits Generated (gal Bz)	Early Credits Demanded (gal Bz)	Surplus / Shortage (gal Bz)	% of Net Early Credit Supply	% of Net Early Credit Demand
Company 1	0	0	0		
Company 2	0	3,539,225	-3,539,225		1.86%
Company 3	50,206,864	3,867,817	46,339,047	10.36%	
Company 4	8,048,513	1,095,769	6,952,744	1.55%	
Company 5	865,453	187,023	678,430	0.15%	
Company 6	48,098,896	41,666,480	6,432,416	1.44%	
Company 7	89,419,215	69,297,769	20,121,446	4.50%	
Company 8	35,628,541	59,287,855	-23,659,314		12.41%
Company 9	6,627,618	975,466	5,652,152	1.26%	
Company 10	0	352,305	-352,305		0.18%
Company 11	34,272,947	184,192	34,088,755	7.62%	
Company 12	0	555,401	-555,401		0.29%
Company 13	3,173,008	12,199,184	-9,026,177		4.73%
Company 14	7,072,043	1,579,656	5,492,387	1.23%	
Company 15	0	1,115,973	-1,115,973		0.59%
Company 16	48,059,499	43,424,323	4,635,176	1.04%	
Company 17	5,554,977	10,157,863	-4,602,886		2.41%
Company 18	410,372	2,167,872	-1,757,500		0.92%
Company 19	0	5,752,804	-5,752,804		3.02%
Company 20	0	73,894,178	-73,894,178		38.76%
Company 21	0	5,505,778	-5,505,778		2.89%
Company 22	125,647,950	38,587,398	87,060,552	19.46%	
Company 23	0	18,800,732	-18,800,732		9.86%
Company 24	27,472,537	13,929,960	13,542,577	3.03%	
Company 25	19,718,663	6,747,108	12,971,555	2.90%	
Company 26	146,615,646	105,384,519	41,231,126	9.21%	
Company 27	14,140,554	18,007,249	-3,866,695		2.03%
Company 28	32,608,280	4,440,272	28,168,008	6.30%	
Company 29	69,312,293	20,330,411	48,981,882	10.95%	
Company 30	3,492,799	25,103,447	-21,610,648		11.34%
Company 31	0	4,792,226	-4,792,226		2.51%
Company 32	9,666,313	3,053,908	6,612,405	1.48%	
Company 33	0	5,214,858	-5,214,858		2.74%
Company 34	0	615,214	-615,214		0.32%
Company 35	16,199,400	6,648,814	9,550,586	2.13%	
Company 36	53,749,916	616,417	53,133,499	11.87%	
Company 37	0	5,980,295	-5,980,295		3.14%
Company 38	12,754,685	0	12,754,685	2.85%	
Company 39	6,580,236	3,516,739	3,063,497	0.68%	
Total	**875,397,218**	**618,576,501**	**256,820,716**	**100.00%**	**100.00%**

As shown above in Table 6.5-14, 20 of the 39 companies have the potential to generate more early credits than they could possibly use during the 2011-2013 early credit generation period (or 2015-2017 time frame for small refiners). The refinery concentration of early credits ranges from <1% to 19%. Since there does not appear to be substantial credit market concentration, there should be significant potential for the 18 refiners seeking early credits to postpone future investments to find them. Additionally, 60% of the early credits are anticipated to be used by the companies which generated them. Because these internal company trades are the easiest to plan and carry out, there is a high likelihood that the predicted early credit reliance would actually occur.

Table 6.5-15. Standard Credit Trading by Company

Company	Std Credits Generated (gal Bz/yr)	Std Credits Demanded (gal Bz/yr)	Surplus / Shortage (gal Bz/yr)	% of Net Std Credit Supply	% of Net Std Credit Demand
Company 1	6,812,377	0	6,812,377	13.12%	
Company 2	0	1,208,597	-1,208,597		2.33%
Company 3	2,005,577	1,320,807	684,770	1.32%	
Company 4	0	374,190	-374,190		0.72%
Company 5	0	43,765	-43,765		0.08%
Company 6	1,837,570	4,093,155	-2,255,585		4.34%
Company 7	15,354,274	10,653,361	4,700,913	9.05%	
Company 8	11,052,495	7,156,828	3,895,667	7.50%	
Company 9	0	333,108	-333,108		0.64%
Company 10	0	120,307	-120,307		0.23%
Company 11	0	62,899	-62,899		0.12%
Company 12	0	189,662	-189,662		0.37%
Company 13	11,785,789	0	11,785,789	22.69%	
Company 14	474,273	0	474,273	0.91%	
Company 15	0	304,052	-304,052		0.59%
Company 16	2,796,506	0	2,796,506	5.38%	
Company 17	0	2,491,856	-2,491,856		4.80%
Company 18	0	740,299	-740,299		1.43%
Company 19	0	1,964,504	-1,964,504		3.78%
Company 20	724,306	14,072,746	-13,348,441		25.70%
Company 21	889,237	1,551,206	-661,970		1.27%
Company 22	6,639,988	4,070,613	2,569,375	4.95%	
Company 23	56,834	477,093	-420,259		0.81%
Company 24	0	4,756,891	-4,756,891		9.16%
Company 25	0	2,418,278	-2,418,278		4.66%
Company 26	6,342,861	18,239,546	-11,896,686		22.90%
Company 27	1,505,238	121,503	1,383,736	2.66%	
Company 28	548,378	1,598,961	-1,050,583		2.02%
Company 29	12,113,619	6,008,460	6,105,159	11.75%	
Company 30	10,958,768	3,811,154	7,147,614	13.76%	
Company 31	147,283	0	147,283	0.28%	
Company 32	0	1,095,767	-1,095,767		2.11%
Company 33	0	1,831,627	-1,831,627		3.53%
Company 34	1,233,715	0	1,233,715	2.38%	
Company 35	0	2,113,754	-2,113,754		4.07%
Company 36	591,320	107,556	483,764	0.93%	
Company 37	0	2,042,189	-2,042,189		3.93%
Company 38	1,718,955	0	1,718,955	3.31%	
Company 39	0	214,625	-214,625		0.41%
Total	95,589,360	95,589,360	0	100.00%	100.00%

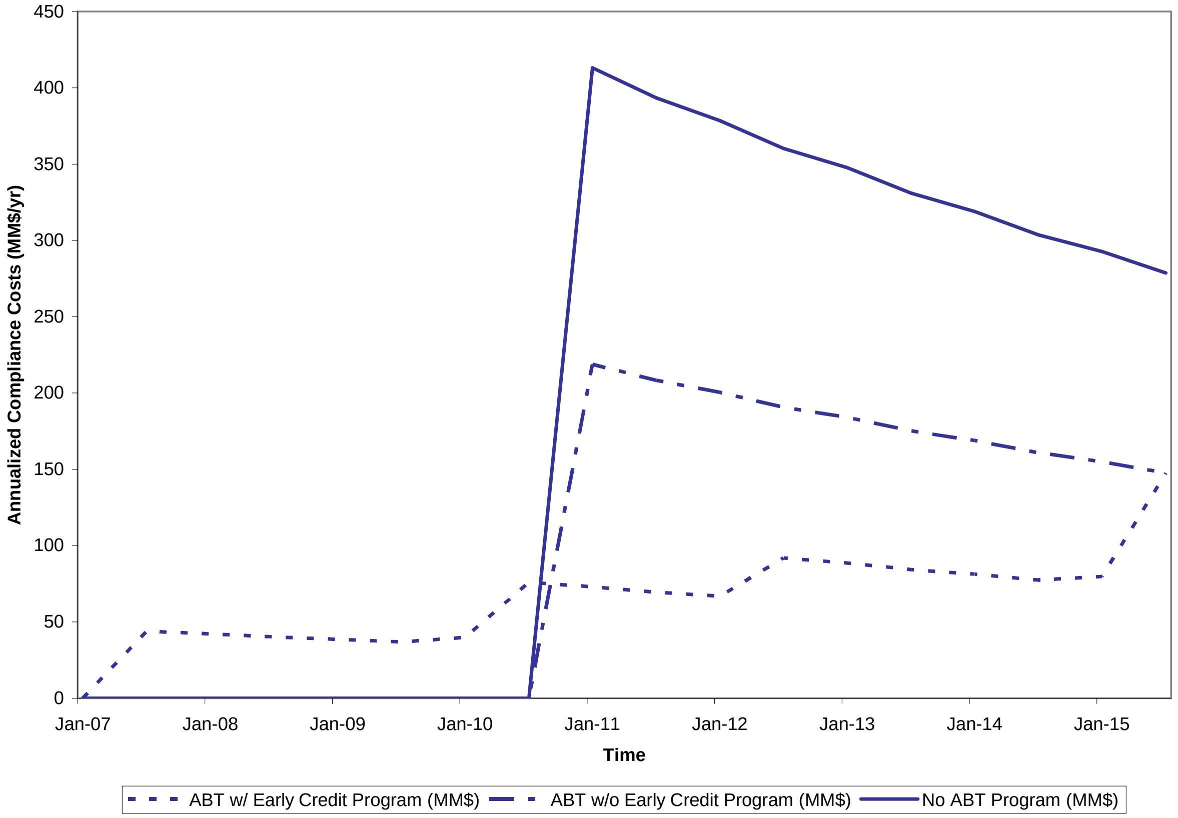
As shown above in Table 6.5-15, 15 of the 39 companies have the potential to generate more standard credits than they could use up in a given year. The refinery concentration of standard credits ranges from <1% to 23%. Since there does not appear to be substantial credit market concentration, there should be significant potential for the 24 refiners predicted to rely upon credits for compliance with the 0.62 vol% standard to find them. Additionally, 35% of the standard credits are anticipated to be used by the companies which generated them. Because these internal company trades are the easiest to plan and carry out, there is a high likelihood that the predicted reliance on standard credits would actually occur.

6.5.4.12 What is the economic value of the ABT program?

In addition to earlier benzene reductions and a more gradual phase-in of the 0.62/1.3 vol% standards (as shown above in Figure 6.5-1), the ABT program results in a more cost-effective program for the refining industry. Our modeling shows that allowing refiners to average benzene levels nationwide to meet the 0.62 vol% standard reduces ongoing compliance costs by about 50% - from 0.51 to 0.27 cents per gallon (as explained in section 9.6.2).

Our modeling further suggest that the early credit program we are finalizing results in the lowest possible compliance costs during the phase-in period (represented as the area under the curve in Figure 6.5-2). Without an early credit program, the total cost incurred by the refining industry from June 1, 2007 through December 31, 2015 is estimated to be $905 million (2003 dollars). With an early credit program, the total amortized capital and operating costs incurred during the same phase-in period is reduced to $608 million, providing about $300 million in savings. In the absence of an ABT program altogether, the total cost incurred during the phase-in period would be $1.7 billion. As a result, the ABT program we are finalizing could save the refining industry up to $1.1 billion in compliance costs from 2007-2015. For a more detailed discussion on compliance costs, refer to section 9.6.2.

Figure 6.5-2. Costs Savings Associated with ABT Program Annualized Compliance Costs vs. Time



The aforementioned program costs and resulting cost savings were estimated based on compliance costs presented in section 9.6.2 and adjusted back to 2007 to account for the time-value of money based on a 7% average rate of return. The computed annual compliance costs for this ABT analysis also consider the projected growth in gasoline production. Gasoline growth rates from 2004-2012 were estimated by the refinery cost model and future growth rates were obtained from EIA’s AEO 2006. A summary of the semi-annual gasoline inputs and respective compliance costs is found below in Table 6.5-16.

Table 6.5-16. ABT Program Cost Comparison

	Total Gasoline Production (MMbbl)	ABT w/ Early Credit Program (MM$)	ABT w/o Early Credit Program (MM$)	No ABT Program (MM$)
Jan-07		0	0	0
Jul-07	1,371	22	0	0
Jan-08	1,385	21	0	0
Jul-08	1,385	20	0	0
Jan-09	1,400	19	0	0
Jul-09	1,400	18	0	0
Jan-10	1,416	40	0	0
Jul-10	1,416	38	0	0
Jan-11	1,431	36	109	207
Jul-11	1,431	35	104	197
Jan-12	1,446	33	100	189
Jul-12	1,446	46	95	180
Jan-13	1,466	44	92	174
Jul-13	1,466	42	88	165
Jan-14	1,485	41	84	160
Jul-14	1,485	39	80	152
Jan-15	1,503	40	77	146
Jul-15	1,503	74	74	139
Total	**24,436**	**608**	**905**	**1,709**

6.6 Feasibility for Recovering Octane

The use of the various benzene control technologies modeled would affect each refinery’s octane in various ways. Rerouting the benzene precursors, adding a benzene saturation unit, adding a new extraction unit, or revamping an existing one, all would reduce the octane of gasoline. In the case that the rerouted benzene precursors are sent to an isomerization unit, there would be a slight increase in octane for the rerouted stream. We evaluated the average octane impacts of each of these technologies on reformate and on the gasoline pool for those refineries assumed to be taking action under the benzene control standard. As we compiled these figures, we observed that there is a large variance in octane impacts for these technologies. The reason for much of the variance in octane impacts is that many refineries are estimated to be using benzene precursor rerouting or some benzene extraction today. These technologies reduce the octane of reformate today. Thus when the reformate treating technologies are applied the octane loss is smaller than if the refinery is not already using benzene precursor rerouting or benzene extraction. Since the refineries with large octane impacts would need to recover all of their octane loss caused by benzene controls, we provide the maximum octane impacts in addition to the average octane impacts. The average and maximum octane impacts on gasoline for each benzene control technology are summarized in Table 6.6-1.

Table 6.6-1. Octane Impacts for Control Technologies Expected to Be Used to Meet the Benzene Standards ((R+M)/2)

	Benzene Precursor Rerouting	Benzene Precursor Rerouting followed by Isomerization of Benzene Precursors	Benzene Saturation	Extraction
Average Octane Impacts	0.13	0.12	0.25	0.13
Maximum Octane Impacts	0.35	0.34	0.40	0.20
Estimated Number of Benzene Control Technologies under the MSAT2 Program	26	28	11	23

We assessed the extent to which various means for recovering octane would have to be applied to recover the octane reduced by the application of benzene control technologies. The various octane recovery means we evaluated included revamping certain octane producing units to produce more of that blendstock, purchasing and blending in high octane blendstocks, and reducing the production of premium gasoline. As shown in Table 6.6-1, depending on a refiner's benzene control technology selection, the volume-weighted average octane impact for those refineries which take steps to reduce their benzene levels averaged 0.13 octane numbers. When weighted across the entire gasoline pool, this decreases to 0.08 octane numbers. The maximum octane loss that we observed over all the technologies is a loss of 0.40 octane numbers. We assess below the ability for differing octane recovery means to recover 0.13, and 0.40 octane number reductions in the gasoline pool, which represents the average and maximum reduction in octane numbers.

Alkylate averages about 93 octane numbers and because it is very low in benzene it is an ideal blendstock for recovering lost octane. Alkylate can be produced within a refinery or it could be purchased from outside sources. Other blendstocks similar to alkylate are isooctane and isooctene. Depending on the feedstocks, isooctane and isooctene can have an octane as high as 100. Along with alkylate, isooctane and isooctene are likely replacements for the phase-out of MTBE by reusing the MTBE feedstocks. Because isooctane and isooctene will largely be produced when MTBE is phased out of gasoline and used to explicitly replace MTBE, it will not be considered in this analysis, although it could still play a marginal role for octane recovery. In Table 6.6-2 below, we estimate the amount of alkylate which would have to be blended into a refiner's gasoline pool to recover the various octane losses described above.

Isomerization converts straight chain hydrocarbons into branched chain hydrocarbons and can also saturate benzene. The isomerization unit increases the octane of light straight run, a gasoline blendstock which averages an octane number of 70, into a gasoline blendstock with an average octane number of about 80. While isomerate is not a high octane blendstock and is generally not sold as one, it is very useful for increasing the octane of a refiner's gasoline while saturating benzene at the same time. In Table 6.6-2, we estimate the volume of light straight run that would have to be isomerized to recover the various octane losses described above.

Ethanol's very high octane number of 115 allows making up the octane loss using a smaller volume than the other blendstocks. Ethanol is an economical source of octane in part due to the federal 51 cents per gallon subsidy. It contains a very small amount of benzene (benzene is present in ethanol only because gasoline is added as a denaturant). The Energy Policy Act of 2005 (EPAct) recently established a renewable fuels requirement that is expected to predominantly be met with the addition of ethanol into gasoline. An estimated 4 billion gallons of ethanol was blended into gasoline nationwide in 2005. By 2012, the EPAct calls for 7.5 billion gallons of renewable fuels to be blended into gasoline and actual ethanol use is anticipated to be considerably higher due to market forces. The increased use of ethanol provides a synergistic match with the octane needs of the benzene standard. In Table 6.6-2 we summarize the volume of ethanol that would have to be blended into gasoline to recover a range of octane losses.

Finally premium gasoline usually meets either a 91 or 93 octane number rating, while regular grade gasoline must meet an 87 octane number requirement, although for high altitude areas the requirement is relaxed to an 85 octane number requirement. The recent increase in energy prices resulted in a reduced demand for premium grade gasoline. From 2000 to 2005, the fraction that premium gasoline comprises of total gasoline consumed in the U.S. decreased from 20 percent to 12 percent. Considering that this reduced demand for premium grade gasoline may continue, we evaluated the extent that the demand in premium grade gasoline would have to continue to be supplanted by regular grade gasoline to make up for the projected loss of octane due to benzene reduction in gasoline (this supplanted octane production means that these refineries producing less premium gasoline would have the potential to increase their octane production potential by this same amount). This shift in premium gasoline demand to regular grade demand to recover the range of octane losses is described in Table 6.6-2.

Table 6.6-2. Percent Changes in Gasoline Content for Recovering Octane Shortfalls (volume percent of gasoline)

	0.13 Octane Number Loss	0.40 Octane Number Loss
Isomerizing Light Straight Run Naphtha	1	4
Blending in Alkylate	2	7
Blending in Ethanol	0.5	2
Reduced 91 or 93 ON Premium Grade Gasoline	3	10

Isomerizing a refinery’s gasoline blendstocks is effective because in addition to addressing octane, it can also treat the benzene normally found in gasoline. It would not be an available technology in those refineries that are already fully using isomerization. The refinery-by-refinery cost model estimates that light straight run feedstock to the isomerization unit typically comprises about 7 percent of each refinery’s gasoline pool so it potentially could meet the octane needs of even the greatest octane needs caused by this rulemaking if isomerization is not already being used. Even those refineries that will be isomerizing all their light straight run prior to the implementation of the benzene standard could reroute the six carbon hydrocarbons around the reformer and send this stream to an isomerization unit to recover at least a part of the octane loss associated with the benzene reduction. An average octane loss of 0.14 octane numbers and the refinery-specific maximum 0.40 octane numbers would require an additional 1 volume percent and 4 percent of the light straight run currently blended into gasoline to be isomerized, respectively.

Alkylate's moderate octane value requires a relatively large volume to make up for the octane losses associated with the removal of benzene. At the estimated highest octane loss, the volume of alkylate would have to nearly double relative to the 12 percent typically blended into gasoline in 2003. Additional alkylate may be able to be produced by increasing the severity of the FCC unit, if there is capacity to do so, that would increase the production of feedstocks to the alkylate unit. Alkylate's very desirable gasoline blending properties, which is high octane, low RVP and sulfur and very low benzene, encourages its use. To replace an average octane loss of 0.14 octane numbers and the refinery-specific maximum 0.40 octane numbers, a refinery would need to produce or purchase and blend in an additional 2 volume percent and 7 percent of alkylate into their gasoline, respectively.

Ethanol is very high in octane which allows the recovery of lost octane caused by the treating of benzene with a smaller volume than the other octane recovery means considered. The additional volume of ethanol expected to be blended into gasoline under EPAct makes it a likely candidate for an octane replacement for a benzene standard. If all of EPAct's renewable requirement is met with the blending of ethanol into gasoline, the 3½ additional billion gallons of ethanol that would be blended into gasoline between today and 2012 would increase ethanol's content in gasoline from 2.8 to 4.7 volume percent, a 1.9 volume percent increase in all U.S. gasoline. To replace an average octane loss of 0.14 octane numbers and the refinery-specific maximum 0.40 octane numbers, a refiner would need to blend in an additional 0.5 volume percent and 2 percent of ethanol in their gasoline, respectively. This provides far more than the octane number increase needed to recover the average octane loss of refineries that reduce their benzene levels to comply with the benzene standard, and even more ethanol use is expected. The phasing-in, under the ABT program, of the benzene standard and its associated octane loss would coincide with the period that EPAct's renewable requirement phases in and ethanol's use expands.

The decreasing demand for premium grade gasoline would provide another means for refiners to recover the octane lost from benzene control. The demand for premium has been supplanted by a higher demand for lower octane regular, freeing up octane producing potential in refineries. Between 2000 and 2005, premium gasoline demand decreased by 8 volume percent. This decrease represents nearly a 0.4 octane number decrease in the gasoline pool. To replace an average octane loss of 0.14 octane numbers and the maximum refinery-specific 0.40 octane numbers, a refiner would need to have shifted 3 volume percent and 10 percent of their gasoline production from premium grade to regular grade, respectively. This indicates that there may be more than enough excess octane producing potential already to satisfy a loss in octane that would be expected to begin in 2007 under the benzene control program.

6.7 Will the Benzene Standard Result in Any New Challenges to the Fuel Distribution System or End-Users?

There are two potential concerns regarding whether the implementation of the benzene standards would adversely impact the fuel distribution system and end-users of gasoline. The first potential concern relates to whether additional product segregation would be needed. The small refiner and ABT provisions in today's notice would result in some refiners producing gasoline with benzene levels below the standard while other refiners would meet the standard through the use of credits or under the small refiner provisions. Thus, gasoline benzene levels would vary on a refinery by refinery basis, much as they always have. Today's proposal would not result in the need for the segregation of additional grades of gasoline in the distribution system. Consequently, we do not the MSAT2 program to require construction of new storage tanks in the fuel distribution system or result in other facility or procedural changes to the gasoline distribution system.

The second potential concern relates to whether the gasoline property changes that might result from the benzene standard could adversely impact the equipment in the fuel distribution system or end-user vehicles. We are aware that a stringent benzene standard is associated with a potential need to make up for some loss of octane. If octane replacement is warranted, we anticipate that refiners accomplish this by blending ethanol or other suitable octane-rich blendstocks, or in some cases by increasing the production of other octane rich refinery streams. Consequently, we expect that there would be no net change in gasoline octane levels as a result of the benzene standards, and no impact on equipment in the distribution system.

We are aware of no other gasoline property changes that might be of potential concern to the distribution system.

6.8 Impacts on the Engineering and Construction Industry

An important aspect of the feasibility of a fuel program is the ability of the refining industry to design and construct any new equipment required to meet the new fuel quality standard. In this section we assess the impact of the gasoline benzene program on demand for engineering design and construction personnel. We will focus on three types of workers that are needed to design and build new equipment involved in benzene reduction: front-end designers, detailed designers, and construction workers. This analysis builds on those done for the 2007 heavy-duty highway and nonroad diesel sulfur rulemakings, and will include the impacts of these programs on the industry's ability to comply with the new benzene standard. We compare the overall need for these workers to estimates of total employment in these trades. In general, it would also be useful to expand this assessment to specific types of construction workers which might be in especially high demand, such as pipe-fitters and welders. However, we are not aware of appropriate estimates of the number of people currently employed in these job categories. Thus, it is not possible to determine how implementing these programs might stress the number of personnel needed in these types of specific job categories.

To carry out this analysis we first estimated the level of design and construction resources required for new and revamped benzene reduction equipment. We next projected the number of these units which would be needed under the gasoline benzene program and how the projects might be spread out over time. We then developed a schedule for when the various resources would be needed throughout each project. Finally, we projected the level of design and construction resources needed in each month and year from 2000 through 2015 and compared this to the number of people employed in each job category.

6.8.1 Design and Construction Resources Related to Benzene Reduction Equipment

The calculation of job-hours necessary to design and build individual pieces of equipment and the number of pieces of equipment per project mirrors the analysis done for the nonroad diesel rulemaking promulgated in 2004. The methodology was originally based on a technical paper authored by Moncrief and Ragsdale[28] in support of a National Petroleum Council study of gasoline and diesel fuel desulfurization and other potential fuel quality changes. Unit types we considered for construction to meet the new standard are light naphtha splitters (LNS) for routing benzene pre-cursors around the reformer unit, benzene saturation units, and benzene extraction units.[G] We assumed that benzene saturation equipment projects were of the same scale as described for a hydrotreater project, while LNS units were 50% smaller projects and benzene extraction units were conservatively 50% larger projects. Consistent with Moncrief and Ragsdale, revamps were assumed to use fewer resources than a new unit. All benzene saturation and LNS units are expected to be new installations, while work on benzene extraction units is split between new and revamped units. Estimated resource needs for these projects are summarized in Table 6.8-1.

Table 6.8-1. Design and construction factors for benzene reduction equipment.

Project type	**LNS**		**Saturation**	**Extraction**	
	New	**Revamp***	**New**	**New**	**Revamp***
Number of pieces of equipment	30	15	60	90	30
Job-hours per piece of equipment					
Front-end design	300	150	300	300	150
Detailed design	1200	600	1200	1200	600
Direct and indirect construction	9150	4575	9150	9150	4575

*Equipment revamps were assumed to use half the usual job-hours per piece of equipment

6.8.2 Number and Timing of Benzene Reduction Units

The next step was to estimate the types of equipment modifications necessary to meet the benzene standard. This was a complex task due to the ABT program, which allows refiners the flexibility to balance their own benzene reductions with purchase of credits from reductions elsewhere, resulting in different types of equipment projects being chosen depending on what is most economical for a particular refinery. Detailed analysis of equipment choices was carried out in our assessment of the costs of the fuel program.[H] Those results provide inputs for this

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[G] These technologies are discussed in detail in Section 6.3.2 of this RIA.

[H] Equipment choice and project timing is covered in more detail in discussions of the averaging, banking, and trading analyses (see Section 6.5 of this RIA).

analysis, shown in Table 6.8-2.

Once equipment types were tabulated, timing of projects had to be considered. Worst-case scenarios of unit startup dates of January 1, 2011 are unlikely for a number of reasons. First, the early credit program is expected to encourage refiners planning relatively simple process modifications, such as revamping or de-bottlenecking of equipment for light naphtha splitting, to take these actions shortly after finalization of the standards. Furthermore, given the flexibility of ABT and the different approaches available for benzene reduction, projects will differ in complexity and scope. Expected project timing, assuming some early compliance, is summarized in Table 6.8-2.[I]

Table 6.8-2. Number and timing of startup for benzene reduction projects.

Start-up date		**2010**	**2012**	**2015 (Jan)**	**2015 (May)**
LNS:	New	31	0	2	8
Saturation:	New	0	7	4	5
Extraction:	New	0	0	0	3
	Revamp	7	0	0	6

6.8.3 Timing of Projects Starting Up in the Same Year

Even if refiners all desired to complete their project on the same date, their projects would begin over a range of months. Thus, two projects scheduled to start up at exactly the same time are not likely to proceed through each step of the design and construction process at the same time. In addition, it is reasonable to assume design and construction of units will be spread out over the calendar year. We assumed 25 percent of the units would initiate design and thus, startup, each quarter leading up to the date upon which they had to be operational.

6.8.4 Timing of Design and Construction Resources Within a Project

The next step in this analysis was to estimate how the engineering and construction resources are spread out during a project. For the nonroad diesel rulemaking we developed a distribution of each type of resource across the duration of a project for the 2007 heavy-duty highway and nonroad diesel sulfur programs, and this methodology was extended for this rulemaking. The fractions of total hours expended each month were derived as follows.

[I] *Ibid.*

Per Moncrief and Ragsdale, front end design typically takes six months to complete. If 25 percent of the refineries scheduled to start up in a given year start their projects every quarter, each subsequent group of the refineries starts when the previous group is halfway through their front end design. Overall, front end design for the four groups covers a period of 15 months, or six months for the first group plus six months for each of the three subsequent groups. In spreading this work out over the 15 months, we assumed that the total engineering effort would be roughly equal over the middle nine months. The effort during the first and last three month periods would be roughly two-thirds of that during the peak middle months. The same process was applied to the other two job categories.[j] The distribution of resources is summarized in Tables 6.8-3 and 6.8-4.

In the case of projects to be completed for 2010, front end design schedules were compressed to half. This seemed reasonable, given that these early projects are expected to either be installation of LNS units or revamps of other units, which do not require extensive design work.

Table 6.8-3. Duration of project phases.

	Front-end design (2010)	**Front-end design (2012+)**	**Detailed engineering (All years)**	**Construction (All years)**
Duration per project	3 months	6 months	11 months	14 months
Total duration for projects starting up in a given calendar year	7 months	15 months	20 months	23 months

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[j] The reader is referred to the Final Regulatory Impact Analyses for the 2007 Heavy Duty Highway Diesel rulemaking (EPA420-R-00-026, Chapter IV Section B.1) and the Nonroad Diesel rulemaking (EPA420-R-04-007, Chapter 5.7) for more detailed description of the methodology used.

Table 6.8-4. Distribution of personnel requirements throughout project.

	Fraction of total hours expended by month for completion years shown			
Month	**Front-end design (2010)**	**Front-end design (2012+)**	**Detailed engineering (All years)**	**Construction (All years)**
1	0.100	0.050	0.020	0.030
2	0.100	0.050	0.030	0.030
3	0.200	0.050	0.040	0.030
4	0.200	0.078	0.040	0.040
5	0.200	0.078	0.040	0.040
6	0.100	0.078	0.050	0.040
7	0.100	0.078	0.050	0.040
8		0.078	0.060	0.050
9		0.078	0.065	0.050
10		0.078	0.075	0.055
11		0.078	0.075	0.055
12		0.078	0.075	0.060
13		0.050	0.060	0.060
14		0.050	0.060	0.055
15		0.050	0.050	0.055
16			0.050	0.050
17			0.040	0.050
18			0.040	0.040
19			0.030	0.040
20			0.020	0.040
21				0.030
22				0.030
23				0.030

6.8.5 Projected Levels of Design and Construction Resources

We calculated the number of workers in each of the three categories required in each month by applying the distributions of the various resources per project (Table 6.8-4) to the number of new and revamped units projected to start up in each calendar year (Table 6.8-2) and the number of person-hours required per project (Table 6.8-1). We converted hours of work into person-years by assuming that personnel were able to actively work 1877 hours per year, or at 90 percent of capacity assuming a 40-hour work week. We then determined the maximum number of personnel needed in any specific month over the years 2007-2015 for each job category both with and without the new benzene control program. The results are shown in Table 6.8-5.

In addition to total personnel required, the corresponding percentage of the relevant U.S. workforce is also shown. These percentages were based on estimates of recently available U.S. employment levels for the three job categories given in Moncrief and Ragsdale: 1920 front end design personnel, 9585 detailed engineering personnel, and roughly 160,000 construction workers. The figure for construction workers was given as 80,000 specifically for the Gulf Coast, where it is estimated that half of refining projects will take place. Based on this, we estimated the available pool of construction personnel nationwide at twice that figure, or

160,000, under the assumption that construction personnel would be distributed proportional to refining capacity on a geographical basis.

Table 6.8-5. Maximum monthly personnel demand.

Program	**Parameter**	**Front-end design**	**Detailed Engineering**	**Construction**
Tier 2 gasoline sulfur, Highway and nonroad diesel sulfur	Max. number of workers	758 (Mar '03)	2,720 (Mar '04)	17,646 (November '04)
	Current workforce*	40%	28%	11%
Gasoline benzene	Max. number of workers	763 (Apr '07)	2,720 (Mar '04)	17,646 (November '04)
	Current workforce*	40%	28%	11%

*Based on recent U.S. employment in trades listed. Year and month of maximum personnel demand is shown in parentheses.

Shown in Table 6.8-5, the gasoline benzene program has a projected maximum monthly requirement for front end design personnel equivalent to the level seen in 2003 for previous programs. Peaks in the other two job categories' monthly personnel demand projected for this program remain below levels previously seen for prior programs. Based on this analysis, projected demand levels represent less than half of the estimated front-end design workforce, and less than one third of the estimated workforce in the detailed design and construction trades

Figures 6.8-1 through 6.8-3 illustrate that average monthly personnel demand trends for the gasoline benzene program, based on annual workload, generally occur after significant peaks related to other programs have passed. Given these results, we believe that the E&C industry is capable of supplying the refining industry with the personnel necessary to comply with the gasoline benzene program.

Figure 6.8-1. Projected Average Monthly Front-End Engineering Personnel Demand Trends 2000-2015.

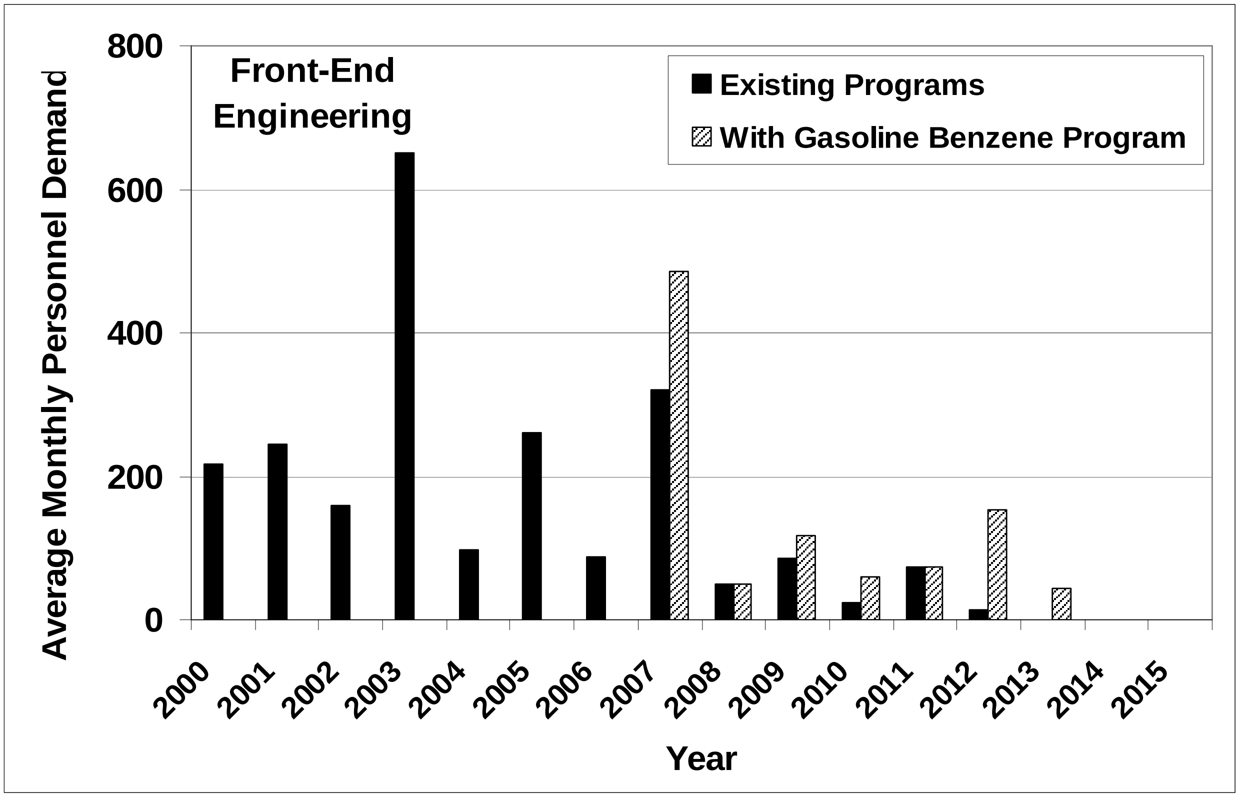


Figure 6.8-2. Projected Average Monthly Detailed Engineering Personnel Demand Trends 2000-2015.

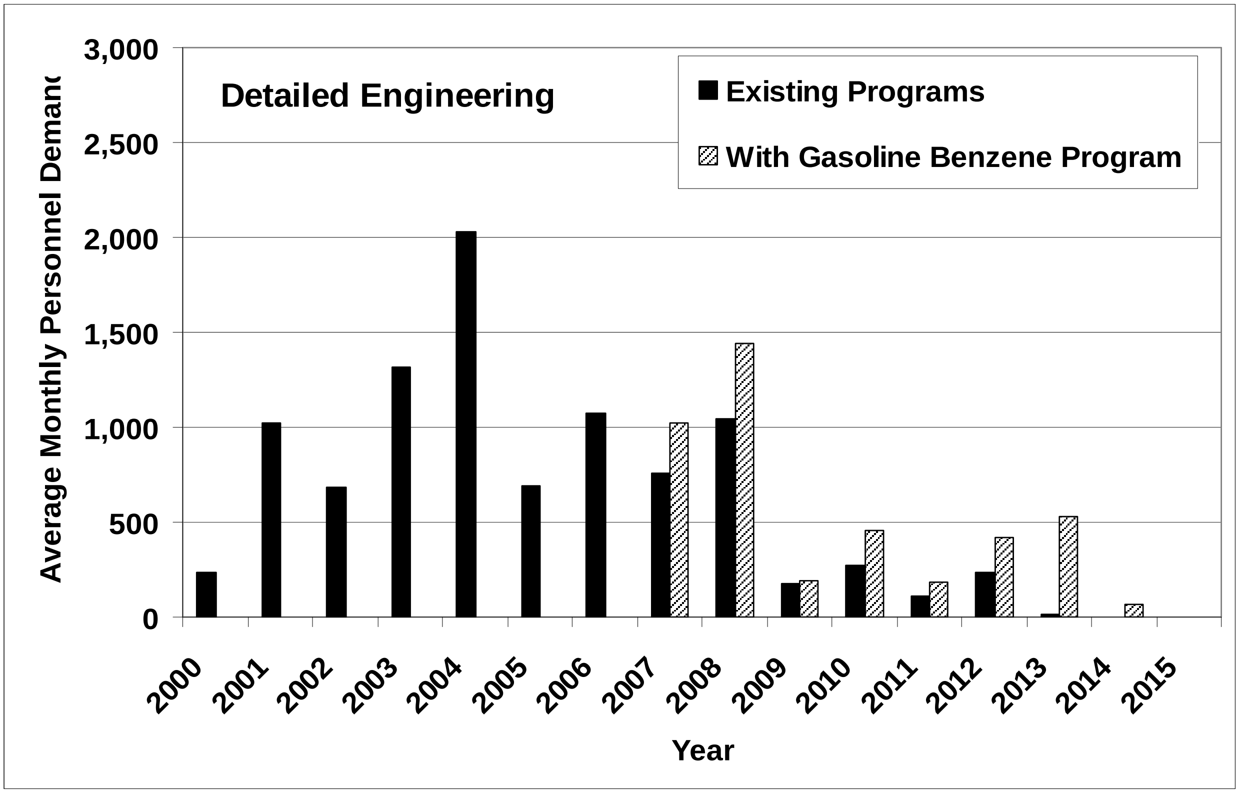
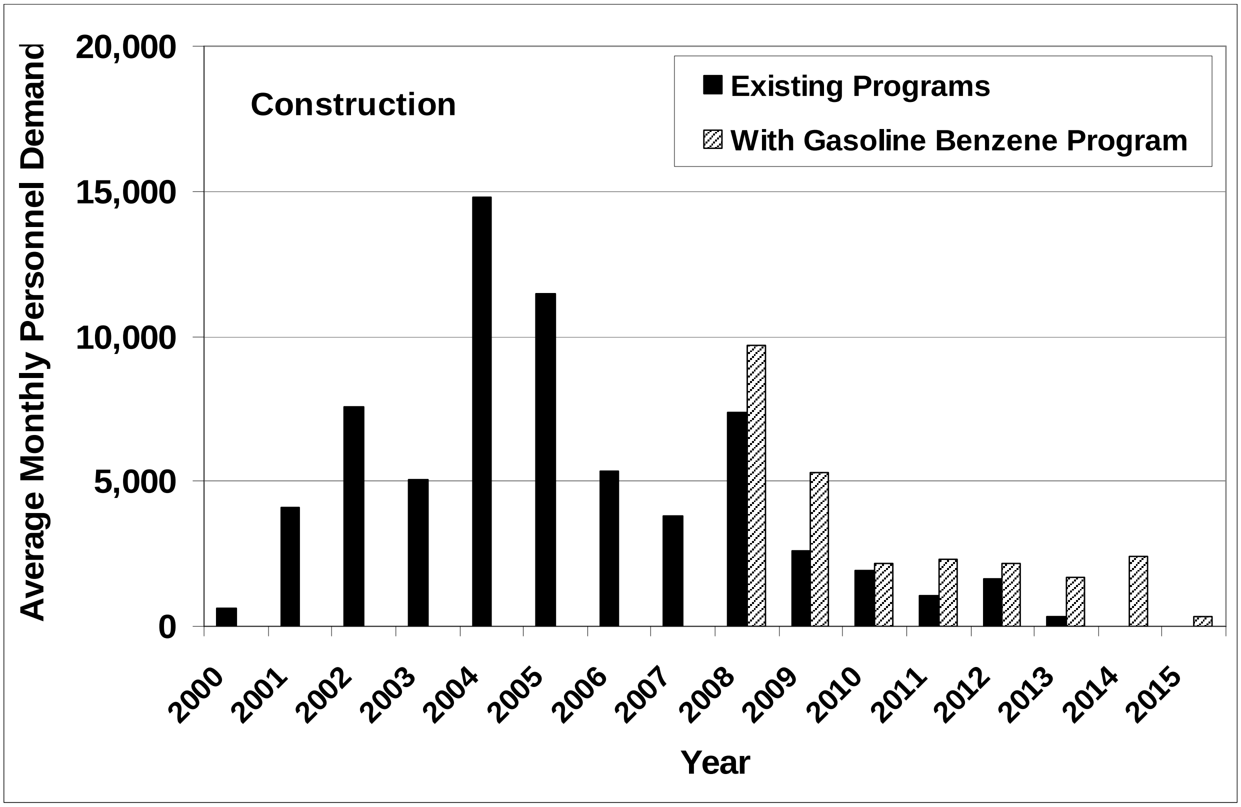


Figure 6.8-3. Projected Average Monthly Construction Personnel Demand Trends 2000-2015.



6.9 Time Needed to Comply with a Benzene Standard

The start date for the benzene standard on January 1, 2011 will give refiners about four years after the rulemaking is signed into law to comply with the program's requirements. This period is being provided to allow refiners to install the capital they need to lower their benzene levels and respond to other associated changes, and to allow this program to dovetail well with other fuel quality programs being implemented around that time. Four years is more than a sufficient amount of time for installing new benzene control capital equipment in refineries. In the Tier 2 rulemaking, we provided our estimate for the amount of time needed to plan, design, construct and start up a FCC naphtha hydrotreater to comply with the sulfur standard. This schedule is summarized in Table 6.9-1.

Table 6.9-1. Lead Time Required Between Promulgation of the Final Rule and Implementation of the Gasoline Sulfur Standard (years)

	Naphtha/Gasoline Hydrotreating	
	Time for Individual Step	Cumulative Time
Scoping Studies	0.5-1.0*	0.5
Process Design	0.5	1.0
Permitting	0.25-1.0	1.25-2.0
Detailed Engineering	0.5-0.75	1.5-2.25
Field Construction	0.75-1.0	2.0-3.0
Start-up/Shakedown	0.25	2.25-3.25

* Can begin before FRM

Table 6.9-1 shows that 2 ¼ to 3 ¼ years is estimated to be needed to install a naphtha hydrotreater. The naphtha hydrotreater investments are significant, costing refiners tens of millions of dollars per refinery and requiring the installation of many pieces of equipment. Some of the equipment needed for a FCC naphtha hydrotreater includes high pressure reactors and hydrogen compressors, that generally require a long purchase lead time, as well as heat exchangers and a furnace. The associated octane loss and hydrogen use could also require the installation of additional hydrogen and octane production capacity.

The benzene control technologies projected to be installed to reduce gasoline benzene levels are typically much less involved and can therefore be installed in the same or less time than the FCC naphtha hydrotreaters. The rerouting of benzene precursors requires that the naphtha splitter distillation column be revamped to provide a better split between the six and seven carbon hydrocarbons to allow the bypassing of the six carbon hydrocarbons around the reformer. In some cases this revamping only requires the addition of some trays or packing in the existing naphtha splitter. However, in other cases, the revamp would require the complete replacement of the existing naphtha splitter. These changed can take up to 1 to 2 years. If the refinery has an isomerization unit, it could further reduce its gasoline benzene level by feeding the rerouted benzene precursor stream to this unit. This additional step can occur with no additional investment by the refinery and therefore takes no appreciable amount of time to implement.

Additional benzene reduction is projected to occur by revamping existing extraction units. The revamp can occur by further reducing the benzene level of the refinery with the extraction unit, or by treating a benzene rich reformate stream of a neighboring refinery. The revamp could occur in one or more places, including the reformate splitter to capture more of its own benzene, expanding the extraction unit, or expanding the distillation towers after the extraction unit. Each of these possible revamp opportunities are similar in nature to those for revamping a light straight run splitter. Thus they can also occur in 1 to 2 years.

The other two means for benzene control are grassroots extraction and benzene saturation units. As grassroots units they both require the installation of numerous pieces of equipment, including furnaces, heat exchangers, the distillation towers, and extraction and saturation reactors, and instrumentation. Grassroots extraction units also require the installation of benzene storage vessels and loading equipment. The design and construction of all these pieces of equipment is why grassroots benzene saturation and extraction units are expected to need a lead time more in line with naphtha hydrotreaters, which is 2 ½ to 3 ½ years.

Refiners would also need to recover lost octane. The octane can be recovered by purchasing high octane blendstocks, such as alkylate, ethanol or isooctane, or by revamping existing octane producing units or installing new units, including alkylate and isomerization units. Revamping existing alkylate or isomerization units is expected to require 1 to 2 years to complete. Installing new octane generating units would likely take no more time than the 2 ¼ to 3 ¼ years estimated for grassroots benzene saturation and extraction units.

Some revamped or new capital may be needed for providing the hydrogen needed to saturate the benzene in isomerization and saturation units, or to make up hydrogen lost by routing the benzene precursors around the reformer. For most refineries we expect that they can use excess hydrogen production capacity or could purchase the needed hydrogen from a third party provider. A few refineries will have to modify their hydrogen plant which would only take 1 – 2 years. Should the refinery be in the position to have to install a new hydrogen plant, it could do so in no more time than the 2 ¼ to 3 ¼ years estimated for grassroots benzene saturation and extraction units.

The 2¼ to 3¼ years identified above for installing the benzene control technologies, and potentially for installing octane recovery and hydrogen production facilities, could allow starting the program after 3 years, in 2010, instead of four years. However, in our assessment of the impacts of the benzene control program on the engineering and construction industry, we identified that an earlier start date would overlap the engineering and construction (E&C) demands of this program with other fuel control programs. The last of the investments being made for the Tier 2 gasoline sulfur control program are occurring in 2010. The 15 ppm sulfur standard mandated by the Nonroad Diesel Fuel program applies to nonroad diesel fuel in 2010 and to locomotive and marine diesel fuel in 2012. Finally, the last of the 15 ppm highway diesel fuel sulfur standard applies in 2010. Implementing this benzene control program in 2010 would result in an overlap of the E&C demands with the various other fuel programs phasing in that year.

Phasing in this benzene fuel control program in 2011 instead would slightly stagger the start year of this benzene fuel program with the start years for the Tier 2, Nonroad and Highway Diesel Fuel sulfur programs. Staggering the start dates may also help refiners seeking funding to make the capital investments.

6.10 Will the Benzene Standards Be More Protective Than Current Programs?

Three fuels programs (RFG, Anti-dumping and MSAT1) currently contain direct controls on the toxics emissions performance of gasoline.[k] The RFG program, promulgated in 1994, contains a fuel benzene standard which requires a refinery's or importer's RFG to average no

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[k] Other gasoline fuel controls, such as sulfur, RVP or VOC performance standards, indirectly control toxics performance by reducing overall emissions of VOCs.

greater than 0.95 vol% benzene annually, with a per-gallon cap of 1.3 vol%.[29, 1] Each refinery's or importer's RFG must also achieve at least a 21.5% reduction in total toxics emissions (as determined by the Complex Model) compared to 1990 baseline gasoline. The Anti-dumping regulations require that a refinery's or importer's CG produce no more exhaust toxics emissions (also using the Complex Model) than its 1990 gasoline. [30,31] This was intended to keep refiners from complying with RFG by simply shifting fuel components responsible for elevated toxics emissions into CG.

The MSAT1 program, promulgated in 2001, was overlaid onto the RFG and Anti-dumping programs. [32] It was not designed to further reduce MSAT emissions, but to lock in overcompliance on toxics performance that was being achieved by that time in RFG and CG under the RFG and Anti-dumping programs. The MSAT1 rule required the annual average toxics performance of a refinery's or importer's gasoline to be at least as clean as the average performance of its gasoline during the three-year baseline period 1998-2000. Compliance with MSAT1 is determined separately for each refinery's or importer's RFG and CG.

The new benzene content standard will apply to all of a refinery's or importer's gasoline, that is, the total of its RFG and CG production or imports. This level of benzene control far exceeds RFG's statutory standard, and puts in place a benzene content standard for CG for the first time. An analysis was carried out to determine how the overall toxics performance of gasoline vehicle emissions under the new standard compares to performance under the relevant pre-existing standards.

6.10.1 Modeling Approach

Two levels of analysis were carried out to address this question. The first was an examination of the relationship between toxics performance of individual gasoline refiners (or other producers) under the new benzene program and their historical or required performance. This analysis was quantitative where changes in fuel parameters were known or could be projected with some confidence, followed by further qualitative examination where changes in other fuel parameters (such as oxygenate blending) could only be projected directionally.

We also undertook a second level of analysis with the aim of producing quantitative results more likely to represent reality at the time of phase-in of the new standard, accounting for the complexities of oxygenate changes as well as sulfur reductions, projected benzene reductions, and changes in the mix of new technology vehicles in future year fleets. This analysis was done on a regional basis, which allowed aggregation of fuel parameters, increasing our confidence in the projection of future trends.

The refinery-by-refinery analysis of toxics emissions performance was conducted using the Complex Model (the same model used for determining compliance with these programs). We used 2004 exhaust toxics performance for CG and 2004 total toxics performance for RFG as benchmarks, which are at least as stringent as the relevant toxics performance baselines. We applied changes to each refiner's fuel parameters for the new benzene standard and the gasoline

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[1] Refiners also have the option of meeting a per gallon limit of 1.0 vol%.

sulfur standard (30 ppm average, 80 ppm max, fully implemented in 2006). The results indicate that all refineries maintained or reduced their emissions of toxics over 2004 due to both sulfur and benzene reductions. Large reductions in sulfur have occurred in almost all refineries under the gasoline sulfur program. We do not expect backsliding in sulfur levels by the few refiners previously below 30 ppm because they had been producing ultra-low sulfur gasoline for reasons related to refinery configuration. We project large reductions in CG benzene levels will also occur along with modest reductions in RFG benzene levels. Because of its petrochemical value and the credit market, we do not expect any refiners to increase benzene content in their gasoline.

In addition, we expect significant changes in oxygenate blending over the next several years, but these are very difficult predict on a refinery-by-refinery basis. Regardless of how individual refineries choose to blend oxygenates in the future, we believe their gasoline will continue to comply with baseline requirements. This is because all RFG is currently overcomplying with the statutory requirement of 21.5% annual average toxics reductions by a significant margin. Similarly, most CG is overcomplying with its 1990 baselines by a significant margin. Furthermore, we believe most refiners currently blending oxygenates will continue to do so at the same or greater level into the future.

The second level of analysis employed MOBILE6.2 to estimate emission rates (mg/mi) for air toxics under a number of existing and projected fuel control cases, and is the subject of the rest of this section. This modeling included evaluation of toxics emissions on a regional level for baseline and future year scenarios. Five regions of the country were examined, divided according to PADDs (defined in 40 CFR 80.41), using PADD-aggregate fuel parameters. In looking ahead to the phase-in period of the gasoline benzene standard, this work accounted for significant changes in gasoline properties since the MSAT1 baseline period. The Tier 2 program, currently phasing in, brings together very low gasoline sulfur standards and stringent vehicle standards that will reduce emissions significantly. In addition, over the next several years, fuel qualities will change in many regions of the country as ethanol blending increases as described in the Renewable Fuels Standard rulemaking. [33]

6.10.1.1 Choice of Analysis Cases and Data Sources

The Energy Policy Act of 2005 requires that toxics emissions baselines for RFG be adjusted to reflect 2001-2002 performance, which would make them slightly more stringent than the 1998-2000 baselines used in the MSAT1 program.[34] However, as provided for in the Act, this action becomes unnecessary and can be avoided if this benzene control program can be shown to bring greater reductions of toxics emissions from vehicles in RFG areas than would be achieved by this baseline adjustment. Therefore, in addition to comparing the gasoline benzene standard to the current MSAT1 program, we also compared it to standards as they would change under EPAct. In addition, we compared projected emissions in 2011 with and without the MSAT2 standards.

For this analysis, MOBILE inputs included fuel parameters and the fleet year being examined, as well as an average daily temperature profile for each region and season. Separate aggregate fuel parameter sets were generated for each PADD for CG and RFG, summer and winter. Model outputs for various compounds and emission types were then aggregated into annualized mg/mi total toxics emissions for an average vehicle in each PADD by RFG and CG.

An MSAT1 baseline case was run using 1998-2000 volume-weighted data aggregated from batch reports submitted to EPA by refiners under the reporting requirements of existing programs. A second set of baseline figures were generated using 2001-2002 batch reports for RFG, based on the requirements of EPAct. It should be noted that the baseline toxics emissions figures generated in this analysis are different from those used to determine compliance with the MSAT1 program. MSAT1 compliance baseline figures are generated by the Complex Model, which includes emissions of POM but not acrolein, and does not account for effects of changes in vehicle technology or fleet mix.

Future cases chosen for comparison included year 2011 without the MSAT2 program, under the MSAT2 fuel program only, and under both the MSAT2 fuel and vehicle programs. An additional case was run for year 2025 including effects of both vehicle and fuel standards. A summary of the cases and datasets examined is given in Table 6.10-1. The future year 2011 was chosen because of the effective date of this standard.[m] The future year 2025 was chosen based on a significant phase-in of vehicles (> 80% of the fleet) produced under the new vehicle standard. Fuel parameter data for the 2011 and 2025 cases were generated by taking 2004 data and making adjustments to account for changes expected due to regulatory programs and projected oxygenate blending trends.

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[m] This analysis assumes a simplified phase-in of the standard. Details of projected phase-in period are covered in Section 6.5 of this RIA.

Table 6.10-1. Choice of Analysis Cases and Data Sources

Case	RFG fuel parameter dataset	CG fuel parameter dataset	Fleet year
MSAT1 Baseline	1998-2000	1998-2000	2002
MSAT1 Baseline as Modified by EPAct	2001-2002	1998-2000	2002
EPAct Baseline, 2011	2004 plus adjustments for: - Low-sulfur gasoline - Increased ethanol blending - MTBE & other ethers phased out	2004 plus adjustments for: - Low-sulfur gasoline - Increased ethanol blending - MTBE & other ethers phased out	2011
MSAT2, 2011 (Fuel standard only)	2004 plus adjustments for: - Low-sulfur gasoline - Increased ethanol blending - MTBE & other ethers phased out - 0.62% benzene std	2004 plus adjustments for: - Low-sulfur gasoline - Increased ethanol blending - MTBE & other ethers phased out - 0.62% benzene std	2011
MSAT2, 2011 (Fuel + vehicle standards)	2004 plus adjustments for: - Low-sulfur gasoline - Increased ethanol blending - MTBE & other ethers phased out - 0.62% benzene std - **20°F vehicle HC std**	2004 plus adjustments for: - Low-sulfur gasoline - Increased ethanol blending - MTBE & other ethers phased out - 0.62% benzene std - **20°F vehicle HC std**	2011
MSAT2, 2025 (Fuel + vehicle standards)	2004 plus adjustments for: - Low-sulfur gasoline - Increased ethanol blending - MTBE & other ethers phased out - 0.62% benzene std - **20°F vehicle HC std**	2004 plus adjustments for: - Low-sulfur gasoline - Increased ethanol blending - MTBE & other ethers phased out - 0.62% benzene std - **20°F vehicle HC std**	2025

6.10.1.2 Adjustment of Fuel Parameters for Future Years

In order to carry out the analysis as realistically as possible, adjustments were applied to fuel parameters when running future year cases. Starting from 2004 gasoline data (the most recent available at the time of the analysis), the changes accounted for in this analysis were sulfur reduction related to the gasoline sulfur program, increased ethanol blending to 9.6 billion gallons per year nationwide as described in the Renewable Fuels Standard rulemaking (9.6 Max-RFG case), phase-out of MTBE and other ethers, and reduction of gasoline benzene levels under the new program. Some of these changes are expected to have predictable secondary effects on non-target fuel parameters that were also considered.

Reduction of Gasoline Sulfur

Under the recent gasoline sulfur rulemaking, as of January 1, 2006 all gasoline (except gasoline produced by small refiners and those covered by the geographic phase-in provisions) is required to meet an average standard of 30 ppm sulfur (80 ppm per-gallon cap). Therefore, MOBILE inputs for gasoline sulfur levels were set to 30 ppm average and 80 ppm max for all PADDs and seasons. No adjustments to other fuel parameters were made as a result of sulfur reductions.

Increased Blending of Ethanol

Under the Energy Policy Act of 2005, EPA was charged with putting in place a regulatory system to ensure that renewable fuels are used in the national fuel pool at an increasing rate through the year 2012, as well as evaluating the air quality, energy supply, and economic impacts of these changes.[35] Part of this work involved projecting corresponding changes to gasoline qualities, the results of which were also used in this analysis. This analysis is described in detail in Chapter 2 of the draft RIA of the proposed Renewable Fuels Standard (RFS); the major points are summarized below.[36]

This analysis used the ethanol blending volumes projected for the scenario of 9.6 billion gallons per year in 2012 with maximum use in RFG, as developed in Section 2.1.4.6 of the RFS draft RIA (in this analysis we did not attempt to adjust ethanol blending for any difference between 2011, the fleet year of the analysis, and 2012). Differences in market share of ethanol and MTBE blending between 2004 and 2012 were used to adjust 2004 fuel parameters. Summer and winter blending ratios were assumed to be equal, and market shares for 2012 were also used in 2025. These figures are shown here in Tables 6.10-2 and 6.10-3.

Table 6.10-2. Projected Changes in Ethanol Use in Gasoline (% volume).

	2004		**2012**	
PADD	**CG**	**RFG**	**CG**	**RFG**
I	0.0%	3.5%	2.3%	10.0%
II	3.2%	10.0%	9.7%	10.0%
III	0.3%	0.5%	0.5%	10.0%
IV	1.8%	-	6.9%	-
V (ex/CA)	2.6%	-	5.1%	-
ALL				

Table 6.10-3. Projected Changes in MTBE Use in Gasoline (% volume).

	2004		**2012**	
PADD	**CG**	**RFG**	**CG**	**RFG**
I	0.0%	7.2%	0.0%	0.0%
II	0.0%	0.0%	0.0%	0.0%
III	0.0%	10.4%	0.0%	0.0%
IV	0.0%	-	0.0%	-
V (ex/CA)	0.2%	-	0.0%	-
ALL				

The secondary fuel parameters adjusted were aromatics, olefins, E200, E300 and vapor pressure (MTBE, ethanol, sulfur, and benzene content were already being changed as a direct result of regulatory or other actions). The impact on each of these parameters was calculated separately for each PADD by CG and RFG, according to the factors in Table 6.10-4. In PADDs where MTBE use was reduced, the MTBE factors shown were applied in a negative direction, meanwhile the ethanol factors were applied in a positive direction where ethanol use was increasing. These factors were developed as part of the RFS proposal.

Table 6.10-4. Fuel Parameter Adjustment Factors for Oxygenates.

	E200 (%)	E300 (%)	Aromatics (Vol%)	Olefins (Vol%)	RVP (psi)
Conventional Gasoline					
Ethanol	+1.0	+0.24	-0.5	-0.16	+0.1
MTBE	+0.52	+0.17	-0.59	0	0
Reformulated Gasoline					
Ethanol	0	0	0	0	0
MTBE	0.1	0.1	0	0	0

Phase-out of Ether Blending

Use of MTBE and other ethers has been outlawed by several states, including California, New York, and Connecticut. All refiners we have spoken with are phasing out production and blending of these at their facilities regardless of such prohibitions, mainly for reasons of potential environmental liability, uncertainties of future markets, and related costs. Furthermore, with the renewable fuels mandate in EPAct, essentially all gasoline oxygenate use has shifted to ethanol. Given these facts, ether content was assumed to be zero in all regions for future year cases.

Reduction of Benzene Content

The final step of fuel quality adjustment for future year cases was to incorporate the gasoline benzene standard. Modeling done to evaluate the cost of the program resulted in projected benzene levels for each PADD. These figures are given in Section 6.5.4 above, and were used as the final benzene levels as summarized in Table 6.10-8 below. Analysis of trends in fuel property data suggested that this reduction of benzene content is expected to be accompanied by an equal reduction in total aromatics content. Therefore, both benzene and aromatics levels were adjusted in this final step.

6.10.1.3 Conversion of Production Properties to In-Use Properties

To analyze the impacts of gasoline quality on vehicle emissions on a large scale, it is important to know the properties of the gasoline consumed in a given state or region of the country as opposed to the gasoline produced there. Some information on point-of-use quality is available through gasoline quality surveys conducted by the Alliance of Automobile Manufacturers and TRW, but these surveys are too limited to use for a detailed national analysis. Very comprehensive data on gasoline production is available through the reporting requirements of other regulatory programs, whereby refiners report gasoline batch volumes and quality information to EPA. However, following production, gasoline is often shipped long distances. Due to the complex nature of the gasoline distribution system and the intentional fungibility of the product, there is no straightforward way to track the vast majority of gasoline after it leaves the refinery. Thus, there is no accurate way to relate gasoline production properties to consumption properties for a state or region of the country.

We assessed whether to attempt to use the very limited survey data or work through the complications of adapting production data for this purpose, and eventually decided that production data would lead to a better overall estimate of fuel quality estimates for broad regions of the country. We estimated the qualities for gasoline as consumed in each of the five PADDs, based on qualities of gasoline produced in each PADD and its movement to other PADDs. EIA collects and reports to the public a variety of data on gasoline production, movement, and consumption. Included in their analyses are quantities of gasoline moved between PADDs, broken down by RFG, CG, and oxygenated CG. By linking this information with gasoline volume and property information from EPA's database, we developed weighted average fuel parameters for gasoline as consumed in each PADD.

Generally speaking, we weighted together the properties of gasoline produced in a PADD with those of gasoline transported into that PADD. Using data from 2004 refiner compliance reports submitted to EPA, gasoline property figures were aggregated into volume-weighted PADD averages. Separate aggregates were made for domestic RFG and CG, as well as imports. Meanwhile, volumes for production, movement, and imports were taken from the EIA Petroleum Supply Annual 2004 and Petroleum Marketing Annual 2004 reports, available from the EIA website.[37] Gasoline volumes used were for 'Finished Motor Gasoline' and were reported by EIA as 'Reformulated,' 'Oxy' and 'Other.' For purposes of this analysis, the 'Oxy' and 'Other' volumes were aggregated together as CG.

Due to differences in the sources of data for gasoline properties and volume figures, some assumptions had to be made to complete the analysis. Major assumptions and their rationale are as follows.

First, gasoline transported into one PADD from another has the weighted average gasoline properties of the gasoline produced in the source PADD. While it is possible that gasoline transported into a PADD is then transported out to another PADD, this information cannot be known given the available data.

Second, when we estimate the properties for gasoline consumed in future years, we assume that that the ratios between flows are the same as in the 2004 data, since future consumption patterns are not known.

Third, because EIA does not supply data on flows between California and the rest of PADD V, some assumptions were required to separate gasoline properties in these areas. The volume of California RFG produced beyond what was consumed (a relatively small quantity) was assumed to be transported into the rest of PADD V, as was any non-RFG gasoline produced in California. Imports reported for PADD V as a whole were apportioned between California and the rest of PADD V based on import data tables available on the EIA website. Furthermore, California RFG transferred into the rest of PADD V, as well as RFG imports into PADDs IV and V, are counted as CG at the point of consumption since there are no federal RFG areas in PADDs IV and V outside of California.

Table 6.10-5 shows a summary of the input figures for gasoline volumes and benzene content in 2004 and Table 6.10-6 shows the benzene levels after the modeled reduction to meet the new benzene standard. Volumes shown would be the same if consumption values were being estimated for another gasoline parameter. Table 6.10-7 shows the estimated benzene levels for gasoline consumed in each PADD and Table 6.10-8 shows the benzene values after the modeled reduction to meet the new benzene standard. Differences between production and consumption volume totals for CG and RFG result from the assumption that all gasoline being consumed in PADDs IV and V is counted as CG, regardless of designation at production. This assumption doesn't make a difference for the final value of the gasoline parameter as consumed in that PADD, only in attribution of the volumes. Table 6.10-9 shows the PADD transfer volumes taken from the EIA data and used in the analysis. Figure 6.10-1 gives a conceptual view of gasoline flows between PADDs with production and consumption benzene levels for 2004; the relative size of the arrows indicates approximately the relative volumes of the transfers.

Table 6.10-5. Inputs to In-Use Analysis based on 2004 Gasoline Benzene.

	Production + Imports					
PADD	Total		CG		RFG	
	vol (MMgal)	bz v%	vol (MMgal)	bz v%	vol (MMgal)	bz v%
I	26,253	0.72	11,414	0.84	14,839	0.63
II	32,016	1.24	26,513	1.33	5,503	0.81
III	55,822	0.87	45,452	0.94	10,370	0.54
IV	4,389	1.55	4,389	1.55	0	0.00
V (ex/CA)	4,613	1.75	4,613	1.75	0	0.00
CA	18,618	0.62	2,379	0.61	16,239	0.62
ALL	141,712	0.94	94,760	1.10	46,952	0.63

*This volume of gasoline is likely for the Phoenix area, which has a state fuels program with requirements similar to federal RFG.

Table 6.10-6. Estimated Benzene Levels After Benzene Control (vol% in 2011) Production + Imports

PADD	CG	RFG
I	0.53	0.52
II	0.63	0.61
III	0.63	0.55
IV	0.90	-
V (ex/CA)	0.67	-
ALL	0.63	0.58

Table 6.10-7. Outputs From In-Use Analysis Based on 2004 Gasoline Benzene and Movement.

	Consumption					
PADD	Total		CG		RFG	
	vol (MMgal)	bz v%	vol (MMgal)	bz v%	vol (MMgal)	bz v%
I	50,125	0.59	30,902	0.61	19,222	0.54
II	40,166	0.62	34,543	0.62	5,623	0.60
III	22,480	0.61	16,978	0.63	5,501	0.55
IV	4,387	0.85	4,387	0.85	0	0.00
V (ex/CA)	9,709	0.65	9,709	0.65	0	0.00
CA	14,846	0.62	0	0.62	14,846	0.62
ALL	141,712	0.62	96,519	0.63	45,192	0.58

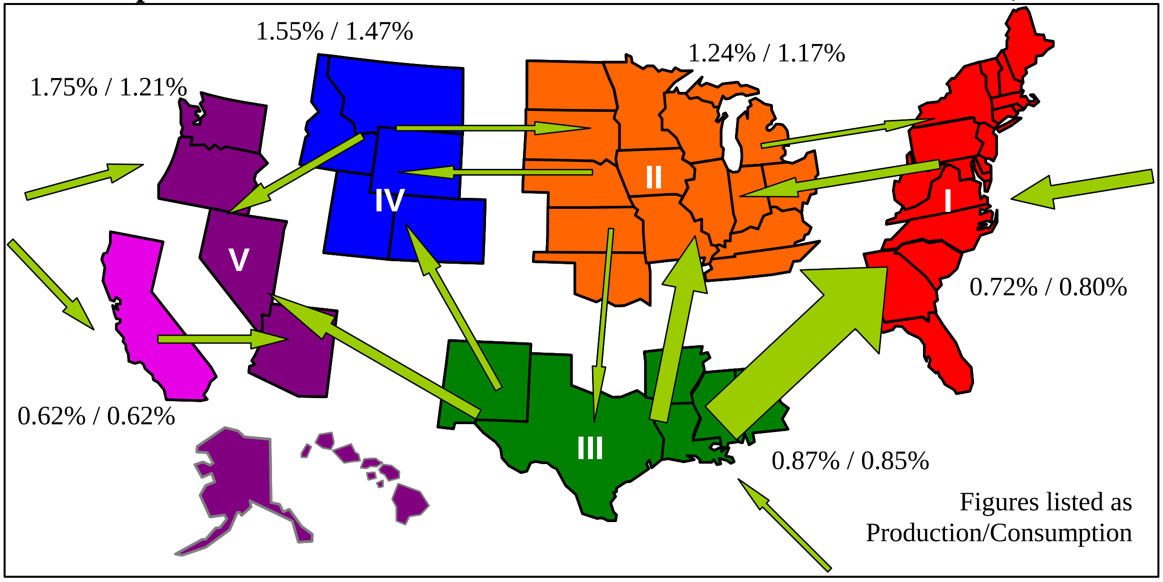
Table 6.10-8. Estimated Benzene Levels after Benzene Control (vol% in 2011) Consumption

PADD	CG	RFG
I	0.61	0.54
II	0.62	0.60
III	0.63	0.55
IV	0.85	-
V (ex/CA)	0.65	-
ALL	0.63	0.58

Table 6.10-9. Gasoline Flows Between PADDs (MMgal in 2004).

			Destination									
			CG					**RFG**				
			I	**II**	**III**	**IV**	**V**	**I**	**II**	**III**	**IV**	**V**
Source	**CG**	**I**		3,265	0	0	0	0	0	0	0	0
		II	268		323	319	0	0	0	0	0	0
		III	22,483	5,361		428	525	0	0	0	0	0
		IV	0	315	0		435	0	0	0	0	0
		V	2	0	0	0		0	0	0	0	0
		CA	0	0	0	0	2,295	0	0	0	0	0
	RFG	**I**	0	0	0	0	0		0	0	0	0
		II	0	0	0	0	0	0		235	0	0
		III	0	0	0	0	0	4,383	354		0	0
		IV	0	0	0	0	0	0	0	0		0
		V	0	0	0	0	0	0	0	0	0	
		CA	0	0	0	0	1,393	0	0	0	0	0

Figure 6.10-1.
Conceptual View of Inter-PADD Transfers and In-Use Benzene Levels, 2004.



These results illustrate a few predominant trends. In-use levels of benzene in gasoline in PADDs II, IV, and V are depressed by lower-benzene gasoline transferred from PADD III. Benzene levels in PADD V are further reduced due to transfers from California. Meanwhile, fuel benzene levels in PADD I increase slightly as a result of imports and transfers from PADD III.

6.10.1.4 Running the MOBILE Model

Version 6.2 of MOBILE was used for this analysis. To run the model and generate meaningful outputs, several inputs were required for each case besides fuel parameters as discussed above.

Temperature Profiles

MOBILE6.2 allows input of a daily temperature profile (24 hourly values) to increase the fidelity of modeling temperature effects on emissions. Representative cities were chosen for CG and RFG areas in each PADD, and their temperature profiles were pulled from the database used in EPA's National Mobile Inventory Model (NMIM). Two profiles were used for each city, July and January, for summer and winter seasons. These cities, listed in Table 6.10-10, were chosen because they are relatively large population areas located near the north-south center of the area associated with use of each fuel type in each PADD.

Note that this choice of representative cities can produce some artifacts in the modeling results where CG and RFG within the same PADD are consumed in slightly different climates. For instance, while RFG in PADD I is generally lower in fuel components like benzene and aromatics than CG in PADD I, the toxics emissions appear lower for CG because it is modeled as being consumed in Norfolk, which has a warmer climate than New York City where RFG consumption is modeled. However, this artifact does not affect the comparisons being made between the various regulatory scenarios in this analysis.

Table 6.10-10. Representative Cities for Temperature Profiles by PADD and Fuel Type.

PADD	RFG	CG
I	New York City, NY	Norfolk, VA
II	Chicago, IL	Indianapolis, IN
III	Dallas, TX	Austin, TX
IV	-	Denver, CO
V	-	Reno, NV

Maximum Gasoline Sulfur Levels

The MOBILE6.2 command “FUEL PROGRAM : 4” was used, which allowed specification of average and maximum sulfur levels for years between 2000 and 2015. Average sulfur levels were calculated as part of the fuel parameter datasets, but maximum sulfur levels needed to be generated for use in the baseline year cases. Due to the requirements of the recent gasoline sulfur program, all cases other than the baselines were assumed to have average sulfur content of 30 ppm with 80 ppm maximum.

For the baseline cases, one approach was to simply take the highest batch sulfur level reported by a refinery in a given season. However, a few problems arise in doing this. First, some of these values exceeded the upper limit on input value of 1,000 ppm imposed by MOBILE6.2. Second, a single very high sulfur batch did not seem representative of maximum sulfur levels to be seen by a significant number of vehicles in a PADD-wide analysis. Therefore, after some review of the datasets, a factor of three times the average sulfur was chosen to represent the maximum sulfur value for CG, while for RFG a factor of two was chosen. This allowed straightforward calculation of a representative maximum that was generally tolerable by MOBILE’s input requirements. In any case where MOBILE’s input limit of 1,000 ppm would have been exceeded using this method (two cases in CG), the maximum sulfur value was simply set to 1,000 ppm.

Conversion of Oxygenate Blending Percentage to MOBILE Input Values

The fuel parameter datasets used in this analysis do not give reliable information about what the actual concentration of the oxygenate was in the vehicle fuel tank. For example, the gasoline data may indicate that on average, gasoline in a certain area had ethanol blended at 5 vol%. However, this could mean that all of the gasoline had 5 vol% ethanol, or half of it had 10 vol% ethanol, each having a different effect on vehicle emissions. Therefore, oxygenate inputs to MOBILE (using the OXYGENATE command) require two values: blending vol% and market share. Converting the average blending percent calculated in the datasets to these values required some assumptions about the blending ratio for each oxygenate type. The figures used were 10.00 vol% for ethanol, 11.04 vol% for MTBE, 12.78 vol% for ETBE, and 12.41 vol% for TAME, based on typical blending volumes for these compounds in RFG or gasohol in the case of ethanol. From these values, appropriate market shares could be derived. MOBILE6.2 does not allow modeling of a fuel with a mix of oxygenates, therefore, the sum of market shares for all oxygenates used must not exceed one.

Start Emission Factor Parameters

Vehicle start emission factors in MOBILE6.2 were adjusted by temperature and vehicle technology to better characterize cold temperature start emissions observed in recent test data for Tier 1, LEV and Tier 2 vehicles. These adjustments are discussed in more detail in Chapter 2 of the RIA. Using a data file set up for phase-in of the cold temperature VOC standards also part of this program allowed modeling of scenarios with and without phase-in of vehicle controls.

Processing of Output from the MOBILE Model

For each case listed in Table 6.10-1, input scenarios were generated for each PADD, for CG and RFG, summer and winter. Output values for 1,3-butadiene, acetaldehyde, acrolein, benzene, and formaldehyde were summed to represent total toxics emissions for each scenario. The summer and winter seasonal results were annualized (averaged) by weighting according to the quantity of gasoline supplied in each season according to data taken from EIA. The resulting figures are presented in Table 6.10-11.

Table 6.10-11. Estimated Annual Average Total Toxics Performance of Light Duty Vehicles in mg/mi Under Current and Projected Scenarios.*

Regulatory Scenario	Fleet Year	RFG by PADD			CG by PADD				
		I	II	III	I	II	III	IV	V
MSAT1 Baseline** (1998-2000)	2002	112	129	97	114	145	107	145	156
EPAct Baseline** (RFG: 2001-2002)	2002	104	121	87	114	145	107	145	156
EPAct Baseline, 2011* **	**2011**	**67**	**78**	**52**	**62**	**83**	**54**	**82**	**88**
MSAT2 program, 2011*** (Fuel standard only)	2011	66	76	52	60	77	52	74	81
MSAT2 program, 2011*** (Fuel + vehicle standards)	2011	64	72	48	56	74	47	70	78
MSAT2 program, 2025*** (Fuel + vehicle standards)	2025	39	45	31	36	45	31	44	48

* Total toxics performance for this analysis includes overall emissions of 1,3-butadiene, acetaldehyde, acrolein, benzene and formaldehyde as calculated by MOBILE6.2. Although POM appears in the Complex Model, it is not included here. However, it contributes a small and relatively constant mass to the total toxics figure (~4%), and therefore doesn't make a significant difference in the comparisons.

** Baseline figures generated in this analysis were calculated differently from the regulatory baselines determined as part of the MSAT1 program, and are only intended to be a point of comparison for future year cases.

*** Future year scenarios include (in addition to the MSAT2 standards, where stated) effects of the Tier 2 vehicle and gasoline sulfur standards, and vehicle fleet turnover with time, as well as rough estimates of the effects of increased ethanol blending and the phase-out of ether blending.

6.10.2 Interpretation of Results

The first row in Table 6.10-11 shows mg/mi air toxics emissions in 2000 under the MSAT1 refinery-specific baseline requirements. The second row shows how these would change by updating the RFG baselines to 2001-02 as specified in EPAct. Since significant changes are expected in the gasoline pool between 2002 and the projected implementation time of the fuel benzene program, such as gasoline sulfur reductions and oxygenate changes, we decided to model a 'future baseline' to allow comparison with the benzene program at the time it becomes effective in 2011.[n] As a result, the third row shows the projected mg/mi emissions in 2011 under the EPAct baseline adjustments, but without the benzene program. The large reductions in air toxics emissions between the EPAct baseline and this 2011 baseline are primarily due to nationwide reduction in gasoline sulfur content to 30 ppm average and significant phase-in of Tier 2 vehicles across the national fleet.

An important comparison is made between rows three and four, where the estimated

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[n] Ibid.

toxics emissions under the new gasoline benzene program only are compared to the projected emissions without the new gasoline program. We also evaluated the effects from inclusion of the new vehicle standard finalized in this rule on toxics emissions at two points in time, shown in the last two rows of the table.

In this analysis, all three RFG areas show a slight improvement in 2011 as a result of the gasoline benzene program in 2011. This is not surprising, since the level of the average benzene standard, 0.62 vol%, is near the RFG benzene content. The effects of the program on CG are larger, as expected given the higher levels of benzene in that gasoline pool. The vehicle standard does not show much effect in 2011, since it is just starting to phase in at that time. By 2025 however, with the fuel benzene program in effect as well as a significant phase-in (estimated at >80%) of the vehicle standards, a reduction in total toxics emissions of more than 60% from the baseline is projected for both CG and RFG areas.

Projected emissions in 2011 are lower under the MSAT2 program than projected to occur otherwise, and much lower than would be required by adjusting RFG baselines to 2001-2002 averages. Therefore, we conclude that adjustment of these baselines as described by EPAct section 1504(b) will not be necessary.

6.10.3 Conclusions

When RFG and CG toxics emissions are evaluated at this new level of benzene control, it is clear that the new gasoline benzene program will result in the RFG, Anti-dumping and MSAT1 emissions performance requirements being surpassed not only on average nationwide, but for every PADD.

In summary, the new benzene program will fulfill several statutory and regulatory goals related to gasoline mobile source air toxics emissions. The program will meet our commitment in the MSAT1 rulemaking to consider further MSAT control. It will also bring emission reductions greater than required under all pre-existing gasoline toxics programs, as well as under the baseline adjustments specified by the Energy Policy Act.

6.11 MSAT Fuel Effects Test Program

6.11.1 Overview of Test Program

We have recently completed a small fuel effects test program in cooperation with several automakers to further evaluate the impacts of fuel property changes on emissions from the latest technology vehicles.[o] This study examined exhaust emissions of regulated pollutants (NMHC, CO, NO_x) and several unregulated compounds of interest (1,3-butadiene, acetaldehyde, acrolein, benzene, ethylbenzene, formaldehyde, n-hexane, naphthalene, toluene, xylene). The fuel parameters being controlled were benzene, sulfur, and volatility.

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[o] Participating manufacturers were DaimlerChrysler, Ford Motor Company, General Motors, Honda, Mitsubishi, and Toyota. Some of these companies are represented by the Alliance of Automobile Manufacturers.

Nine Tier 2 compliant production vehicles ranging in model year from 2004-2007 and meeting the Tier 2 Bin 5 or Bin 8 emission standards were tested on chassis dynamometers at three industry labs and NVFEL over the course of several months. The vehicles were fitted with catalysts that were laboratory-aged to simulate a service life of approximately 120,000 miles. Before testing began, a correlation vehicle was circulated to verify that lab-to-lab measurement variation for all pollutants was within acceptable limits.

Each vehicle was tested three times on five fuels, with a repeat of the first fuel at the end of the sequence. Four of the test fuels were intended to allow comparisons of the effects of the three parameters of primary interest, and consisted of a base fuel to which butanes, benzene, and sulfur were added sequentially to create three additional fuels. In addition to these four fuels, non-oxygenated Phase 3 California RFG was also tested as an independent baseline. Fuel property data for the five test fuels is given in Table 6.11-1. In this table, the Fuel ID is shorthand for how the fuel was made; for instance, BASE is the blending base, while BASERB has butanes (RVP) and benzene added. This is denoted in the second row below the Fuel ID.

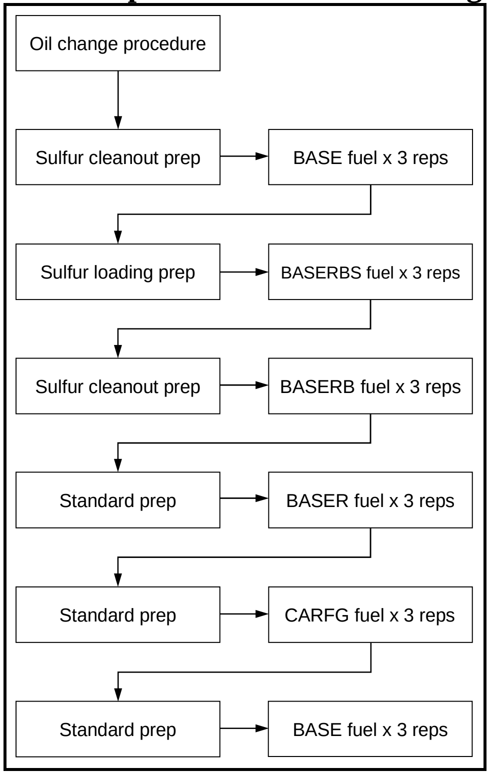
Table 6.11-1. Test fuel properties.

Fuel ID	**BASE**	**BASER**	**BASERB**	**BASERBS**	**CARFG**
Description	Blending base	Add butane	Add benzene	Add sulfur	California RFG
RVP, psi	6.93	9.08	9.01	9.05	6.95
T10, °F	138.7	127.2	126.7	127.8	136.8
T50, °F	223.5	221.0	219.6	220.6	210.0
T90, °F	324.0	324.5	324.1	324.0	305.3
Aromatics, vol%	31.4	28.5	28.1	28.1	21.2
Olefins, vol%	4.2	3.9	4.0	4.0	6.7
Benzene, vol%	0.59	0.58	1.10	1.09	0.41
Sulfur, ppm	6	6	6	32	5
Density, g/ml	0.747	0.742	0.742	0.743	0.733
Octane, R	93.2	93	92.5	92.6	91.0
Octane, M	84.7	85	85.3	85.3	83.7
Octane, (R+M)/2	89.0	89.0	88.9	89.0	87.4
Energy, Btu/gal net	18436	18487	18488	18486	18609
H/C ratio	1.82735	1.86184	1.86267	1.86127	1.94208
Unwashed gums, mg/100 ml	1.4	2.4	2.2	2.2	not measured
Carbon Weight Fraction	0.867	0.865	0.865	0.865	0.860

Figures 6.11-1 through 6.11-4 show conceptual overviews of the test procedures. All test cycles consisted of the cold start Federal Test Procedure (FTP). Figure 6.11-1 shows the order in which we tested seven of the nine vehicles on the program fuels. The remaining two vehicles were tested in a different order. In cases where the sulfur cleanout prep was indicated, two replicates of the EPEFE high-speed, high-load cycle were conducted immediately before the

final drain and fill.[p] The purpose of this type of prep procedure was to equilibrate the catalyst with the low sulfur fuel. Where a sulfur loading prep was indicated, a 3-hour 35 mph cruise was conducted immediately before the final drain and fill. The purpose of this prep procedure was to equilibrate the catalyst with higher sulfur fuel, simulating conservatively the conditions that might occur in typical suburban driving. The term LA4 indicates a drive cycle commonly used for preps, which is an abbreviated portion of the FTP consisting of the first two bag periods.

Figure 6.11-1. Conceptual Overview of Testing Procedures.



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[p] EPEFE is the European Programme on Emissions, Fuels and Engine Technologies, which developed a protocol for purging contaminates from aftertreatment systems consisting of repeated cycles of high speed cruising and extended accelerations.

Figure 6.11-2. Conceptual Overview of Oil Change Procedure.

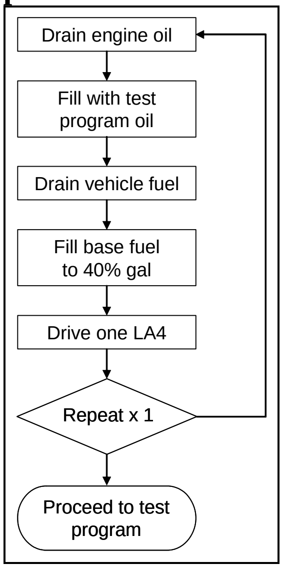


Figure 6.11-3. Conceptual Overview of Vehicle Prep Procedure.

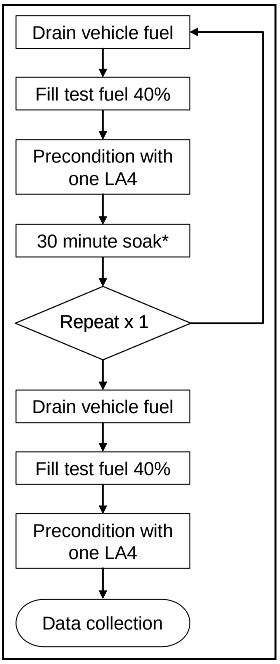
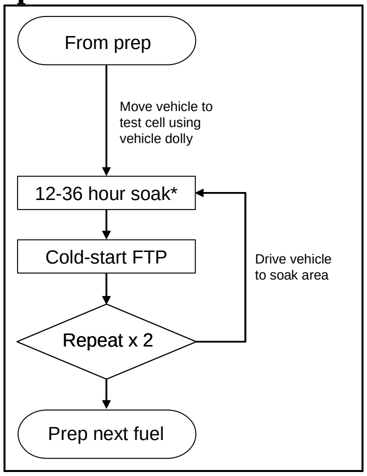


Figure 6.11-4. Conceptual Overview of Data Collection Procedure.



In all, 162 tests were executed to cover all the fuels and vehicles. Each test resulted in regulated and unregulated emissions data, for a total of 2,592 individual three-bag composite emissions observations across all pollutants.

6.11.2 Key Findings and Next Steps

Data collected during the test program were analyzed both by EPA and an independent statistician under contract from the Alliance of Automobile Manufacturers. Table 6.11-2 summarizes the findings of the contract statistician.[38]

Table 6.11-2. Summary of Significant Effects from Contract Statistician.

Pollutant	Fuel	Significant Effect	Relative To
THC	CARFG	less than	All Other Fuels
NMHC	CARFG	less than	All Other Fuels
CO	BaseRBS	greater than	Base
NO_x	BaseRBS	greater than	All Other Fuels
CO_2	CARFG	less than	Base, BaseRB

An independent analysis of the data conducted internally by EPA generated more detailed results, and generally found similar trends where the two analyses overlapped. This work used the SAS software system to run a mixed model on log-transformed 3-bag composite measurements. Depending on the context of the experiments, the model can accommodate parameters as either random or fixed. In this case, parameters indicating which lab and which vehicle were being tested were assumed to be random effects, while the fuel effect was taken as fixed. This allowed for greater use of all the data collected. For example, since the addition of benzene does not have a significant effect on VOC or NO_x emissions, the effect of RVP for these pollutants can be determined by comparing the base fuel to both the BASER and BASERB fuels.

Due to the limited size of the test program, we also used an alpha value of 0.90 instead of 0.95 as the criterion for determining statistical significance.

Table 6.11-3 summarizes the EPA findings. The effect of changes in fuel sulfur content was relatively large and statistically significant on NO_x and CO, and smaller though still statistically significant for total hydrocarbons (THC). Another finding of importance is that the change in fuel benzene content produced a statistically significant change in exhaust benzene consistent with the estimated benefits of the fuel controls as stated in the proposal of this rulemaking.[39] Thus, the effect of fuel benzene on benzene exhaust emissions appears to be little affected by changes in vehicle technology. Also worth noting is that unlike past programs on older technology vehicles, these data suggest that reducing gasoline volatility from 9 to 7 psi RVP under normal testing conditions (75°F) may actually increase as opposed to decrease exhaust emissions of toxic VOC compounds. It also appears that there is a large statistically significant effect of fuel benzene on acetaldehyde emissions, though the mechanism for this is uncertain. If borne out in future testing, reducing fuel benzene will provide additional air toxics benefits as well. Further details of the results are given in the table.

Table 6.11-3. Summary of Findings from EPA analysis.

Pollutant	Effects (% Difference)*		
	RVP (7 to 9 psi)	**Benzene (0.6 to 1.1 vol%)**	**Sulfur (6 to 32 ppm)**
Total Hydrocarbons	NS	NS	12.07
CH_4	NS	NS	47.62
NMHC	*NS*	*NS*	*NS*
CO	*NS*	*NS*	*20.23*
NO_x	*NS*	*NS*	*48.44*
1,3-Butadiene	NS	NS	NS
Acetaldehyde	NS	36.82	NS
Benzene	NS	18.53	NS
Ethylbenzene	-11.72	NS	NS
Formaldehyde	NS	NS	19.81
n-Hexane	NS	NS	NS
Styrene	NS	NS	NS
Toluene	-12.24	NS	NS
M,P-Xylene	-10.95	NS	NS
O-Xylene	-12.08	NS	NS

*Statistical significance was determined using $\alpha = 0.90$; NS indicates no significant effect at this level. Percent difference is positive if there is an increase in emissions when the content of the listed fuel property is increased. Regulated pollutants are shown in italics.

Clearly the data from this scoping study indicate that there may be benefits to future fuel controls, though in many cases the size of the test program was not sufficient to determine effects with statistical confidence. At this time, EPA is hoping to conduct a more comprehensive fuel effects test program, as directed by the Energy Policy Act of 2005, in cooperation with stakeholders and other interested parties, to generate new data over the next several years. We expect that work will produce updated emissions models, as well as sufficient data to make decisions about future fuels programs.

6.12 Analysis of Future Need for RFG Surveys of Toxics and NO_x Performance under MSAT2

The RFG surveys were created by EPA as part of the RFG program to ensure compliance with a provision of the Clean Air Act which states that all RFG areas must have gasoline meeting certain performance requirements.[40] Gasoline is often produced far away from where it is consumed and shipped via a distribution system that treats it as a fungible commodity. The RFG retail surveys were put in place as a way to measure and document fuel properties at the point of consumption.

Once the MSAT2 program is fully implemented, our analyses indicate that all gasoline will meet or exceed statutory requirements under the RFG program as well as existing NO_x performance standards. Therefore, we will no longer require demonstration of compliance with these programs, and believe it follows that retail surveys for these standards are no longer necessary.[q] To verify that this is a reasonable course of action, we have conducted an analysis of projected emissions performance for future RFG.

6.12.1 Total Toxics Reduction

Within a given RFG area, total toxics emissions as defined by the Complex Model must be reduced over Clean Air Act baseline gasoline by 20.0% on a per-gallon basis, or 21.5% on an annual average basis.[41] Once the MSAT2 and gasoline sulfur programs have been fully implemented, our analyses show that emissions of total toxics from RFG will be reduced beyond what is required by the applicable statutory and regulatory requirements.

To verify that this will be the case in all RFG areas, we performed a refinery-by-refinery analysis for each refinery that produced RFG in 2004. We used 2004 batch report data as a baseline, and then modified each refinery's sulfur level to meet a 30 ppm average standard and benzene level to meet what our cost modeling projects as the applicable PADD-average RFG benzene content.[r] We also removed all ethers and replaced them with 3.5 weight percent oxygen as ethanol. This change in oxygenate blending is outlined in the documents generated for the NPRM of the RFS rulemaking.[42] Resulting PADD-average RFG fuel parameter values are given in Table 6.12-1. Note that the analysis was done for each refinery, but due to control of confidential business information and the need to use PADD-averages for some input assumptions, PADD aggregates are shown here.

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[q] More discussion of this topic can be found in Section VI.B.3 of the preamble of this rulemaking.

[r] See section 6.5.4 of this chapter.

Table 6.12-1. Projected PADD-Average RFG Fuel Parameters Under MSAT2.

PADD	MTBE wt%O	Ethanol wt%O	Sulfur ppm	RVP psi	E200 vol%	E300 vol%	Aromatics vol%	Olefins vol%	Benzene vol%
1	0	3.5	30	9.51	50.86	82.91	20.34	14.03	0.52
2	0	3.5	30	9.65	53.50	85.26	17.97	5.04	0.61
3	0	3.5	30	9.15	52.34	83.09	18.31	11.35	0.55

Using the individual refinery fuel parameters, we calculated projected total toxics emissions reductions. The results indicate that no refinery's RFG is expected to fall below 25% total toxics reduction on an annual average basis. In fact, there is considerable overcompliance of all RFG beyond what is required by applicable statutes and/or regulations, and we do not believe there will be any risk of noncompliance in any particular area. These results indicate that continuation of RFG surveys for toxics performance under MSAT2 is not needed. More detailed results are given in Table 6.12-2.

Table 6.12-2. Projected RFG Toxics Reductions Under MSAT2.

PADD	Annual Average Total Toxics Reduction Over CAA Baseline Gasoline	Lowest Refinery Annual Average Total Toxics Reduction Over CAA Baseline Gasoline
1	28.1%	25.5%
2	30.3%	27.4%
3	29.8%	25.5%

6.12.2 NO_x Reduction

Within a given RFG area, NO_x emissions as defined by the Complex Model must be reduced over Clean Air Act baseline gasoline by 5.0% on a per-gallon basis during the VOC season (summer), or 6.8% on an annual average basis.[43]

To verify this will occur in all RFG areas under the MSAT2 program, we performed a refinery-by-refinery analysis in parallel to the one described above for toxics using the same model and the same adjusted fuel parameters. The results of this analysis indicate that no refinery's RFG is expected to fall below 9% reduction in NO_x emissions over the baseline gasoline in the summer season, or approximately 8% reduction on an annual average basis. More detailed results are given in Table 6.12-3.

Table 6.12-3. Projected RFG NO_x Reductions Under MSAT2.

PADD	Annual Average NO_x Reduction Over CAA Baseline Gasoline	Lowest Refinery Annual Average NO_x Reduction Over CAA Baseline Gasoline	Lowest Refinery Summer Average NO_x Reduction Over CAA Baseline Gasoline
1	11.4%	8.3%	9.4%
2	15.6%	13.0%	10.6%
3	13.7%	11.3%	10.9%

Given these results, we arrive at the same conclusion as for toxics: that there will be no significant risk of noncompliance with NO_x requirements in any particular RFG area. Therefore, continuation of RFG surveys for NO_x performance under MSAT2 is not needed.

Appendix 6A: Additional Background on Refining and Gasoline

We believe our discussion of how the benzene content of gasoline can be reduced would be enhanced with a deeper discussion of how refineries work. In addition to discussing the various units involved in producing gasoline, we also discuss aspects of crude oil -- the primary feedstock for refineries – gasoline and other products produced by refineries. Because of the affect of benzene control on octane, we discuss the octane specifications in detail as well. The information in this Appendix supplements some important information about refineries presented above. Section 6.1 provides an overview of refining. Section 6.3 provides a detailed discussion of how reformers work as well as a discussion about the technologies which reduce the benzene levels in gasoline.

6A.1 Petroleum Refining

Petroleum refineries have been part of our general landscape for at least 150 years. The earliest examples were little more than a barrel or bucket sitting on rocks or blocks over an open fire. During those early years, the heavy fractions of crude oil were more valuable when used as grease for wheels and fuel for heating and lights. The light fractions were either boiled off or poured-out into a nearby ditch or pond.

Today, petroleum refining is an altogether different industry. The most identifiable characteristic of most refineries in the U.S., apart from their names, of course, are their crude throughputs, in barrels per day (bpd). The largest domestic refineries run up to 490,000 bpd of crude shipped to them by ocean-going barges, pipelines, and trucks from all over the world. The smaller refineries, of which there are few, run about 10,000 bpd, on average. Even these smaller facilities occasionally run some foreign crude supplied to them by pipeline; some from Canada is shipped by pipeline while most of the rest is hauled by marine tankers to terminals along our coasts. From there the crude is shipped to various parts of the country via pipeline, rail, and truck.

Most petroleum refineries are much alike, regardless of crude throughput; they consist of processing units with nearly identical names, the most important of which are: crude units, vacuum units, reformers, isomerization units, fluid catalytic crackers, hydrocrackers, cokers, and sulfur recovery units. All refineries have at least one crude unit; many of the larger refineries have more than one. Most, if not all have at least one or more vacuum units. If a refiner sells gasoline, he certainly has a reformer. As a refiner adds units to improve his ability to convert crude barrels into lighter, more valuable products (especially gasoline in the U.S.), he increases the complexity of his facility. The main differences among the refineries are the sizes or capacities of the units. Admittedly, all refineries don’t have all the units; but to the extent a refinery has them, it is similar to the others. We believe we should also make the point that even though two or more refiners may have nearly identical units of some kind, none will likely produce identical products. Similarities notwithstanding, crude variations and operating philosophies tend to make significant variations in finished products.

We feel it is neither possible, nor for that matter necessary, to describe every possible refinery configuration in order to explicate the effects we believe this rule have on refinery operations and finished gasoline following the promulgation of this rule.

The “refinery” to which we refer in the following discussion should not be construed to be any specific refinery or refineries in the U.S., or the world for that matter. None of the units will have a specific flow rate, unless it is germane to our discussion. Our discussion is qualitative; we most certainly do not imply nor will we provide any sort of weight or volume material balance around any unit or the total refinery. Many refineries may have a few of, several of, or all of the units we discuss. Our discussion of the crudes, intermediates, and finished products will also be generic by nature, but will hopefully depict them well enough to be clear about what is meant. We will focus mainly on how benzene is currently produced, and how and why it is usually found in gasoline; we will then discuss ways refiners may be able to reduce its final concentration in their gasoline.

We will briefly describe how the primary units operate within an average refinery, with slightly more detailed discussions of the units that affect the final concentration of benzene in gasoline. However, the first topic we will discuss is crude oil, since it is both the primary feedstock to most U.S. refineries and since most crude contains at least some naturally occurring benzene.

6A.2 Crude Oil

While crude oil is the main feedstock for most refineries, occasionally other stocks may be purchased which are either processed further or blended directly into finished products. Crude oil is generally described as a complex mixture of hundreds of different compounds made up of carbon and hydrogen, the molecular weights of which vary from 16 for methane, the simplest, to perhaps several hundred, for the most complex. The principal hydrocarbon species are paraffins (alkanes), naphthenes (cycloparaffins), and aromatics; benzene, the subject of this rule, is an aromatic. There are also many combinations of these species, such as alkyl naphthenes, alkyl aromatics, and polycyclic compounds (two or more aromatic compounds joined into a single molecule). Crude also contains inorganic substances including atoms of sulfur, nitrogen, and oxygen, as well as metals such as iron, vanadium, nickel, arsenic, and chromium, in varying concentrations depending on the source of the crude. Collectively, because these atoms are neither carbon nor hydrogen, they are sometimes called “heteroatoms.” More commonly, they are referred to simply as contaminants. Certain heavy crude oils from younger geologic formations (e.g., Venezuelan crudes) contain less than 50 percent hydrocarbons and a high proportion of organic and inorganic compounds containing heteroatoms. Over the years, many refinery processes have been developed to remove or reduce their concentrations to low-levels because they damage catalysts. Likewise, our recent rules were promulgated in order to reduce the negative effects some of these heteroatoms have had on the environment.

In the world each day, a huge volume of crude oil is produced, shipped, and refined. It is sold according to its quality and availability. The market price of a particular crude is usually calculated according to formulae that relate its API Gravity and sulfur content, and perhaps other criteria, to an agreed upon index. These indexes vary according to other indexes, depending on where the crude located. Nevertheless, at any given time, it is a reasonable expectation that nearly any refinery in the U.S. could be processing crude from almost any country in the world.

As a brief introduction to what follows, we note that the gasoline produced by most modern refineries consists of several blendstocks, most of which are usually produced in that refinery. We used the term “usually” in the previous sentence, since from time-to-time, refiners purchase feedstocks and blendstocks from other sources. During the early days, refiners used simple distillation (fractionation) technology, to recover as much naturally occurring straight-run gasoline as possible. During the past 60 to 70 years, there has seen a steady drive to develop processes and catalysts that convert as much as possible of any given crude barrel into high-quality, light products such as gasoline and diesel. Today, in the U.S., there is very little finished fuel that hasn’t in some fashion been upgraded after it leaves the crude unit. This has been especially the case for gasoline. However, even now or at least in the near future, relatively more kerosene and diesel will be processed as a result of recent low-sulfur rules.

As far as reducing the benzene content of gasoline is concerned, a refiner may be fortunate enough to purchase crude with less naturally occurring benzene and fewer benzene-precursors. Regardless, since much crude contains at least some benzene and benzene-precursors, the crude unit is usually the first opportunity a refiner has to begin controlling the final benzene concentration in his gasoline. However, that “first opportunity” doesn’t come at the beginning of the process. Consequently, we feel our discussion will be made more intelligible by describing the entire process, beginning with the crude unit and including several other benzene producing processes. We will then high light the points where process changes can be made to control both the naturally occurring benzene and the reformer feed benzene precursor content which will ultimately reduce the overall content in the gasoline going to market.

6A.2.1 Crude Desalting

Usually, water, or brine, from a variety of sources is recovered with crude at the time it’s produced. Crude and water are often produced as an emulsion as a result of the recovery pump’s shearing action. One of the main reasons the water is called brine is that it usually contains a variety of water-soluble salts and suspended solids, which are potentially corrosive and otherwise damaging, but also tend to stabilize the emulsions. Depending on the oil’s composition, its pH, and to some extent, the quantity of suspended solids, some emulsions gradually “break” on their own in a field tank. Occasionally, however, tight emulsions form that can only be broken using heat and sometimes an emulsion breaker. One of the first and most important lab tests run on raw crude is called the test for “Basic Sediment & Water” (BS&W). Oil field operators are usually able to reduce the BS&W of most crude to around one percent or less, by volume, before the crude is shipped to a refiner

While some contaminants may settle-out in the feed tank with the water, refiners have learned that desalting ahead of the crude unit is usually economically very beneficial. Even at 1% or less, BS&W can still cause problems. Inorganic, water-soluble salts, e.g., sodium, calcium, and magnesium chlorides can hydrolyze in a crude furnace and eventually combine with water (condensed stripping steam) usually found in most crude tower-overhead systems to form acidic solutions that are very corrosive to the overhead internals. Consequently, most refiners choose to desalt their crude ahead of the crude unit. Desalting is a continuous operation, during which warm crude is vigorously mixed at the proper mix-ratio with clean water and occasionally some proprietary chemical or other, after which the oil/water mixture is allowed to separate with the aid of an electrostatic precipitator. The water and sediment are continuously withdrawn and sent to water disposal facilities. The washed crude is fed to the crude preheat train.

6A.2.2 Atmospheric Crude Unit

We will use the term “straight-run” from time-to-time in the following discussion. It refers specifically to any product produced from crude by an atmospheric unit, especially the crude unit. We believe this is a fairly common usage. As such, the rest of the streams in the refinery are processed further in some manner and are no longer “straight-run” products.

6A.2.3 Preflash

Most crude contains some light gas, most of which is butane; crude occasionally contains some propane and isobutane, but their percentages are usually quite low. Often, refiners use a preflash unit to remove the butanes and occasionally propane. Occasionally, a preflash unit may be used to make a single distillation cut between the C_5’s and C_6’s or the C_6’s and C_7’s. In effect, this sets the final boiling point (FBP) of the light cut, which is fed to an isomerization unit. A refiner also has the option of making the preflash cut between the C_6’s and C_7’s, and sending the C_6- cut over the top. This cut is then fed to the main crude column above the heavy straight run tray. This is usually done in order to unload the feed zone and reduce the vapor traffic in the lower rectification sections of the main column.

Preflash units, often referred to in the early days simply as knock-out drums or tanks, were and still are, usually located somewhere in the feed line after the feed pump. Early on, they were often no more than a simple tank with a diameter-to-height (or length/diameter or head-space) ratio sufficient to reduce the flowrate enough for the gas to separate from the liquid phase and be removed under pressure control. Initially, many of these drums were horizontal, bullet-type, tanks similar to those used to store liquefied petroleum gas (LPG) and/or other light-hydrocarbons. Over time, a variety of internals, such as baffles and packing, were added to improve the separation efficiency. Again, depending on the volume, the off gas is usually sent to the suction-side of the wet gas compressor in the FCC gas concentration (gas-con) unit for recovery; if the volume is small it is ordinarily sent to the fuel gas system.

As discussed above, the actual vessel may not have been more than a simple flash drum that would provide at most only one or two theoretical separation stages and essentially no stripping. Ordinarily, a refiner doesn’t expect to accomplish much more than to make a reasonably clean, if somewhat inconsistent gas/liquid separation; clean liquid/liquid cuts were seldom really possible, of course depending on the equipment and controls. Nevertheless, it was usually sufficient for degassing purposes; preflash units have become increasingly more complex and efficient as refiners have geared-up to increase efficiency, refine an increasing variety of crudes, and to meet the more stringent quality and compositional requirements necessary for low-sulfur and reduced toxics compliance. Currently, many, if not most units include a distillation-type tower (similar to a crude tower, but usually much shorter), with trays or packing and a reboiler (thermosiphon or heater/furnace type) to provide stripping. Generally, this kind of preflash unit will not only efficiently remove the light gas referred to above, but can also make a fairly decent or clean, single, overhead/bottoms cut to remove the C_5/C_6 light ends from the rest of the crude; we note here that preflash towers usually don't have side-draws. In recent years, electronic process controls, e.g., distributed control systems (DCS), have begun to play a significant roll in helping operators make cleaner cuts than were previously possible using the older pneumatic controllers to control what were fairly inefficient preflash towers/vessels.

The preflash operating conditions, such as flowrate, feed temperature, tower pressure, and reflux and reboiler rate, would be set according to the feed composition and the desired cut. The overhead, consisting of pentanes and lighter and some hexanes is condensed, cooled, and collected in an overhead accumulator and degassed, e.g., the non-condensable gases are removed from the accumulator under pressure control. Part of this condensed hydrocarbon is pumped as reflux to the tower's top tray or, if the tower is packed rather than trayed, to the top of the packing; ordinarily, there are no side-draws. The off-gas from the preflash is usually sent to the wet-gas compressor in the fluid catalytic cracker (FCC) gas-concentration (gas-con) unit, if there is enough gas and the refinery has a gascon, as most modern refineries do. The excess overhead liquid, under level control, is sent to a naphtha splitter.

6A.2.4 Crude Unit

Regardless, the desalted crude preheated in feed/effluent heat exchangers against hot crude tower product rundowns to recover process heat. It is subsequently fed either to the preflash or to the crude charge furnace for trim heating to about 650° to 700° F and fed to the flash zone of the crude tower at a pressure slightly higher than atmospheric. An ordinary crude tower consists of a steel cylindrical column, which is usually around 100 ft. to 120 ft. tall to accommodate the number of trays and their spacing, and whose diameter is set according to the design feedrate. We won't discuss the minutiae of the heat and mass transfer dynamics of crude fractionation at this point, but we will mention that the tower diameter is set according to the feedrate, such that the vapor/liquid velocities in the tower and the tray liquid volume and residence times will allow the transfer of heat and material to reach a condition of stable equilibrium at each tray. A common assumption that may cast some light on the vapor/liquid traffic in a crude tower is that, at equilibrium, the moles of liquid traveling down the tower will equal the moles of vapor traveling up the tower.

The distillation or fractionation "tray" of which we speak, is a type of plate or tray (usually a type of steel or steel alloy about a quarter-inch thick) installed at equal distances apart, one above the other, beginning just above the feed zone and continuing up the entire height of the column. These are ordinarily called distillation, fractionation, or simply tower trays and are usually designed and spaced according to specific criteria involving far too many factors for us to discuss here. Regardless, on average, while there could be as many as or seven or eight trays between each draw tray, there may be as few as four or five. The number usually has to do with desired product purity, but is also related to tray design limitations such as pressure drop per tray and with column height.

The trays are designed to maintain a specified liquid level on their surface, deep enough for good vapor/liquid contact, but as more condensed liquid falls onto a tray and reaches the predetermined maximum level, there must be a mechanism by which excess liquid can fall down to the next tray. A couple of ways are to drill specified diameter holes in the tray (these trays are usually called “sieve trays”) or to install “down-comers” from one bubble-cap tray to next tray below.

Please note that we have mentioned only two types of trays, sieve and bubble cap, which are quite common and have been in use for many years. There are in fact several others, many of which are of proprietary design. There are many designs, but the purpose of all of them is to provide a way for the vapor traveling up and liquid traveling down to come in contact in order to provide for heat and mass transfer at as low-pressure drop as possible. At each tray the liquid is enriched with heavier components and the vapor is enriched with lighter components. At specific levels in the column, design engineers predict that the condensed liquid will look like one of the products the refiner would like to produce. They install draw trays at these levels, from which the straight-run products are each withdrawn.

As we mentioned in the first paragraph of this section, the hot crude is fed to the feed or flash zone of the atmospheric crude column or tower. Within the flash or feed zone, the components whose characteristics, e.g., boiling points, are such that they vaporize, separate from those components that remain in the liquid phase at tower conditions. The vapors begin to rise into the rectifying section of the tower while the heavier liquid falls into the tower stripping section. We will briefly discuss the tower bottom operation first, followed by a discussion of the vapor phase as it leaves the flash zone. The last crude tower stream we’ll discuss will be the heavy straight run, which is fed to the reformer to become one of the more important gasoline blendstocks. Our discussion of gasoline and how it’s produced will proceed from there.

6A.2.5 Atmospheric Tower Gasoil and Residuum; Vacuum Unit

The heavy ends of the crude, which didn’t vaporize in the feed zone, fall down over three or four stripping trays installed in the crude tower bottom. High-pressure steam is injected under the bottom tray to strip out any remaining light-ends. The stripped crude tower bottoms (ATB) are removed, cooled against feed and sent to storage. There are times when the ATB’s may be fed directly to a vacuum tower; regardless, there is usually provision for sending at least a slipstream to storage.

Vacuum Unit: We have included a discussion of the vacuum unit as part of this section. It plays an important role in producing road asphalt, and lube oil feedstocks as well as feed for the FCC, an important gasoline and diesel producing process and occasionally the coker. In some cases, the AGO, which we will presently discuss is fed to the FCC while the ATB is fed to a vacuum unit rather than directly to the FCC.

A vacuum unit is necessary in order to process the heavy or high boiling ATB stream to recover the components which, separately, are more valuable in other markets. Most crude begins to thermally crack at around 700° F and atmospheric pressure; some crude will begin to crack at as low as 650° F, while others may not begin until upwards of 750° F. It is therefore necessary to use a vacuum unit to lower the boiling points of the ATB components. The vacuum may be generated using stream driven eductors or, more recently by using vacuum pumps. As a rule, the greater the vacuum is, the better. The entire design of the unit is of course critical in order to make the desired separations and recoveries. One very important issue is the design of the tower feed line and the tower flash zone. If the feed has not sufficiently vaporized in the tower feed line, it may explosively vaporize in the flash zone, to not only make the vapor/liquid separation as clean as possible, but rapidly expanding vapors can also dislodge tower internals. If the tower is being used to produce asphalt, the flash zone operation is critical. If the feed vaporizes explosively in the flash zone, the high velocity vapor components may carry asphaltenes upward with them, and eventually contaminate the heavy vacuum gasoil.

A vacuum tower ordinarily produces a low-volume overhead that boils in the heavy naphtha to kerosene range. These are generally light components that didn’t strip out of the ATB with stripping stream at the conditions in the crude tower bottom, but which readily separate out under vacuum tower conditions. The unit usually produces a small volume of light-vacuum gasoil, which is routinely fed to the distillate hydrotreater and eventually to distillate blending. The lower side cut is called heavy vacuum gas oil, HVGO. We use the term “cut” for convenience, knowing that the draws from the vacuum tower aren’t “true” distillation cuts in the technical sense of the term, used when discussing fractional distillation. The number of theoretical stages in a vacuum tower is usually quite low compared to a crude tower; perhaps no more than nine or 10 theoretical stages for the entire tower. Depending on the crude source, HVGO may qualify as lube stock; otherwise, it would be fed to an FCC. If the original crude was asphaltic, the vacuum resid or vacuum tower bottoms (VTB) may qualify as asphalt for use in the paving and roofing industries or could also be fed to a hydrocracker or a coker. Another important difference between vacuum towers and crude towers is that vacuum towers are true distillation towers. The draw trays are referred to as total draw trays; that is, there is liquid released from the tray down to the section below it, so there is no true internal reflux. The “internal reflux” is provided by “pump-arounds.” That is, light and heavy vacuum gasoil is pumped into a distribution nozzle some distance above each of the two draws. There may also be “pump-back” streams, which are pumped back to the tower under a draw tray. Another important stream is the one pumped back under the HVGO draw tray, which washes contaminants such as asphaltenes from the vapors leaving the flash zone. Most vacuum units can produce several grades of asphalt, a few of which may be back-blended to produce others, as needed. Some refiners use solvent deasphalting to produce finished asphalt. High-flash point asphalt is usually air-blown in a plant designed specifically to produce roofing asphalt. We also note that not all asphalts are alike. Some are especially good for producing road oil and asphalt, but not for producing roofing asphalt; the reverse is also true. Polymer modified asphalt has become very popular with highway engineers. Some types of asphalt work well when blended with polymers to improve their highway performance, while others do not. With few exceptions, asphalt qualities and the uses for which asphalt may be produced are closely related to the crude from which the asphalt was originally derived. Vacuum tower bottoms may also be fed to a coker, from which liquids may be recovered along with the coke.

For several reasons, the products derived from a barrel of average crude coming directly from a crude unit have become increasingly less useful for market. There appear to be at least two reasons; there are probably others. One is that the average crude barrel available to U.S.

refiners has gradually become heavier (e.g., has a lower percentage of light straight-run products such as naphtha and diesel and more heavy cuts such as the AGO and ATB that we've just discussed). Moreover, heavier crude usually contains increasingly higher percentages of contaminants, which must be removed by some type of downstream processing. Secondly, not only has the demand for light products (especially gasoline and diesel) grown quite rapidly, but likewise the finished product quality specs, apart from those imposed by government regulations, have become very high.

We will now discuss the crude tower operation above the flash zone. The fraction of the crude that vaporizes in the feed or flash zone at the above referenced temperatures and pressures, separates from the heavy liquid fraction and (the vapor) begins to rise upward through the tower. As it rises it becomes progressively cooler and the heaver fractions begin to condense. In effect, once the tower reaches a state of dynamic equilibrium, the vapor traveling up and condensed liquid falling down the column are continually contacting each other to exchange heat and mass. The first draw tray above the flash or feed zone will begins to fill with liquid which eventually becomes atmospheric gasoil (AGO) when it is finished.

In this section, we will discuss the specifics of how the AGO draw is handled. We note that the other side-draws above the AGO are handled in much same manner; other than listing them, they won't be discussed. The withdrawn liquid is fed to a steam stripper to adjust its flash point. This is necessary because the liquid taken from the column will always contain at least some of the lighter, lower boiling components, which condense higher in the column, but that are continually part of the traffic in that section. This withdrawn liquid contains components, besides the AGO cut, such components as diesel, kerosene, heavy and light naphtha, and steam used to strip the tower bottoms. These are all removed from the AGO by steam stripping. A steam stripper is a small cylindrical vessel, into which about four to six perforated (sieve trays) are installed. The draw liquid is fed into the side of the column at the top through a distribution nozzle or pipe and falls down over the trays, while high pressure (>150 psi) steam is injected into the column under the bottom tray. The stripping steams does not actually physically strip the light ends from the liquid. Rather, its presence changes the partial pressure of the light ends and helps them disengage from the hot liquid, following which they are carried up and out of the stripper top along with the steam. These gaseous components are fed back into the crude tower just above the draw tray and once again become part of the tower traffic. The stripper bottoms are usually cooled against crude feed in a feed/effluent exchanger, water cooled, and sent to storage.

The vapor above the AGO draw continues up the tower, progressively cooling and condensing as it travels. Draw trays are installed at levels where diesel, kerosene, and heavy naphtha (heavy straight-run, HSR), are each withdrawn from the tower in that respective order proceeding upward. Each is stripped, cooled, and sent to storage much the same as we described for the AGO.

The crude tower overhead, which usually consists of C_5's thru C_{11}'s, is ordinarily fed to a naphtha splitter (see below). The usual configuration has a feed flow controller, which maintains a steady feedrate to the splitter. It is installed in a pipe or line position from which it can control the crude tower overhead flow such that it can feed the splitter directly from the crude tower overhead drum. However, if the crude tower overhead rate becomes too high for the splitter, the splitter feed controller can open a valve in another line that will send the excess to storage. On the other hand, if the crude tower overhead flow is too low, the splitter feed controller can close the valve to storage and open still another valve to draw makeup feed volume through a different line from storage. In other words, this arrangement not only maintains a constant feedrate to the splitter, but the crude overhead storage tank provides surge capacity for the crude unit as well as feed to the splitter should either come down unexpectedly. Additionally, some refiners use a reformer feed tank to which splitter bottoms run down and from which the reformer is fed to provide some surge capacity for the reformer in case of splitter-unit problems.

6A.2.6 Naphtha Splitter

The naphtha splitter cuts the C_5's and some C_6's into the overhead while most of the C_6's and C_7+ cut is removed from the tower bottom. Pentanes do not make good reformer feed. They are not converted into aromatics and although they have a relatively decent octane, it is somewhat lower than usual reformate and actually dilutes the reformate octane. Another drawback of having pentanes in the reformer feed is that they usually crack to gas and thus actually reduce finished liquid yield.

We believe it is noteworthy that until recently, most of the C_6's were typically fed to the reformer. Cyclohexane, for example, with a clear RON of around 83.0, is usually converted to benzene which has an octane blending value >100. Also, naturally occurring benzene boils in approximately the same boiling range and has been an important gasoline blending component for many years. Nevertheless, despite best efforts, some C_6's ended up in the isom feed. We believe it is also worth noting that prior to the lead phase down this stream was routinely called light-straight run and was very susceptible to tetraethyl lead (TEL). As a rule, TEL raised the clear LSR by around 15 numbers; this varied somewhat depending on the crude source. Fortunately, most refiners were able to install isom units to replace the octane lost with the removal of lead.

The splitter overhead typically contains at least some of the following light hydrocarbons: isopentane, normal pentane, cyclopentane, 2, 2 dimethylbutane, 2, 3 dimethylbutane, 2 methylpentane, 3 methylpentane, normal hexane, methylcyclopentane, cyclohexane, and benzene. The isomerization (isom) unit bottoms are routinely fed to a naphtha reformer. Until recently, e.g., promulgation of the MSAT rules, the splitter distillation cut was made approximately between the C5's and C6's, providing a C5 minus cut to the isom and the C6 - FBP cut to the reformer. We will discuss these cuts as they apply to benzene reduction in more detail later.

6A.2.7 Hydrotreating

We will discuss hydrotreating technology because it plays an important role in the feed preparation for many of the units we will be discussing. Hydrotreaters use catalysts at high temperatures and pressures with fairly pure (>75% and of ten >95% pure hydrogen to remove contaminates, such as sulfur, nitrogen, and heavy metals from a variety of feedstocks to other units. The “hydro-” prefix indicates hydrogen is used in the main reactions. Hydrotreaters may be referred to by a variety of names such as hydrodesulfurization units (specifically remove sulfur), distillate hydrotreater, or hydrodenitrification units (specifically remove nitrogen). Also, the acronym HDT is often used when referring to a distillate hydrotreater; HDN refers to a naphtha treater, an important pretreater for a reformer. There are also FCC feed hydrotreaters, usually called “cat feed hydrotreaters.” There are of course, pumps, compressors, heat exchangers, high- and low-pressure separators, as well as flashpoint stabilization units associated with these units. Hydrotreaters use hydrogen from either a steam/methane reformer or a catalytic naphtha reformer.

The catalyst usually consists of a combination of cobalt, molybdenum and nickel, applied to the surface of an alumina extrudate. Over time the catalyst deactivates as a result of coking and/or metal poisoning and must be either decoked or else replaced. When the catalyst deactivates, the coke can be burned off (either in the reactor or off-site by a contractor) and reused. Typically catalyst can be used a few times before it needs to be replaced. It is ordinarily not possible to regenerate a poisoned catalyst.

Sulfur compounds are converted into hydrogen sulfide, which is routinely removed from the process recycle and/or off gas in an amine extraction unit, following which the hydrogen sulfide is removed from the amine and converted into elemental sulfur. Nitrogen is removed using a sour water stripper, as ammonia, which is removed in an ammonia recovery plant.

The reactor is the dominant feature. Hot feed, the temperature of which depends on the catalyst type, the stream being treated and the contaminants being removed, is usually mixed at high pressure with hot hydrogen gas, usually from a catalytic reformer and fed down-flow through a distribution tray, onto the catalyst bed. If the reactor is tall and has several beds, the mixed hydrocarbon/hydrogen stream being treated may be withdrawn from open spaces or gaps between some of the beds and fed back to the next bed through a re-distribution tray. This helps prevent channeling, especially if the stream is liquid. Catalyst is not consumed in the process, but lowers the activation energy of the chemical reactions needed to remove the contaminants. As a rule, the heavier the feed and the more difficult the contaminants are to remove, then the higher will likely be the temperature and pressure of the process. Catalyst type obviously plays a pivotal role in setting the operating conditions. For example, if a catalyst is a “hot catalyst” the operating condition may be less severe than for a less-active catalyst. We mention here that the reformer and the FCC are units whose feeds are usually hydrotreated. If the FCC doesn’t have a feed hydrotreater, the heavy crackate, a potential gasoline blendstock, may need to be treated in order to meet sulfur specs. The light cycle oil will also need to be treated before it is used in distillate blending; if the light cycle oil can be stored separately, it could potentially be sold in the fuel oil market; otherwise, it would need to be hydrotreated before it could be sold into the ULSD market

6A.2.8 Fluid Catalytic Cracker

Generally FCC feedstocks are made up of heavy or lower API Gravity fractions, such as AGO, ATB, and HVGO. For many years, before the demand for light products reached the level it is today, these fractions were marketed as fuel oil, mostly in heavy industry. However, the demand for light products, especially for gasoline, was a great motivator for the development of processes that would convert these low-value heavy oils into higher-value light products. Cracking, a generic reference to the process began to be used commercially the early part of the 20th century. The first units were called thermal crackers which used high temperatures to thermally crack heavy stocks. Eventually, fixed-bed catalytic crackers were used, one of which was the Houdry fixed bed process the success of which was recognized in the late 1930's. Around that time, work was going on to develop a process using finely powdered catalyst, which subsequently led to the development of the fluidized bed catalyst cracker or fluid catalytic cracker (FCC). Originally, grinding fixed-bed catalyst material produced the finely powdered catalyst. More recently it has been produced by spray-drying a slurry of silica gel and aluminum hydroxide in a stream of hot flue gas. If done properly, a catalyst can be produced consisting of small spheres in the range of 1-50 microns particle-size.

FCC feed hydrotreaters have become more common as a result of recent government regulations limiting sulfur in diesel and gasoline. Many refiners have determined that feed hydrotreaters improve the liquid volume recovery sufficiently, in some cases, to earn a reasonable return on their investment.

Regardless of whether the feed has been hydrotreated, the fresh feed and possibly FCC fractionator bottoms or heavy cycle oil are fed into a riser with hot catalyst; the catalyst is typically regenerated, a topic of which we will speak in a moment. The charge can be heated by an available source, e.g., furnace or heat exchange. As the feed vaporizes, the cracking reactions begin and entire mix is carried upward through the riser. At the riser top, the mixture is fed into a reactor from which the catalyst and hydrocarbons are separated. The reactor effluent hydrocarbon stream is fed to the FCC fractionator, while the catalyst falls down a pipe into the catalyst regenerator. During the cracking reactions, coke forms on the catalyst and deactivates it. The coke is burned off in the regenerator and essentially reactivated and prepared for reuse; an air blower supplies the required combustion air to the regenerator. The regenerated catalyst passes down the regenerator standpipe to the bottom of the riser, where it joins the fresh feed and the cycle repeats. Over time, part of the catalyst becomes unusable, e.g., is crushed into fines, and is replaced on a continual basis from catalyst storage, such that a proper amount of catalyst of sufficient activity is always available. In what is sometimes referred to as a power recovery system, a stream of flue gas drives a turbine, which is connected to the air blower. In that catalyst fines would quickly erode the turbine vanes, the flue gas stream passes through several small cyclone separators before it reaches the turbine. The waste heat in the flue gas is finally used to generate steam.

The fractionator separates the reactor effluent into three main streams. The crackate or cat gasoline and mixed olefins are removed in the overhead; the light cycle oil, a side cut, is steam stripped and sent to storage to eventually be used in distillate blends; the fractionator bottoms are often referred to as slurry oil or heavy cycle oil. Occasionally the heavy cycle oil is fed as a recycle stream back to the FCC riser, but is seldom recycled to extinction; it may also be fed to a coker. The light olefins are sent to the gas concentration unit (gascon) for recovery and further processing into polymer gasoline and alkylate.

While the FCC cat gasoline does contain some benzene, it is not a major contributor to the total benzene concentration in finished gasoline. We don't expect much will be done to reduce the benzene in cat gasoline.

6A.2.9 Alkylation

The alkylation process combines a mixture of propylene and butylene which are usually produced by the FCC, with isobutane in the presence of an acid catalyst, usually either sulfuric or hydrofluoric acid. The product, alkylate, is a mixture of high-octane, branched-chain paraffinic hydrocarbons. Alkylate is considered to be a high-grade blendstock because it has high octane and contains essentially no contaminants. Two of the more common processes use either sulfuric or hydrofluoric acid as catalyst.

In the sulfuric acid catalyzed process, propylene, butylene, amylene, and isobutene are used. Isobutane, often produced by a butane isomerization unit, and the acid catalyst are mixed and fed through reaction zones in a reactor. The olefins are fed through distributors into each zone as the sulfuric acid/isobutane mixture flows over baffles from zone to zone.

The reactor effluent is separated into hydrocarbon and acid phases in a settler, from which the acid is recycled to the reactor for reuse. Some acid is routinely lost and must be made up. The hydrocarbon phase is washed with caustic for pH control (to completely neutralize the acid) before it is fed, in series, to a depropanizer, a deisobutanizer, and a debutanizer. The deisobutanizer bottoms or alkylate can be sent directly to gasoline blending; the isobutane is usually recycled back to feed and the propane may be recycled back to the gascon unit for propane recovery.

6A.2.10 Thermal Processing

Thermal processing was one of the first ways early refiners processed crude. There are essentially three current processes that qualify as thermal processors: delayed coking, fluid coking, and visbreaking. All are used for the purpose of producing more valuable products such as catalytic cracker feed and to reduce fuel oil make. Of themselves, they produce only minor volumes of naphtha which must be severely hydrotreated and generally reformed before it can be used as a gasoline blendstock.

6A.3 Gasoline

A previous rule provided several important health benefits by reducing the benzene content in gasoline. We believe the health data gathered since then provides strong support for removing even more benzene. We will review the refining processes that produce the usual components from which gasoline is formulated; our discussion of specific units that produce benzene will be more detailed. We believe this will provide coherence to our discussion of how refiners can reduce gasoline benzene content. It is important to note that regardless of the negative health effects, benzene also contributes to gasoline octane and, thereby, to our ability to produce the engines that help power the world's economy. We will also discuss ways refiners may be able to recover the octane lost as a result of removing benzene.

Refineries in the U.S. are complex industrial plants that process various crude oil feedstocks into many important products. Among the most important of these, but certainly not limited to them, are gasoline, jet fuel, kerosene, diesel fuel, fuel oil, and asphalt. Many refinery intermediate streams, such as those produced by fluid catalytic cracking (FCC), become feedstocks to processes in the chemical industry. The sophistication of these refineries varies, from simple to very complex. The level of complexity is defined by the various types of equipment (i.e., units) in use at the refinery. Refineries have been built (or added to) during different engineering ‘eras’, e.g. they utilize different generations or technologies to achieve similar refining goals, all the while attempting to maximize profitability. While, modern day refineries process crude oil from nearly all countries of the world, the crude oil processed at each, varies geographically, according to availability and pricing, and of course according to where it markets its products. We will discuss how a refinery works in somewhat more detail in a later section. Our focus for this section is automotive gasoline.

6A.3.1 Gasoline as a Complex Mixture

While gasoline is not actually formulated around its chemical composition, per se, it does have a few specific characteristics, somewhat related to the chemicals of which it consists, that are very important and should be high-lighted. With regard to those specific chemical or compositional characteristics, we describe modern gasoline as a complex mixture of hydrocarbons (compounds of carbon and hydrogen) which boil in the range of about 100° F to around 410° F (C5 to C12, paraffins, isoparaffins, aromatics, naphthenes, and olefins). Gasoline has a specific gravity of around 0.7; its API Gravity is about 65. We note that this is the boiling range for the fraction of gasoline that is liquid at ambient temperature and the sea level air pressure. Most gasoline, regardless of the season, contains some n-butane (boiling point at sea level: around 31° F), used to adjust the RVP; gasoline RVP varies seasonally from around 7 psi to15 psi. Many regions, cities, etc., of the nation vary both below and above that range. If a sample of gasoline is allowed to stand in an open container, the butane (and probably some volume of the other light components) will likely weather-off, quite rapidly. The next species, in the boiling order, would be isopentane, which boils at about 82° F, followed by n-pentane, which boils at about 96° F; this accounts for the initial boiling temperature we reported above. A chromatogram would likely detect all the low-boiling species, but a normal ASTM D-86 distillation would only pickup those species boiling above the ambient temperature. The low-boiling components, which don’t normally condense in the non-pressurized lab equipment, would be reported as losses; even so this would, in fact, be a measure of their percentage in the gasoline sample.

Gasoline is formulated to fire, modern spark-ignited, internal-combustion engines. Diesel, a much heavier product, is used to fire pressure-ignited engines, an altogether different technology. The initial boiling point (IBP) is controlled so as to provide easy cold and hot start, prevent vapor lock, and maintain low evaporation and running-loss emissions. Midpoint volatility is controlled to promote quick warm-up and reasonable short-trip fuel economy, power, and acceleration. The final boiling point (FBP) is controlled to promote fuel economy and to provide good energy density.

As we discussed earlier, IBP of standard gasoline is around 100° F. However, as we also discussed, low-boiling components, such as n-butane, which usually don't show up in a boiling-point table, are added to increase volatility; there must be components present that will vaporize at lower than ambient temperature and pressure, otherwise, an engine won't start, especially during cold times. Only gasoline vapor burns; the liquid does not. Normal-butane also changes the partial pressure of the mix to allow other heavier components to more easily vaporize. Isopentane also plays an important role in this process. Consequently, during cold months, the amount of n-butane in gasoline is normally increased. On the other hand, older engines with carburetors, had problems if there was too much light product in the fuel; the carburetor could vapor-lock and the engine wouldn't start. Fuel-injected engines have reduced that problem. Even so, the issue of lower vapor-pressure today has more to do with reducing the volume of unburned hydrocarbons being released into the environment. We mentioned above, that at ambient conditions, n-butane will quite rapidly evaporate from gasoline. If it isn't maintained at lower concentrations and otherwise carefully controlled, during warm and hot months, it will likely evaporate.

The FBP of gasoline is usually controlled around two factors. Reformers produce reformate, one of the important octane producers for the gasoline pool. Reformers convert C_9-C_{12} cycloparaffins and alkyl-paraffins into alkylbenzenes (propyl-, isopropyl-benzene), which have high blending octanes, but which also boil at about 400° F to 420° F. Other important reactions take place in the reformer, which we will discuss in more detail in the reformer section. The combustion pattern in current spark-ignited engines will efficiently burn only hydrocarbons that boil at or below the referenced temperature. Gasoline is formulated around a fairly delicate balance of light and heavy components. Depending on the several factors, a refiner may choose or be asked to either raise or to lower the FBP of his gasoline. If the FBP is raised, it may be possible to use more butane to makeup the RVP; if it is lowered, less butane can be added. It should be clear that there are practical limits to either raising or lowering the FBP. If lowered too far, little butane can be added, and regardless, the entire blend becomes relatively more volatile and more difficult to control in an automobile fuel tank.

Even though we intend to discuss fluid catalytic cracking (FCC) later, we will mention here that as a result of "cracking" (mostly FCC) most gasoline currently sold in the U.S. contains at least some olefins (hydrocarbon compounds which have at least one double-bond between two carbons). These compounds are quite unstable and over even short time periods tend to polymerize into long-chained, highly branched compounds commonly referred to as "gums." Olefins are a particular problem around the injector nozzles of fuel-injected engines. If detergents aren't added, deposits tend to build up and disrupt injector operation. Additives are used that interrupt the oxidation of these compounds, including during combustion, and thus help reduce gum deposits. Other additives are also used to enhance performance and provide protection against oxidation and rust formation.

With regard to gasoline as a blended, marketable liquid fuel, we describe it as a mix of intermediate streams from a variety of refinery units. The manner in which an individual refinery is configured and operated, including purchasing additional blendstocks from other refineries, affects the final batch quality. Two refineries, even with similar configurations and similar crude feeds, but operated differently produce gasolines with quite different chemical compositions.

Gasoline is exposed to a wide variety of mechanical, physical, and chemical environments. Thus the properties must be balanced to give satisfactory engine performance over a very wide range of operating conditions. In nearly every case, the composition of a gasoline batch sold in a specific area of the country is the result of a variety of compromises among both automobile and fuel manufacturers.

Each batch or blend is comprised of a unique distribution of compounds, mostly hydrocarbons, which when mixed properly achieve the performance-based requirements for commercial gasoline. It would not be unusual to find that as many as 14, or more, different blendstocks may be available at a single complex refinery; a few of these are: light straight run (LSR), isomerate, reformate, cracked light and heavy gasoline, hydrocracked gasoline, polymer gasoline (cat poly gasoline), alkylate, n-butane, and perhaps other additives in minor amounts. The percentages of these stocks usually fluctuate, up and down, in each blend; from time-to-time, for a variety of reasons, a component may not be used at all. Gasoline and the stocks from which it is composed are sometimes referred as “the gasoline pool.” We also note that multiple units produce blendstocks of a similar type. For example, three different reformers usually produce reformate with slightly different properties. Several of the large, complex refineries have several units in multiples. The overall variety of blend stocks provides refiners with a multitude of options for producing gasoline that meets ASTM and performance-based requirements.

Gasoline with ethanol is not shipped by pipeline but is splash-blended at the terminal as the gasoline is loaded onto a truck for delivery to an end-user. This makes it necessary for refiners to produce a low-vapor pressure gasoline component or blendstock which can be shipped via pipeline, into which the ethanol can be blended. The vapor pressure of the final mix must meet local RVP requirements.

All gasolines are not created equal, because, as we mentioned, gasoline is formulated according to performance- and not compositional-based specs; few if any gasolines, including batches from within the same refinery, end up having the same chemical composition. The ‘recipe’ for blending a specific gasoline grade at any given refinery depends upon several factors including, (1) inventories of the various blendstocks, (2) the operating status of the various refining units, (3) the specific regulatory requirements for the intended market, and, of course, (4) maximizing profit. Most modern refineries have engineers, economists, and marketers that continually run linear programs (LP) using input from several sources, including lab, operations, and inventory data, gathered from over the entire refinery, in real-time. Blending can be automated and almost automatically self-adjust, as in-line monitors and other data-gathering devices provide continuous feedback on product properties and unit production rates. As crude and product supplies and costs shift up and down, along with market effects and processing costs, LP operators are able to make adjustments to blending recipes, as often as from batch to batch.

While some blending (e.g., addition of some oxygenates) may occur at the final distribution terminal, the majority of a gasoline’s properties are achieved through the blending that occurs within the refinery, although many gasoline service stations blend regular and premium gasoline to produce mid-grade at the pump. Though it may be obvious, we, nevertheless, point out that such an operation means refiners and shippers needn't ship a third grade of gasoline.

6A.3.2 Octane

Historical Context

Much of where we are today with regard to how hydrocarbon fuels, including those which contain benzene, and the internal combustion engine have come to affect the environment, has to do with the somewhat parallel development and eventual convergence of several discoveries, inventions, and wars that occurred over an approximately 150-year span of recent history. We believe a brief outline of that history will provide a helpful context for the discussion that follows.

As has often happened in history, the discovery or invention of one thing has lead to the invention, discovery, or new use of something else. As is likewise often the case, the demand or supply for one or another of these "things" causes an ebb and flow in the supply and demand of the other. Such was very much the case with crude oil and its many derivatives, such as gasoline, diesel, and jet fuel and the internal combustion engine and the turbine or jet engine. Crude oil and a few of its derivatives have been used in many parts of the world for centuries. On the other hand, the internal combustion engine, by historical standards, is a fairly recent invention.

By the early 1880's researchers and inventors eventually determined that internal combustion engines "knocked" or "pinged" less when fired with gasoline produced from certain varieties of crude oil than with that derived from others, but no one knew exactly why.

Eventually, they learned that, for a specific engine compression-ratio, gasoline produced from certain varieties of crude oil knocked less than gasoline derived from others. According to our current knowledge regarding the naturally occurring gasoline components that boost octane, we suspect that one reason for the differences may have been that the "anti-knock" gasoline had a higher concentration of branched-chain hydrocarbons in the C5 - C9 range. It is also possible that the fuel contained some concentration of natural occurring aromatics. Since "poorly" processed natural gasoline made up most of the available supply (although some volume was recovered from natural gas wells), engine and auto manufacturers were forced to limit the effective compression ratio and therefore the horsepower of their engines.

It was evident, early on, that compression-ratio and horsepower were related. For example, an early (1901) 3-cylinder engine had a compression ratio of 2 to 1. It had only six to eight horsepower and a top speed of about 20 miles per hour. Within eight or nine years, Henry Ford's model T engine had a compression ratio of about 4.5 to 1 and at 20 horsepower was capable of speeds above 30 miles per hour. These engines began to "knock" or "ping" at about this compression-ratio using the fuel available at the time. As demand grew, the supply of usable gasoline gradually became limited and its quality decreased. As fuel supplies worsened, engine manufacturers tried to adjust, until for example, in 1916, the Model T engine's compression-ratio had been reduced to 3.8 to one. Some chemicals, including benzene and alcohol, which allowed higher compression ratios without engine knock, were widely used in high performance racing engines of the era. It was through race-track testing (much the same as happens today with race cars and developments in the auto/fuels industry) that benzene and other aromatics came into common use, if not as single component fuels, certainly, as additives.

Octane Number

Until "octane number" was established, the only practical way to determine whether a fuel would ping in an engine was to fire it in the engine. If the compression ratio of the engine was already set, the only way to eliminate the ping was to continue trying various fuels or adding chemicals such as benzene, toluene, alcohol, or whatever was available until the pinging stopped. It was possible to set the compression ratio of an engine to match the available fuel, but eventually that fuel would run out. During this early period, when little was really known about gasoline, many attempts were made to determine which component or components were responsible for reducing or eliminating pre-ignition ping. Neither then, nor since then, has anyone been able to clearly explain "why" one chemical species helps reduce or eliminate ping while a different species not only does not help, it may even exacerbate the problem. Nor has anyone been able to produce a single component, full-purpose gasoline. We discussed earlier that gasoline has been formulated according to performance criteria: made from components light enough to readily ignite, even in cold conditions; with others heavy enough to not require pressurized containment and to provide some energy density.

Eventually, a mechanism was deduced which helped explain how, in a particular engine at a specified compression ratio, one gasoline knocked or pinged while another did not. Ideally, a carefully timed spark ignites an air/fuel mixture, injected above the piston of a spark-ignited engine, just as the piston compression stroke begins to increase the pressure, temperature, and density of the mixture. A flame front, likewise ideally, should spread out somewhat smoothly and uniformly across the piston-face from the point of the spark, to consume what remains of the unburned mixture. Further, and again ideally, the gaseous products of combustion expand and produce a gradually increasing "push" against the piston until all the fuel is consumed as the piston reaches the top of the compression stroke and then begins its power stroke. To return to the instant the spark fires and as the compression stroke continues, radiant heat from the burning fuel rapidly raises the temperature of the unburned fuel. Additionally, as the flame front spreads across the piston, the hot combustion gases expand at an increasing rate and tend to compress the unburned part of the air-fuel mixture, further increasing its density and raising its temperature. If the unburned air-fuel mixture is heated beyond its ignition temperature before the piston reaches its proper position it "autoignites," instantaneously and explosively. When this happens it causes a pressure wave to interfere with the ideal or at least more desirable pressure wave in the cylinder. This wave-interaction generates a wildly fluctuating, third pressure wave. The combination of these wildly interacting, fluctuating waves is responsible for the knocking or pinging sound. This violent mistimed release of energy and the subsequent abnormal pressure waves can be quite destructive and may shorten the life of the engine. (We note again, that while it's helpful to understand how or why an engine knocks, we still don't know why some chemicals reduce knock and others don't.)

It gradually became clear, as mentioned previously, that some types of chemicals reduced pre-ignition ping. That is, that C_5 to C_{12} branched paraffins contribute high octane blending values; straight-chain paraffins have very low numbers. We also know that aromatics, such as benzene, toluene, mixed xylenes, and other alkylbenzenes have high octane blending values.

An interesting phenomenon presents itself when gasoline octane is compared to diesel cetane. We are not making a full-on technical comparison, but would like to merely point out the following, as a matter of some interest. Aromatics, as a general rule improve the octane of gasoline; straight-chained paraffins are poor octane producers. On the other hand, aromatics reduce diesel cetane, while paraffins improve cetane number. The interesting part of the comparison is that diesel engines are compression-ignited engines and compression (compression ratio) is very much involved in pre-ignition ping or knock, especially if aromatic content is low and paraffin content is high. A rather simplistic explanation seems to be that paraffins promote compression ignition. This is not a conclusion; merely a comment. (See our discussion, above, of the combustion process in a spark-ignited engine.)

To select a way of rating the propensity of a particular gasoline batch to knock, the Cooperative Fuel Research Committee (CFRC) was set up in 1927 made up of representatives from the American Petroleum Institute, the American Manufacturers Assn., the National Bureau of Standards, and the Society of Automotive Engineers. A single-cylinder, variable compression-ratio engine was built and fuel samples were prepared of various pure hydrocarbons, including normal heptane distilled from the sap of the Jeffrey Pine. This engine or perhaps more precisely the variable compression-ratio technology incorporated into it, allowed researchers to fire mixtures of pure hydrocarbons and at the same time vary the engine compression-ratio to determine the compression-ratio at which a particular fuel or fuel mixture would knock. Likewise, the engine could be used to determine which fuel, from among a variety of formulations, would not knock or ping at a specified compression-ratio.

In 1929, as part of the effort to standardize fuel quality, a proposal came before the CFRC to actually use a variable compression-ratio engine to rate the ignition characteristics of various gasolines. Although a few committee members were concerned that such an engine would be far too complicated for routine use, by 1931 a prototype was built and displayed at a meeting of the American Petroleum Institute. Eventually the skeptics were persuaded and thousands of the engines were subsequently built, many of which continue to be in use.

“Octane number” eventually became the numerical measure by which the ignition characteristics of a fuel would be defined. It is a unit-less figure that represents the resistance of gasoline to autoignite when exposed to the heat and pressure of a combustion chamber in an internal-combustion engine. Such premature detonation is indicated by the knocking or pinging noises as discussed above.   Eventually, the industry agreed to recognize the octane number determined by comparing the performance of a test gasoline with the performance of a mixture of iso-octane (2, 2, 4 trimethyl pentane) and normal heptane as a valid measure of a gasoline’s resistance to autoignition. The octane number is, simply, the percentage of iso-octane in a mixture whose performance is the same as that of the gasoline being tested. For example, the gasoline is given an 80 octane rating, if the test gasoline performs the same as a mixture of 80% 2, 2, 4, trimethyl pentane and 20% normal heptane. Straight-line extrapolation is used to determine octane numbers higher than 100.

The CFRC subsequently determined that several tests would be required in order to provide an octane rating that was useful over the entire range of potential operating conditions. Around 1926, a test using an engine, similar to the one described above, was developed and designated: Motor Octane Number (MON). A similar, but improved method, Research Octane Number (RON) was developed in the late 1930's. Subsequently, two methods were developed and recognized by the American Society of Testing Materials (ASTM): the Motor Method or MON (ASTM D357) and the Research Method or RON (ASTM D908). The results of the two test methods vary from gasoline to gasoline.

Currently, the RON is determined by a method that measures fuel antiknock level in a single-cylinder engine under mild operating conditions; namely, at a moderate inlet mixture temperature and a low engine speed. RON tends to indicate fuel antiknock performance in engines at wide-open throttle and low-to-medium engine speeds. Generally, a gasoline's performance under high loads and at high speeds is reflected in the MON, while its performance under lighter loads and at lower speeds is reflected in the RON results.

MON is determined by a method that measures fuel antiknock level in a single-cylinder engine under more severe operating conditions than those employed in the RON method; namely, at higher inlet mixture temperature and higher engine speed. It indicates fuel antiknock performance in engines operating at wide-open throttle and high engine speeds. Also, Motor octane number tends to indicate fuel antiknock performance under part-throttle, road-load conditions.

Three octane numbers are currently in use in the United States. The MON and RON numbers are determined, as described above. Usually the RON is higher than the MON. The third octane number is an average of the MON and RON numbers, (R+M)/2. By definition, this is the octane rating of a gasoline that can be legally sold to the public and by federal mandate must be clearly posted on all pumps that dispense gasoline to the public. Accordingly, regular, unleaded gasoline has an octane number of about 87 (R+M)/2, while premium unleaded gasoline is rated at about 93 (R+M)/2. In other parts of the country, usually in higher elevations, regular unleaded may be 85 (R+M)/2 and premium 91 or 92 (R+M)/2.

Octane requirements can change with altitude, air temperature, and humidity, depending on a vehicle's control system. Newer vehicles have sensors to measure and computers, to adjust for such changes in ambient conditions. Regardless of changes in ambient conditions, these vehicles are designed to use the same octane rated gasoline at all ambient operating conditions. This new technology began to be used extensively in 1984. This technology, while constantly evolving and improving, is used on almost all new vehicles. The octane requirements of an older vehicles decrease as altitude increases. One of the problems of increasing altitude is that the decreased air pressure doesn't provide adequate oxygen in the air/fuel mixture.

We mention here that fuel with antiknock ratings higher than required for knock-free operation, do not improve engine performance. On the other hand, as we mentioned previously, pre-ignition knock can damage an engine.

6A.4 Kerosene and Diesel

This information is provided mainly to complete our discussion of the crude fractionation column. The first or upper side draw on the crude column usually produces kerosene. If the refinery doesn’t have a preflash, the overhead will essentially be LSR for isom feed while the first side draw will then be heavy straight-run, HSR. Whereas in the past the Air Force used naphtha based JP-4 turbine fuel, the kerosene based fuel JP-8 is now being used. As such, some refiners may be fortunate enough to produce some volume of straight-run JP-8 from this draw. Regardless, the stream is steam stripped to set the vapor pressure, cooled, and sent to storage to be used in blends to produce a variety of distillate range fuels, including possibly JP-8.

The diesel is drawn from the tower several trays below the kerosene draw. Diesel is used in a wide variety of ways including to power highway vehicles, construction and mining equipment, and locomotive and marine engines; it is also use to generate electricity and to heat homes in several areas of the U.S. Nowadays, most kerosene and diesel is hydrotreated. High sulfur diesel can be used to heat homes and aviation turbine fuel may have sulfur up a concentration of about 0.5 wt. %. It is common practice in colder regions of the country for truckers to mix some volume of kerosene into their diesel to improve his diesel’s cold flow properties during winter months. Prior to ultra-low sulfur diesel (ULSD), common straight-run kerosene was used for this purpose, since the kerosene sulfur content was usually not so high as to cause sulfur compliance problems for the diesel. However, as a result of the recent ULSD rules, refiners may need to hydrotreat or desulfurize more, if not most, of their kerosene for this market. Consequently, many refiners will likely hydrotreat the combined kerosene/diesel stream and re-separate them where the market justifies it. We recognize that there may be other ways of handling this problem.

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Chapter 7: Table of Contents

Chapter 7: Portable Fuel Container Feasibility and Test Procedures

Section 183 (e) of the Clean Air Act provides statutory criteria that EPA must evaluate in determining standards for consumer products. The standards must reflect "best available controls" as defined by section 183 (e)(3)(A). Determination of the "best available controls" requires EPA to determine the degree of reduction achievable through use of the most effective control measures (which extend to chemical reformulation, and product substitution) after considering technological and economic feasibility, as well as health, energy, and environmental impacts. Chapters 1 through 3 discuss the environmental and health impacts of portable fuel container (PFC) emissions. Chapter 10 discusses the economic feasibility of PFC controls and the fuel savings associated with controlling PFC emissions. This chapter presents the technological feasibility of controlling emissions from PFCs. All of these analyses and information form the basis of EPA's belief that the evaporative emission standards reflect the "best available controls" accounting for all the above factors.

This chapter presents available data on baseline emissions and on emission reductions achieved through the application of emission control technology. In addition, this chapter provides a description of the test procedures for determining evaporative emissions.

Evaporative emissions from PFCs containing gasoline can be very high.[A] This is largely because PFCs are often left open and vent to the atmosphere and because materials used in the construction of the plastic PFCs generally have high permeation rates. Evaporative emissions can be grouped into three main categories:

DIURNAL: Gasoline evaporation increases as the temperature rises during the day, heating the PFC and venting gasoline vapors.

PERMEATION: Gasoline molecules can saturate plastic PFCs, resulting in a relatively constant rate of emissions as the fuel continues to permeate through the walls of the PFC.

REFUELING: Gasoline vapors are always present in typical containers. These vapors are forced out when the container is filled with liquid fuel.

The use of PFCs also results in losses through spillage, both during transportation and usage of the cans to refill vehicles and equipment.

7.1 Permeation Emissions

The California Air Resources Board (ARB) investigated permeation rates from PFCs with no emissions controls.[1,2] The ARB data is compiled in several data reports on their web site and is included in our docket. Table 7.1-1 presents a summary of this data which was

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[A] Diesel and kerosene fuels have very low volatility levels and therefore much lower evaporative emissions compared to gasoline.

collected using the ARB Test Method 513.[3] Although the temperature in the ARB testing is cycled from 65 – 105° F with 7 pound per square inch (psi) Reid Vapor Pressure (RVP) fuel, the results would be similar if the data were collected at the temperature range and fuel used by EPA of 72-96° F with 9 psi RVP fuel. This is because the lower temperature and higher RVP effectively offset one another. The average permeation emissions from uncontrolled containers were 1.57 g/gallon/day.

Table 7.1-1. Permeation Rates for HDPE PFCs Tested by ARB

PFC Capacity [gallons]	Permeation Loss [g/gal/day]
1.0	1.63
1.0	1.63
1.0	1.51
1.0	0.80
1.0	0.75
1.0	0.75
1.3	0.50
1.3	0.49
1.3	0.51
1.3	0.52
1.3	0.51
1.3	0.51
1.3	1.51
1.3	1.52
2.1	1.88
2.1	1.95
2.1	1.91
2.1	1.78
2.5	1.46
2.5	1.09
5.0	0.89
5.0	0.62
5.0	0.99
5.0	1.39
5.0	1.46
5.0	1.41
5.0	1.47
6.6	1.09

7.2 Permeation Emissions Controls

7.2.1 Sulfonation

The California Air Resources Board (ARB) collected test data on permeation rates from sulfonated PFCs using California certification fuel.[4] The results show that sulfonation can be used to achieve significant reductions in permeation from plastic fuel containers. This data was collected using a diurnal cycle from 65 – 105° F. The average emission rate for the 32 sulfonated PFCs was 0.35 g/gal/day; however, there was a wide range in effectiveness of the sulfonation process for these PFCs. Some of the data outliers were actually higher than baseline emissions. This was likely due to leaks in the PFCs which would result in large emission increases due to pressure built up with temperature variation over the diurnal cycle. Removing these five outliers, the average permeation rate is 0.17 g/gal/day with a minimum of 0.01 g/gal/day and a maximum of 0.64 g/gal/day. This data suggests that more than a 90% reduction in permeation is possible through sulfonation. This data is presented in Table 7.2-1.

Table 7.2-1. Permeation Rates for Sulfonated Plastic PFCs Tested by ARB

PFC Capacity [gallons]	Permeation Loss [g/gal/day]
1	0.05
1	0.05
1	0.05
1	0.06
1	0.06
1	0.06
1	0.08
1	0.12
1	0.14
1	1.23
1	1.47
1	1.87
2	0.02
2	0.02
2	0.48
2	0.54
2	1.21
2.5	0.03
2.5	0.08
2.5	0.32
2.5	0.38
2.5	0.42
2.5	0.52
2.5	0.64
2.5	0.80
5	0.01
5	0.04
5	0.05
5	0.06
5	0.11
5	0.13
5	0.15

Variation can occur in the effectiveness of this surface treatment if the sulfonation process is not properly matched to the plastic and additives used in the container material. For instance, if the sulfonater does not know what ultraviolet (UV) inhibitors or plasticizers are used, they cannot maximize the effectiveness of their process. Earlier data collected by ARB showed consistently high emissions from sulfonated fuel containers; however, ARB and the treatment manufacturers agree that this was due to inexperience with treating fuel containers and that these issues have since been largely resolved.[5]

ARB also investigated the effect of fuel slosh on the durability of sulfonated surfaces. Three half-gallon fuel tanks used on small SI equipment fuel tanks were sulfonated and tested for permeation before and after being rocked with fuel in them 1.2 million times.[6,7] These fuel tanks were blow-molded high density polyethylene (HDPE) tanks used in a number of small SI applications including pressure washers, generators, snowblowers, and tillers. The results of the testing show that an 85% reduction in permeation was achieved on average even after the slosh testing was performed. Table 7.2-2 presents these results which were recorded in units of g/m^2/day. The baseline level for Set #1 is an approximation based on testing of similar fuel tanks, while the baseline level for Set #2 is based on testing of those tanks.

The sulfonater was not aware of the materials used in the fuel tanks sulfonated for the slosh testing. After the tests were performed, the sulfonater was able to get some information on the chemical make up of the fuel tanks and how it might affect the sulfonation process. For example, the UV inhibitor used in some of the fuel tanks is known as HALS. HALS also reduces the effectiveness of the sulfonation process. Two other UV inhibitors, known as carbon black and adsorber UV, are also used in similar fuel tank applications. These UV inhibitors cost about the same as HALS, but have the benefit of not interfering with the sulfonation process. The sulfonater claimed that if HALS were not used in the fuel tanks, a 97% reduction in permeation would have been seen.[8] To confirm this, one manufacturer tested a sulfonated tank similar to those in Set #2 except that carbon black, rather than HALS, was used as the UV inhibitor. This fuel tank showed a permeation rate of 0.88 g/m^2/day at 40°C [9] which was less than half of what the CARB testing showed on their constant temperature test at 40°C.[10] A list of resins and additives that are compatible with the sulfonation process is included in the docket.[11,12]

Table 7.2-2. Permeation Rates for Sulfonated Fuel Tanks with Slosh Testing by ARB Over a 18-41°C Diurnal

Technology Configuration	Units	Tank 1	Tank 2	Tank 3	Average
Set #1 Approximate Baseline	g/m^2/day	10.4	10.4	10.4	10.4
Set #1 Sulfonated	g/m^2/day % reduction	0.73 93%	0.82 92%	1.78 83%	1.11 89%
Set #1 Sulfonated & Sloshed	g/m^2/day % reduction	1.04 90%	1.17 89%	2.49 76%	1.57 85%
Set #2 Average Baseline	g/m^2/day	12.1	12.1	12.1	12.1
Set #2 Sulfonated	g/m^2/day % reduction	1.57 87%	1.67 86%	1.29 89%	1.51 88%
Set #2 Sulfonated & Sloshed	g/m^2/day % reduction	2.09 83%	2.16 82%	1.70 86%	1.98 84%

About a year and a half after the California ARB tested the Set #2 fuel tanks, we performed permeation tests on these fuel tanks. During the intervening period, the fuel tanks remained sealed with California certification fuel in them. We drained the fuel tanks and filled them with fresh California certification fuel. We then measured the permeation rate at 29°C. Because this is roughly the average temperature of the California variable temperature test, similar permeation rates would be expected. The untreated fuel tanks showed slightly lower permeation over the constant temperature test as compared to the ARB test. This difference was likely due to the difference in the temperature used for the testing. However, the sulfonated fuel tanks showed an increase in permeation as compared to the ARB test. This increase in permeation appears to be the result of the 1.5 year additional fuel soak. After this long soak, the average permeation reduction changed from 84% to 78%. Table 7.2-3 presents this comparison.

Table 7.2-3. Permeation Rates [g/m^2/day] for Sulfonated Fuel Tanks Tested by ARB and EPA on CA Certification Gasoline with a 1½ Year Fuel Soak Differential

Technology Configuration	Temperature	Tank 1	Tank 2	Tank 3	Average
Baseline, CARB testing	18-41°C	12.1	12.1	12.1	12.1
Baseline, EPA testing after 1.5 year additional fuel soak	29°C % change	11.5 -5%	11.4 -6%	11.2 -7%	11.4 -6%
Sulfonated, CARB testing	18-41°C	2.09	2.16	1.70	1.98
Sulfonated, EPA testing after 1.5 year additional fuel soak	29°C % reduction from EPA baseline	2.48 78%	2.73 76%	2.24 80%	2.5 78%

After the above testing, we drained the fuel tanks and filled them with certification gasoline splash-blended with 10% ethanol (E10). We then soaked the fuel tanks for 20 weeks to precondition them on this fuel. Following the preconditioning, we tested these fuel tanks for permeation at 29°C (85°F). Table 7.2-4 presents these emission results compared to the emission results for three baseline tanks (untreated) that were subject to the same preconditioning. Percent reductions are presented based on the difference between the sulfonated fuel tanks and the average results of the three untreated fuel tanks.

Table 7.2-4. Permeation Rates for Sulfonated Fuel Tanks on E10 Fuel at 29°C

Technology Configuration	Units	Tank 1	Tank 2	Tank 3	Average
Baseline (untreated)	g/m^2/day	13.9	13.7	14.4	14.0
Sulfonated	g/m^2/day % reduction	3.91 72%	4.22 70%	2.92 79%	3.69 74%

One study looked at the effect of alcohol in the fuel on permeation rates from sulfonated fuel tanks.[13] In this study, the fuel tanks were tested with both gasoline and various methanol blends. No significant increase in permeation due to methanol in the fuel was observed.

7.2.2 Fluorination

Another barrier treatment process is known as fluorination. The fluorination process causes a chemical reaction where exposed hydrogen atoms are replaced by larger fluorine atoms which form a barrier on surface of the container. In this process, PFCs are generally processed post production by stacking them in a steel container. The container is then voided of air and flooded with fluorine gas. By pulling a vacuum in the container, the fluorine gas is forced into every crevice in the fuel containers. As a result of this process, both the inside and outside surfaces of the PFCs are treated. As an alternative, containers can be fluorinated on-line by exposing the inside surface of the PFC to fluorine during the blow molding process. However, this method may not prove as effective as off-line fluorination which treats the inside and outside surfaces.

We tested one fluorinated HDPE fuel tank which we bought off the shelf and sent to a fluorinater for barrier treatment. The fuel tank type used was a 6-gallon portable marine fuel tank. The fuel tank was soaked for 20 weeks with certification gasoline prior to testing. We measured a permeation rate of 0.05 g/gal/day (0.56 g/m^2/day), which represents more than a 95 percent reduction from baseline. We then began soaking this fuel tank on E10, subjected it to the required pressure and slosh testing, and retested the fuel tank. The post-durability testing showed a permeation rate of 0.6 g/gal/day (6.8 g/m^2/day). As discussed below, we believe that the impact of the durability testing on the effectiveness of fluorination can be minimized if the fluorination process and material properties are matched properly. In addition, this fuel tank was treated to a significantly lower level of fluorination than is now available. However, this data supports the need for the durability testing requirements included in the program.

The California Air Resources Board (ARB) collected test data on permeation rates from fluorinated fuel containers using California certification fuel.[14, 15] The results show that fluorination can be used to achieve significant reductions in permeation from plastic fuel containers. This data was collected using a diurnal cycle from 65 - 105°F. For the highest level of fluorination, the average permeation rate was 0.04 g/gal/day, which represents a 95 percent reduction from baseline. Earlier data collected by ARB showed consistently high emissions from fluorinated PFCs; however, ARB and the treatment manufacturers agree that this was due to inexperience with treating fuel containers and that these issues have since been largely resolved.[16] The ARB data is presented in Table 7.2-5.

Table 7.2-5. Permeation Rates for Fluorinated Plastic PFCs Tested by ARB

Barrier Treatment*	PFC Capacity [gallons]	Permeation Loss [g/gal/day]
Level 4	1	0.05
	1	0.05
(average =0.09 g/gal/day)	1	0.06
	5	0.11
	5	0.11
	5	0.15
Level 5	1	0.03
	1	0.04
(average =0.07 g/gal/day)	1	0.05
	1	0.05
	1	0.07
	1	0.08
	1	0.11
	1	0.11
	1	0.12
	2.5	0.04
	2.5	0.04
	2.5	0.05
	2.5	0.07
	2.5	0.07
	5	0.05
	5	0.10
	5	0.11
SPAL	5	0.04
(average =0.04 g/gal/day)	5	0.04
	5	0.04

*designations used in ARB report; shown in order of increasing treatment

All of the data on fluorinated PFCs presented above were based on PFCs fluorinated by the same company. Available data from another company that fluorinates fuel containers shows a 98 percent reduction in gasoline permeation through a HDPE fuel tank due to fluorination.[17]

ARB investigated the effect of fuel slosh on the durability of fluorinated surfaces. Two sets of three fluorinated fuel tanks were tested for permeation before and after being sloshed with fuel in them 1.2 million times.[18,19] These fuel tanks were 0.5 gallon, blow-molded HDPE tanks used in a number of small SI applications including pressure washers, generators, snowblowers, and tillers. The results of this testing show that an 80% reduction in permeation was achieved on average even after the slosh testing was performed for Set #1. However, this data also showed a 99 percent reduction for Set #2. This shows the value of matching the barrier treatment process to the fuel tank material. Table 7.2-6 presents these results, which were recorded in units of $g/m^2/day$. The baseline level for Set #1 is an approximation based on testing of similar fuel tanks, while the baseline for Set #2 is based on testing of those tanks.

Table 7.2-6. Permeation Rates for Fluorinated Fuel Tanks with Slosh Testing by ARB Over a 65-105° F Diurnal

Technology Configuration	Units	Tank 1	Tank 2	Tank 3	Average
Set #1 Approximate Baseline	$g/m^2/day$	10.4	10.4	10.4	10.4
Set #1 Fluorinated	$g/m^2/day$ % reduction	1.17 89%	1.58 85%	0.47 96%	1.07 90%
Set #1 Fluorinated & Sloshed	$g/m^2/day$ % reduction	2.38 77%	2.86 73%	1.13 89%	2.12 80%
Set #2 Approximate Baseline	$g/m^2/day$	12.1	12.1	12.1	12.1
Set #2 Fluorinated	$g/m^2/day$ % reduction	0.03 >99%	0.00 >99%	0.00 >99%	0.01 >99%
Set #2 Fluorinated & Sloshed	$g/m^2/day$ % reduction	0.07 99%	0.11 99%	0.05 >99%	0.08 99%

About a year and a half after the California ARB tests on the Set #2 fuel tanks, we performed permeation tests on these fuel tanks. During the intervening period, the fuel tanks remained sealed with California certification fuel in them. We drained the fuel tanks and filled them with fresh California certification fuel. We then measured the permeation rate at 29°C. Because this is roughly the average temperature of the California variable temperature test, similar permeation rates would be expected. The untreated fuel tanks showed slightly lower permeation over the constant temperature test. This difference was likely due to the difference in the temperature used for the testing. However, the fluorinated fuel tanks showed an increase in permeation. This increase in permeation appears to be the result of the 1.5 year additional fuel soak. Even after this long fuel soak, the fluorination achieves more than a 95% reduction in permeation. Table 7.2-7 presents this comparison.

Table 7.2-7. Permeation Rates [g/m^2/day] for Fluorinated Fuel Tanks Tested by ARB and EPA on CA Certification Gasoline with a 1½ Year Fuel Soak Differential

Technology Configuration	Temperature	Tank 1	Tank 2	Tank 3	Average
Baseline, CARB testing	18-41°C	12.1	12.1	12.1	12.1
Baseline, EPA testing after 1.5 year additional fuel soak	29°C % change	11.5 -5%	11.4 -6%	11.2 -7%	11.4 -6%
Fluorinated, CARB testing	18-41°C	0.07	0.11	0.05	0.08
Fluorinated, EPA testing after 1.5 year additional fuel soak	29°C % reduction from EPA baseline	0.56 95%	0.62 95%	0.22 98%	0.47 96%

After the above testing, we drained the fuel tanks and filled them with certification gasoline splash-blended with 10% ethanol (E10). We then soaked the fuel tanks for 20 weeks to precondition them on this fuel. Following the preconditioning, we tested these fuel tanks for permeation at 29°C (85°F). Table 7.2-8 presents these emission results compared to the emission results for three baseline tanks (untreated) that were subject to the same preconditioning. Percent reductions are presented based on the difference between the fluorinated fuel tanks and the average results of the three untreated fuel tanks. The slight increase in permeation on the E10 fuel was similar for the baseline and fluorinated fuel tanks and still resulted in reductions above 95 percent.

Table 7.2-8. Permeation Rates for Fluorinated Fuel Tanks on E10 Fuel at 29°C

Technology Configuration	Units	Tank 1	Tank 2	Tank 3	Average
Baseline (untreated)	g/m^2/day	13.9	13.7	14.4	14.0
Fluorinated	g/m^2/day % reduction	0.43 97%	0.62 96%	0.62 96%	0.56 96%

Another study also looked at the effect of alcohol in the fuel on permeation rates from fluorinated fuel tanks.[20] In this study, the fuel tanks were tested with both gasoline and various methanol blends. No significant increase in permeation due to methanol in the fuel was observed.

One automobile manufacturer used fluorination to reduce permeation on HDPE fuel tanks to meet the LEV I vehicle standards. This manufacturer used similar or more stringent requirements for fuel soak, durability, and testing than finalized today. At 40°C, this manufacturer stated that they measured 0.15-0.2 g/day for fluorinated tanks compared to over 10 g/day for untreated HDPE fuel tanks.[21]

7.2.3 Barrier Platelets

Another approach for reducing permeation emissions is to blend a low permeable resin in with the HDPE and extrude it with a single screw. The low permeability resin, typically ethylene vinyl alcohol (EVOH) or nylon, creates non-continuous platelets in the HDPE fuel tank which reduce permeation by creating long, tortuous pathways that the hydrocarbon molecules must navigate to pass through the container walls. The trade name typically used for this permeation control strategy is Selar® for nylon and Selar RB® for EVOH. Although the barrier is not continuous, this strategy can still achieve greater than a 90 percent reduction in permeation of gasoline. EVOH has much higher permeation resistance to alcohol than nylon; therefore, it would be the preferred material to use for meeting our new standard, which is based on testing with a 10 percent ethanol fuel.

We tested several portable PFCs and marine fuel tanks molded with low permeation non-continuous barrier platelets. Six of the containers tested were constructed using nylon as the barrier material. The remainder of the containers were constructed using EVOH as the barrier material. The sixth container was tested on E10 (10% ethanol) to evaluate the effectiveness of this material with alcohol blended fuel. The containers with the EVOH barrier were all tested on E10.

Testing was performed after the containers had been filled with fuel and stored at room temperature. We soaked the containers with gasoline for 22 weeks and the tanks with E10 for 37 weeks. The purpose of the soak period was to ensure that the fuel permeation rate had stabilized. The containers were drained and then filled with fresh fuel prior to the permeation tests. We did not run slosh and pressure tests on these containers. However, because the barrier platelets are integrated in the can wall material, it is not likely that pressure or slosh testing would significantly affect the performance of this technology.

Table 7.2-9 presents the results of the permeation testing on the containers with barrier platelets. These test results show more than an 80 percent reduction for the nylon barrier tested on gasoline. However, the nylon barrier does not perform as well when a fuel with a 10% ethanol blend is used. Testing on a pair of 2 gallon containers with nylon barrier showed 80% percent higher emissions when tested on E10 than on gasoline. We also tested PFCs that used EVOH barrier platelets. EVOH has significantly better resistance to permeation on E10 fuel than nylon. For the containers blended with 6% EVOH, we observed a permeation rate of about 0.08-0.09 g/gal/day on E10 fuel.

Table 7.2-9. Permeation Rates for Plastic Fuel Containers with Barrier Platelets Tested by EPA at 29°C

Percent Selar®*	Capacity [gallons]	Test Fuel	Fuel Soak [weeks]	g/gal/day	g/m^2/day
Nylon barrier platelets					
unknown**	2	gasoline	40	0.54	–
unknown**	2	E10	40	0.99	–
4%	5	gasoline	22	0.35	4.1
4%	5.3	gasoline	22	0.11	1.2
4%	6.6	gasoline	22	0.15	1.6
4%	6.6	gasoline	22	0.14	1.5
EVOH barrier platelets					
2%	6.6	E10	37	0.23	3.0
4%	6.6	E10	37	0.14	1.9
4%	6.6	E10	37	0.15	2.0
6%	6.6	E10	37	0.08	1.4
6%	6.6	E10	37	0.09	1.4

*trade name for barrier platelet technology used in test program
** designed to meet California permeation requirement

Manufacturers raised a concern about whether or not a container using barrier platelets would have a stabilized permeation rate after 20 weeks. In other words, manufacturers were concerned that this technology may pass the test, but have a much higher permeation rate in-use. We tested one of the 4% and 6% EVOH containers on E10 again after soaking for a total of 104 weeks (2 years). The measured permeation rates were 2.0 and 1.4 g/m^2/day for the 4% and 6% EVOH containers, respectively, which represents no significant changes in permeation from the 37 week tests. In contrast, we measured the 4% nylon tanks again after 61 weeks and measured permeation rates of 2.8 and 2.7 g/m^2/day, which represented about an 80-90% increase in permeation compared to the 22 week tests.

The California ARB collected test data on permeation rates from PFCs molded with Selar® low permeation non-continuous barrier platelets using California certification fuel. This data was collected using a diurnal cycle from 65-105°F. The results show that this technology can be used to achieve significant reductions in permeation from plastic fuel containers. This test data showed that more than a 90 percent reduction in permeation is achievable through the use of barrier platelets. However, all of this testing was performed on California certification fuel, which does not include ethanol.

Table 7.2-10. Permeation Rates for PFCs with Barrier Platelets Tested by ARB on California Fuel

Percent Selar®*	Container Capacity [gallons]	Permeation Loss [g/gal/day]
4%	5	0.08
	5	0.09
(average =0.12 g/gal/day)	5	0.13
	5	0.16
	5	0.17
	6	0.08
	6	0.10
6%	5	0.07
	5	0.07
(average =0.09 g/gal/day)	5	0.07
	5	0.08
	5	0.12
	5	0.17
	6	0.06
	6	0.07
8%	5	0.08
	5	0.10
(average =0.07 g/gal/day)	6	0.05
	6	0.06

*trade name for barrier platelet technology used in test program

Table 7.2-11 presents permeation rates for HDPE and three Selar RB® blends when tested at 60°C on xylene.[22] Xylene is a component of gasoline and gives a rough indication of the permeation rates on gasoline. This report also shows a reduction of 99% on naptha and 98% on toluene for 8% Selar RB®.

Table 7.2-11. Xylene Permeation Results for Selar RB® at 60°C

Composition	Permeation, g mm/m^2/day	% Reduction
100% HDPE	285	–
10% RB 215/HDPE	0.4	99.9%
10% RB 300/HDPE	3.5	98.8%
15% RB 421/HDPE	0.8	99.7%

7.2.4 Multi-Layer Construction

PFCs may also be constructed out of multiple layers of materials, and some PFC manufacturers have started using this technology. In this way, the low cost and structural advantages of traditional materials can be utilized in conjunction with higher grade materials which can provide effective permeation resistance.

Coextruded barrier technology has been long established for blow-molded automotive fuel tanks. Data from one automobile manufacturer showed permeation rates of 0.01-0.03 g/day for coextruded fuel tanks at 40°C on EPA certification fuel. They are using this technology to meet LEV II vehicle standards. For comparison, they reported permeation rates of more than 10 g/day for standard HDPE fuel tanks.[23]

Another study looks at the permeation rates, using ARB test procedures, through multi-layer vehicle fuel tanks.[24] The fuel tanks in this study were 6 layer coextruded plastic tanks with EVOH as the barrier layer (3% of wall thickness). The outer layers were HDPE and two adhesive layers were needed to bond the EVOH to the polyethylene. The sixth layer was made of recycled polyethylene. The two test fuels were a 10 percent ethanol blend (CE10) and a 15 percent methanol blend (CM15). See Table 7.2-12.

Table 7.2-12. Permeation Results for a Coextruded Fuel Tank Over a 65-105°F Diurnal

Composition	Permeation, g/day	% Reduction
100% HDPE (approximate)	6 - 8	–
3% EVOH, 10% ethanol (CE10)	0.2	97%
3% EVOH, 15% methanol (CM15)	0.3	96%

7.3 Diurnal Emissions

The above sections discuss permeation emissions and permeation emissions control. These emissions are part of the overall evaporative emissions, or diurnal emissions, from PFCs. PFCs as a system also emit evaporative emissions from seals and spouts. PFCs have high evaporative emissions when they are left open. In order to meet emissions standards, manufacturers would use cans with spouts that automatically close and seal well around the opening to the can where the spout attaches. Automatic closing spouts have been designed for the California program. These spouts are typically manufactured with springs that close the cans automatically when the cans are not being used to refill equipment. In addition, these cans vent through the spouts, and the vents typically found on the back of the cans are removed. This is important because open vents can be a significant source of evaporative emissions.

CARB conducted a feasibility study for their PFC standards and concluded that a 0.3 g/gal/day standard was feasible in the 2009 time-frame.[25] CARB conducted testing of three different PFCs designed to meet emissions standards. They were tested in two ways: with the spout attached and with the spouts removed and the PFCs sealed. The results for the sealed cans represent the amount of permeation emissions observed. This data was collected using a diurnal cycle from 65-105°F with 7 RVP fuel. As noted above, the results would be similar if the data were collected at the temperature range and fuel used by EPA of 72-96°F with 9 psi RVP fuel, because the lower temperature and higher RVP offset one another. The PFCs with spout were soaked for 160 days and the sealed cans were soaked for 174 days prior to testing. The results of the testing are provided below in Table 7.3-1. The results show the average of three identical cans per manufacturer. CARB did not identify the manufacturers or the permeation barriers used.

Table 7.3-1. Results of CARB Diurnal Testing (g/gal/day)

	Sealed PFC	PFC w/ Spout
Manufacturer A	0.1	0.2
Manufacturer B	0.0	0.7
Manufacturer C	0.2	0.2

CARB indicated that the results from Manufacturer B increased because of one faulty spout which significantly increased the average emissions. The results indicate that the 0.3 g/gal./day standard is feasible. The results also indicate that a faulty spout or seal around the opening of the PFC would likely lead to emissions significantly above the standard. Manufacturers would need to focus on controlling variability in their manufacturing process to ensure spouts are durable and well matched to the PFCs and do not allow evaporative emissions to escape.

7.4 Testing Procedures

The test procedure for diurnal emissions is to place the PFC with the spout attached in a SHED[B], vary the temperature over a prescribed profile, and measure the hydrocarbons escaping from the fuel container. The final result would be reported in grams per gallon where the grams are the mass of hydrocarbons escaping from the fuel tank over 24 hours and the gallons are the nominal PFC capacity. The test procedure is based on the automotive evaporative emission test described in 40 CFR Part 86, Subpart B, with modifications specific to PFC applications. The hydrocarbon loss must be measured either by weighing the cans before and after the diurnal cycle or by measuring emissions directly from the SHED. Three identical containers must be tested for three diurnal cycles. The daily emissions for each container are to be averaged together for comparison with the standard, rounded to the nearest one-tenth of a gram. Each container must meet the standard to demonstrate compliance with the standard.

Manufacturers must test cans in their most likely storage configuration. The key to reducing evaporative losses from PFCs is to ensure that there are no openings on the cans that could be left open by the consumer. Traditional cans have vent caps and spout caps that are easily lost or left off cans, which leads to very high evaporative emissions. We expect manufacturers to meet the evaporative standards by using automatic closing spouts and by

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[B] Sealed Housing for Evaporative Determination removing other openings that consumers could leave open. However, if manufacturers choose to design cans with an opening that does not close automatically, we are requiring that containers be tested in their open condition. If the PFCs have any openings that consumers could leave open (for example, vents with caps), these openings thus must be left open during testing. This applies to any opening other than where the spout attaches to the can. We believe it is important to take this approach because these openings could be a significant source of in-use emissions.

Spouts must be in place during testing because this would be the most likely storage configuration for the emissions compliant cans. Spouts will likely still be removable so that consumers will be able to refill the cans, but we would expect the containers to be resealed by consumers after being refilled in order to prevent spillage during transport. We do not believe that consumers will routinely leave spouts off cans, because spouts are integral to the cans' use and it is obvious that they need to be sealed. Testing with spouts in place will also ensure that the cans seal properly at the point where the nozzle attaches to the can. If cans do not seal properly, emissions will be well above the standards.

7.4.1 Temperature Profile, Length of Test, Fill Level

PFCs will be tested over the same 72-96°F (22.2-35.6°C) temperature profile used for automotive applications. This temperature profile represents a hot summer day when ground level ozone emissions (formed from hydrocarbons and oxides of nitrogen) would be highest. This temperature profile would be for the air temperature in the SHED.

The automotive diurnal test procedure includes a three-day temperature cycle. The purpose of this test length is to ensure that the carbon canister can hold at least three days of diurnal emissions without vapor breaking through the canister. For PFCs, we do not believe that a three-day test is necessary. Prior to the first day of testing, the fuel will be stabilized at the initial test temperature. Following this stabilization, a single 24-hour diurnal temperature cycle will be run. Because this technology does not depend on purging or storage capacity of a canister, multiple diurnal cycles per test should not be necessary.

Diurnal emissions are not only a function of temperature and fuel volatility, but of the size of the vapor space in the PFC as well. The fill level at the start of the test will be 50% of the nominal capacity of the PFC. Nominal capacity, defined as the volume of fuel to which the PFC can be filled when sitting in its intended position, is to be specified by the manufacturer. The vapor space that normally occurs in a PFC, even when "full," is not considered to be part of the nominal capacity of the PFC.

7.4.2 Test Fuel

Consistent with the automotive test procedures, we are requiring that the test take place using 9 RVP certification gasoline. About 20-30% of fuel sold in the U.S. contains ethanol and this percentage is expected to increase due to the Energy Policy Act. We are requiring the use of E10, which is a blend of 90% certification gasoline blended with 10% ethanol for diurnal testing of PFCs. As noted in Section 7.2, ethanol in the fuel can increase permeation emissions for some permeation barriers such as nylons if not properly accounted for in the design of the PFCs. Other available permeation barriers do not allow significantly higher emissions when ethanol is present in the fuel. Testing with E10 helps ensure that manufacturers would select materials with emissions performance that does not degrade significantly when ethanol is present in the fuel.

7.4.3 Preconditioning and Durability Testing

We are applying essentially the same preconditioning and durability testing requirements for PFCs that we have established for permeation control requirements for recreational vehicles. We are also requiring a durability demonstration for spouts. As with the diurnal testing, the preconditioning and durability testing are to be performed on the complete PFC with the spout attached (except for pressure cycling as noted below).

7.4.3.1 Preconditioning

It takes time for fuel to permeate through the walls of containers. Permeation emissions will increase over time as fuel slowly permeates through the container wall, until the permeation finally stabilizes when the saturation point is reached. We want to evaluate emissions performance once permeation emissions have stabilized, to ensure that the emissions standard is met in-use. Therefore, we are requiring that prior to testing the PFCs, the cans need to be preconditioned by allowing the can to sit with fuel in them until the hydrocarbon permeation rate has stabilized. Under this step, the PFC must be filled with E10, sealed, and soaked for 20 weeks at a temperature of 28 ± 5°C. As an alternative, we are allowing that the fuel soak could be performed for 10 weeks at 43 ± 5°C to shorten the test time. During this fuel soak, the PFCs must be sealed with the spout attached. We have established these soak temperatures and durations based on protocols EPA has established to measure permeation from fuel tanks made of HDPE.[26] These soak times should be sufficient to achieve stabilized permeation emission rates. However, if a longer time period is necessary to achieve a stabilized rate for a given PFC, we are requiring that the manufacturer to use a longer soak period (and/or higher temperature) consistent with good engineering judgment.

7.4.3.2 Durability Testing

To account for permeation emission deterioration, we are specifying three durability aging cycles: slosh, pressure-vacuum cycling, and ultraviolet (UV) exposure. They represent conditions that are likely to occur in-use for PFCs, especially for those cans used for commercial purposes and carried on truck beds or trailers. The purpose of these deterioration cycles is to help ensure that the technology chosen by manufacturers is durable in-use, represents best available control, and the measured emissions are representative of in-use permeation rates. Fuel slosh, pressure cycling, and UV exposure each impact the durability of certain permeation barriers, and we believe these cycles are needed to ensure long-term emissions control. Without these durability cycles, manufacturers could choose to use materials that meet the certification standard but have degraded performance in-use, leading to higher emissions. We do not expect these procedures to adversely impact the feasibility of the standards, because there are permeation barriers available at a reasonable cost that do not deteriorate significantly under these conditions. As described above, we believe including these cycles as part of the certification test is preferable to a design-based requirement.

For slosh and pressure cycling, we are requiring the use of durability tests that are based on draft recommended Society of Automotive Engineers (SAE) practice for evaluating permeation barriers.[27] For slosh testing, the PFC must be filled to 40 percent capacity with E10 fuel and rocked for 1 million cycles. The pressure-vacuum testing contains 10,000 cycles from -0.5 to 2.0 psi. The pressure cycling may be performed by applying pressure/vacuum through the opening where the spout attaches, rather than by drilling a hole in the container. The third durability test is intended to assess potential impacts of UV sunlight (0.2 µm - 0.4 µm) on the durability of a surface treatment. In this test, the PFCs must be exposed to a UV light of at least 0.40 Watt-hour/meter^2 /minute on the PFC surface for 15 hours per day for 30 days. Alternatively, PFCs may be exposed to direct natural sunlight for an equivalent period of time. We have also established these same durability requirements as part of our program to control permeation emissions from recreational vehicle fuel tanks.[28] While there are obvious differences in the use of PFCs compared to the use of recreational vehicle fuel tanks, we believe the test procedures offer assurance that permeation controls used by manufacturers will be robust and will continue to perform as intended when in use.

We are also allowing manufacturers to do an engineering evaluation, based on data from testing on their permeation barrier, to demonstrate that one or more of these factors (slosh, UV exposure, and pressure cycle) do not impact the permeation rates of their PFCs and therefore that the durability cycles are not needed. Manufacturers would use data collected previously on PFCs or other similar containers made with the same materials and processes to demonstrate that the emissions performance of the materials does not degrade when exposed to slosh, UV, and/or pressure cycling. The test data must be collected under equivalent or more severe conditions as those noted above.

In its recently revised program for PFCs, California included a durability demonstration for spouts. We are requiring a durability demonstration consistent with California’s procedures. Automatically closing spouts are a key part of the emissions controls expected to be used to meet the new standards. If these spouts stick or deteriorate, in-use emissions could remain very high (essentially uncontrolled). We are interested in ways to ensure during the certification procedures that the spouts also remain effective in use. California requires manufacturers to actuate the spouts 200 times prior to the soak period and 200 times near the conclusion of the soak period to simulate spout use. The spouts’ internal components are required to be exposed to fuel by tipping the can between each cycle. Spouts that stick open or leak during these cycles are considered failures. The total of 400 spout actuations represents about 1.5 actuations per week on average over the average container life of 5 years. In the absence of data, we believe this number of actuations appears to reasonably replicate the number that can occur in-use and will help ensure quality spout designs that do not fail in-use. We also believe that adopting requirements consistent with California will help manufacturers to avoid duplicate testing.

The order of the durability tests would be optional. However, as discussed above, we require that the PFC be soaked to ensure that the permeation rate is stabilized just prior to the final permeation test. If the slosh test is run last, the length of the slosh test may be considered as part of this soak period. Where possible, the deterioration tests may be run concurrently. For example, the PFC could be exposed to UV light during the slosh test. In addition, if a durability test can clearly be shown to not be necessary for a given product, manufacturers may petition to have the test waived. For example, manufacturers may have data showing that their permeation barrier does not deteriorate when exposed to the conditions represented by the test procedure.

After the durability testing, once the permeation rate has stabilized, the PFC is drained and refilled with fresh fuel, the spout is placed back on the container, and the PFC is tested for diurnal emissions.

7.4.4 Reference Container

We are requiring the use of a reference container during testing. In cases where the permeation of a PFC is low, and the PFC is properly sealed, the effect of air buoyancy can have a significant effect the measured weight loss. Air buoyancy refers to the effect of air density on the perceived weight of an object. As air density increases, it will provide an upward thrust on the PFC and create the appearance of a lighter container. Air density can be determined by measuring relative humidity, air temperature, and air pressure.[29]

One testing laboratory presented data to EPA on their experience with variability in weight loss measurements when performing permeation testing on PFCs.[30] They found that the variation was due to air buoyancy effects. By applying correction factors for air buoyancy, they were able to greatly remove the variation in the test data. A technical brief on the calculations they used is available in the docket.[31]

A more direct approach to accounting for the effects of air buoyancy is to use a reference container. In this approach, an identical PFC to that being tested would be tested without fuel in it and used as a reference PFC. Dry sand would be added to this PFC to make up the difference in mass associated with the test cans being half full of fuel. The reference PFC would then be sealed so that the buoyancy effect on the reference PFC would be the same as the test PFCs. The measured weight loss of the test PFC could then be corrected by any measured changes in weight in the reference can. The California Air Resources Board has required this approach for measuring PFC emissions, and they refer to the reference PFC as a “trip blank.”[32]

References for Chapter 7

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Chapter 8: Impact of New Requirements on Vehicle Costs

Chapter 5 on vehicle feasibility describes the changes to Tier 2 vehicles we believe will be needed to meet new cold temperature NMHC standards and new evaporative emissions standards. This section presents our analysis of the average vehicle-related costs associated with those changes.[A] For our analysis, we considered incremental hardware costs and up-front costs for research and development (R&D), tooling, certification, and facilities. This section includes both per vehicle and nationwide aggregate cost estimates. All costs are in 2003 dollars.

8.1 Costs Associated with a New Cold Temperature Standard

8.1.1 Hardware Costs

As described in Chapter 5, we are not expecting hardware changes to Tier 2 vehicles in response to new cold temperature standards. Tier 2 vehicles are already being equipped with very sophisticated emissions control systems. We expect manufacturers to use these systems to minimize emissions at cold temperatures. We were able to demonstrate significant emissions reductions from a Tier 2 vehicle through recalibration alone. In addition, a standard based on averaging allows some vehicles to be above the numeric standard as long as those excess emissions are offset by vehicles below the standard. Averaging would help manufacturers in cases where they are not able to achieve the numeric standard for a particular vehicle group, thus helping manufacturers avoid costly hardware changes. The phase-in of standards and emissions credits provisions also help manufacturers avoid situations where expensive vehicle modifications would be needed to meet a new cold temperature NMHC standard. Therefore, we are not projecting hardware costs or additional assembly costs associated with meeting new cold temperature NMHC emissions standards.

8.1.2 Development and Capital Costs

Manufacturers would incur research and development costs associated with a new cold temperature standard and some may also need to upgrade testing facilities to handle increased number of cold tests during vehicle development.

R&D

Manufacturers currently have detailed vehicle development processes designed to ensure Tier 2 vehicles meet all applicable emissions standards throughout the useful life. These processes include cold temperature development and testing for the cold CO standard. New NMHC standards would add engineering effort and emissions testing to the Tier 2 vehicle development cycle for each vehicle durability group. Manufacturers would need to calibrate emissions controls to optimize emissions performance and potentially refine those calibrations to ensure acceptable vehicle performance. Based on discussions with manufacturers and our

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[A] This chapter discusses costs for Tier 2 vehicles. We believe the costs would be the same or lower for California certified LEV-II vehicles. Tier 2 and LEV-II must meet very similar emissions standards. LEV-II vehicles, however, must currently meet a 50°F standard which may reduce the costs associated with meeting a 20°F.

feasibility testing described in Chapter 5, we are projecting an average increase of 160 hours of engineering staff time and 10 additional cold temperature development tests for each durability group.[B] The level of effort is likely to vary somewhat by durability group and also by manufacturer, depending on their engines and emissions control systems. However, we believe our estimate is conservatively high based on our test program. We were able with less than 80 hours of engineering effort to significantly reduce emissions from a heavier test weight vehicle with relatively high emissions to levels well below the 0.5 g/mile fleet average standard level. We understand that additional engineering time may be needed as the vehicles proceed through their development cycle so we have doubled the hours needed to 160 hours. We also believe that the average R&D costs are likely conservatively high because the projection ignores the carryover of knowledge from the first vehicle groups designed to meet the new standard to others phased-in later.

We estimate that the R&D costs would be incurred on average three years prior to production. We increased the R&D costs by seven percent each year prior to introduction to account for time value of money. This resulted in an average R&D cost per durability group of about $42,400. To determine a per vehicle cost, we divided total annual vehicle sales by the number of durability groups certified by manufacturers (16,948,000 vehicles sold divided by 295 durability groups) to determine an estimate of average number of vehicles sold per durability group (about 57,500 vehicles/durability group). [1,2] Finally, for the cost analysis, the fixed R&D costs were recovered over five years of production at a rate of seven percent.

Test Facility Upgrades

Manufacturers currently have testing facilities capable of cold temperature testing due to the cold CO standard and also for vehicle development. We are anticipating additional vehicle development testing due to the new cold temperature NMHC standard. During discussions with manufacturers, manufacturers expressed a wide range of concern regarding their testing capabilities. Some manufacturers will likely be able to absorb this additional testing with their current facilities. Other manufacturers expressed the need to upgrade facilities to handle the additional volume of testing. We believe that the proposed phase-in of the standards helps to minimize the number of additional tests that will be needed in any given year and that major new facilities will not be needed. However, we recognize that facility upgrades may be needed in some cases to handle additional test volumes. For our cost analysis, we are including an average facilities cost of $10 million for each of the six largest manufacturers which make up about 88 percent of the vehicles sold. This is based on discussions with manufacturers and our general experiences with testing facilities costs. We believe the remaining manufacturers have limited product lines with relatively few durability groups and will either be able to cover the additional testing with their current facilities or by contracting out a small number of tests as needed.

We estimate that the facility costs will be incurred on average three years prior to the start of the program because the facilities will be needed during vehicle development. As with R&D costs, we increased the facilities costs by seven percent each year prior to introduction to account for time value of money. This resulted in an overall facility cost industry-wide of about $73,500,000. We projected that the facilities costs will be recovered over 10 years of production

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[B] We estimated costs using $60 per engineering hour and $2,500 per test.

at a seven percent rate of return. To determine an average per vehicle cost, we divided the annualized cost by annual sales.

Certification Costs

We are not projecting an increase in certification costs. Manufacturers are currently required to measure HC when running the cold CO test procedure during certification.[3] We do not believe the standard adds significantly to manufacturers' current certification process. Development testing is included in the estimated R&D costs described above.

8.1.3 Total Per Vehicle Costs

Our estimated per vehicle cost increase due to the new standards is relatively small because we are projecting no hardware costs, tooling costs, or certification costs, and fixed costs for R&D and facilities are recovered over large unit sales volumes. We estimate the average per vehicle cost will be about $0.62 due to both the R&D and facilities costs during the first five years of the program. The costs would be reduced to $0.44 after the five year recovery period for R&D costs.

As discussed above, we believe the cold temperature standards are feasible for Tier 2 vehicles. We are also including other program provisions such as lead time, phase-in, averaging, and early emissions credits that would help ease the transition to the new standards and avoid costly vehicle redesign and new hardware. Costs associated with the new standard are fixed costs for facilities upgrades and vehicle development. We are projecting average vehicle development costs for vehicle recalibration and software design for cold temperature emissions control. The costs associated with facilities are well understood based on past experience with testing facilities and will vary depending on the current facilities of each manufacturer. The development costs will also vary due to the wide variety of vehicles and the averaging program. Costs could be higher if vehicles not yet phased in to the Tier 2 fleet are more difficult to control than anticipated relative to those already phased in to the Tier 2 program. Costs may be lower because the above analysis does not consider manufacturers being able to transfer knowledge and experience from one vehicle family to the next. However, we do not expect the average per vehicle cost to be considerably higher or lower than the costs projected. These fixed costs are recovered over a large number of vehicles. Although we don't believe we have significantly over or underestimated costs, even if the costs are twice those projected here, the per vehicle costs would remain under $1.30 per vehicle.

We received comments from one limited product line manufacturer that it believes it will be unable to meet the new standard without additional hardware "such as a secondary air injection system or hydrocarbon trap or significantly alter our United States fleet mix to 100% expensive SULEV certified vehicles." The commenter did not provide cost information in their comments. Other manufacturers' comments supported our leadtime, phase-in, and other transitional provisions as providing the flexibility needed to meet the standards with Tier 2 vehicle hardware. We continue to believe that manufacturers will be able to meet the standards through vehicle development without additional hardware. However, we conducted a sensitivity analysis in response to this comment, assuming the commenter would use new hardware to meet the cold temperature standard. The commenter's sales represent about 1% of US light-duty vehicle sales. If one percent of new vehicles required additional hardware costing $100 - $200 per vehicle, the average cost would increase from $0.62 to the range of $1.60 - $2.60 per vehicle. We used this relatively large range of cost because it is not clear what new hardware or combination of hardware the commenter might use on its vehicles. Also, we believe there will be significant incentive for manufacturers to find alternative to using additional hardware in order to remain competitive, considering that other manufacturers are unlikely to be making hardware changes. Additional discussion of the comments received on the vehicle cold temperature standard is provided in Chapter 3 of the Summary and Analysis of Comments for this rule.

8.1.4 Annual Total Nationwide Costs

To estimate annual costs, we distributed the R&D costs over the phase-in schedule shown below in Table 8.1-1 and amortized the costs over a five-year time period after vehicle introduction using a seven percent discount rate. Based on certification data, we estimated that about 14% (42 out of 295) of durability groups are HLDT/MDPV durability groups. The phase-in schedule is needed to reasonably account for the timing of the R&D investment.

Table 8.1-1. Phase-in Schedule Used in Cost Analysis

Vehicle GVWR (Category)	2010	2011	2012	2013	2014	2015
≤ 6000 lbs (LDV/LLDT)	25%	50%	75%	100%		
> 6000lbs (HLDT/MDPV)			25%	50%	75%	100%

For the facilities cost, we projected that all facility modifications would occur prior to the start of the program and would be amortized over a ten-year time period. We do not expect the phase-in schedule to impact the timing of facilities upgrades. Manufacturers will likely upgrade facilities prior to the first year of the phase-in. Table 8.1-2 provides annual nationwide cost estimates. Table 8.1-3 provides non-annualized aggregate costs.

Table 8.1-2. Annual Nationwide Vehicle Costs

Calendar Year	LDV/LLDT Cost	HLDT/MDPV Cost	Facilities Cost	Total cost
2009	0	0	0	0
2010	653,858	0	10,465,114	11,118,971
2011	1,307,715	0	10,465,114	11,772,829
2012	1,961,573	108,546	10,465,114	12,535,232
2013	2,615,430	217,091	10,465,114	13,297,635
2014	2,615,430	325,637	10,465,114	13,406,181
2015	1,961,573	434,182	10,465,114	12,860,869
2016	1,307,715	434,182	10,465,114	12,207,011
2017	653,858	325,637	10,465,114	11,444,608
2018	0	217,091	10,465,114	10,682,205
2019	0	108,546	10,465,114	10,573,659
2020	0	0	0	0
2021	0	0	0	0
2022	0	0	0	0
2023	0	0	0	0
2024	0	0	0	0
2025	0	0	0	0
2026	0	0	0	0
2027	0	0	0	0
2028	0	0	0	0
2029	0	0	0	0
2030	0	0	0	0
2031	0	0	0	0
2032	0	0	0	0
2033	0	0	0	0
2034	0	0	0	0

Table 8.1-3. Non-Annualized Nationwide Vehicle Costs

Calendar Year	LDV/LLDT Cost	HLDT/MDPV Cost	Facilities Cost	Total cost
2006	0	0	0	0
2007	2,188,450	0	60,000,000	62,188,450
2008	2,188,450	0	0	2,188,450
2009	2,188,450	363,300	0	2,551,750
2010	2,188,450	363,300	0	2,551,750
2011	0	363,300	0	363,300
2012	0	363,300	0	363,300
2013	0	0	0	0
2014	0	0	0	0
2015	0	0	0	0
2016	0	0	0	0
2017	0	0	0	0
2018	0	0	0	0
2019	0	0	0	0
2020	0	0	0	0
2021	0	0	0	0
2022	0	0	0	0
2023	0	0	0	0
2024	0	0	0	0
2025	0	0	0	0
2026	0	0	0	0
2027	0	0	0	0
2028	0	0	0	0
2029	0	0	0	0
2030	0	0	0	0
2031	0	0	0	0
2032	0	0	0	0
2033	0	0	0	0
2034	0	0	0	0

8.2 Costs Associated with Evaporative Standards

The standards for evaporative emissions, which are equivalent to the California LEV II standards, are technologically feasible now. As discussed earlier in Chapter 5, the California LEV II program contains numerically more stringent evaporative emissions standards compared to existing EPA Tier 2 standards, but because of differences in testing requirements, we believe the programs are essentially equivalent. This view is supported by manufacturers and current industry practices. (See section V.C.5 of today's rule for further discussion of such test differences -- e.g., test temperatures and fuel volatilities.) A review of recent model year certification results indicates that essentially all manufacturers certify 50-state evaporative emission systems.[4] Based on this understanding, we do not expect additional costs since we expect that manufacturers will continue to produce 50-state evaporative systems that meet LEV II standards.

As discussed in the section V.C.3 of final rule, some manufacturers are still developing flex fuel vehicles (FFVs) and the evaporative control systems in some cases have not been fully field tested and certified on the non-gasoline fuel (for example E-85, which consists of 85 percent ethanol and 15 percent gasoline). Only a few FFV systems have been certified thus far to California LEV-II standards on the non-gasoline fuel. It is likely, however, that other vehicles will be certified to LEV-II standards in the future so that the vehicles can be offered for sale in California as FFVs. We are providing more lead time to manufacturers to certify to the new evaporative standards on the non-gasoline fuel. At this time, however, we do not expect significant hardware changes to these evaporative control systems or a significant increase in the average costs for vehicles due to the new standards. The few systems already on the market available in California are not significantly different from the systems used on current Tier 2-certified FFVs.

References for Chapter 8

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[2] Certification data for the 2005 model year.

[3] 40 CFR Subpart C.

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Chapter 9: Costs of the Gasoline Benzene Program and Other Control Options Considered

This chapter provides a summary of the methodology used and the results obtained from our cost analyses of the benzene control program as well as various other benzene control options considered. We start by summarizing the refinery models used for our analysis. We then describe our detailed methodology for estimating the benzene control costs for our benzene program followed by the results. We present the results from our energy and supply analyses for our benzene program. Finally, we discuss and compare the results of an oil industry cost analysis for various benzene programs, including one which is similar to the benzene program that was submitted as comments to the proposed rulemaking.

9.1 Methodology

9.1.1 Overview

Prior to the proposed rule, we retained the services of Abt Associates, Inc., (Mathpro) under subcontract to ICF, Inc., to assess the cost of potential air toxics emissions control programs. Abt Associates initially ran their linear program (LP) refinery cost model to investigate various air toxic emissions control programs for gasoline. LP refinery models are proven tools for estimating the costs for fuels programs which control fuel quality.[1] A series of gasoline quality control programs were evaluated using the LP refinery model including benzene, total toxics and sulfur and RVP control.

While the LP refinery models are necessary and appropriate for many analyses, they also have several important limitations of relevance here. When used to model the cost of nationwide fuel control programs on the entire refining industry, LP refinery models are usually used to model groups of refineries in geographic regions called PADDs which are defined above in Chapter 6. The LP refinery model averages the costs over the refineries represented in the PADDs; however, the technology chosen by the refinery model would normally be the lowest cost technology found by the refinery model. This may represent an unreasonable choice of technologies for individual refineries because of how refineries are configured and the technologies to which they have access. While the choice of technologies can be limited based on an approximate analysis of what mix of technologies would best suit the group of refineries modeled in each PADD, this would only provide an approximate estimate of the cost incurred. Also the LP refinery model would not be a sensible tool for estimating the credit averaging between PADDs. The PADD trading issue could be partially overcome by iterating between PADD refinery model runs, thus estimating the number of credits traded between PADDs and estimating the level of benzene control in each PADD. However, the need to make multiple runs for each PADD for each case, coupled with the need to run multiple control cases for different benzene standards, would be very time consuming, costly and still would only result in approximate estimates of the benzene levels achieved and the cost incurred.

For this reason, EPA contracted Abt Associates to develop a refinery-by-refinery cost model which models the capability for each refinery to install the available benzene control technologies available to them to reduce their gasoline benzene levels.[2] The advantages that this form of cost model has over the LP refinery model are that:

1. The cost for applying the benzene control technologies available to each refinery can be modeled for each refinery;
2. The benzene level achievable by applying each benzene control technology can be estimated for each refinery, which allows estimating the benzene level achievable in each PADD and across the entire refining industry;
3. The benzene control cost-effectiveness (cost per amount of benzene reduction achieved) for each benzene control technology modeled in each refinery can be compared to that of the others;
4. The most cost-effective benzene control strategy for each refinery can be chosen after considering the cost-effectiveness of benzene control technologies available at all the refineries and considering the level of the benzene standard.

This strategy results in the optimum selection of benzene control technologies consistent with how the ABT program would be expected to affect benzene control investments by the refining industry attempting to minimize its costs. For this reason, the refinery-by-refinery cost model was used to estimate the cost for various benzene standards both with and without ABT programs, and the LP refinery model was used for the other air toxics control programs considered. Because certain refinery-specific information necessary for estimating the cost of benzene control with the refinery-by-refinery cost model was not publicly available, it was necessary to find a way to estimate this information. The inputs and outputs from the LP refinery cost model provide this needed information and it was utilized in the refinery-by-refinery cost model. The information from the LP refinery model used in the refinery-by-refinery cost model is described in Section 9.1.3.

Newly creating the refinery-by-refinery modeling tool raises questions about its viability. For example, the LP refinery model has been used by Abt Associates for dozens, if not hundreds, of refinery modeling studies for a variety of clients, including the oil industry, the automobile industry, and government. These modeling studies have exposed this LP refinery modeling tool to many opportunities for internal and external review and continued adjustment to better model fuel quality changes imposed on the refining industry. Even though refinery modeling expertise was relied upon during the creation of the refinery-by-refinery model, it still has not been exposed to multiple opportunities for scrutiny. For this reason the refinery-by-refinery cost model was evaluated three different ways. First, the model was reviewed by EPA's refining modeling expert who has been conducting cost analyses on fuel programs for nearly 15 years. Another check on the model was conducted by comparing its cost estimates for benzene control with the same benzene control case evaluated with the LP refinery cost model. Finally, two peer reviews were conducted on the refinery-by-refinery cost model by two refinery industry consulting firms. These two refining industry consultant peer reviews were conducted late in the proposal process, which did not allow for adjustments to the refinery model in time for the proposal. However, their principal comments were addressed prior to undertaking the cost analysis for the final rulemaking. The peer review comments and how we addressed them are summarized at the beginning of Section 9.1.2.

A key assumption associated with the analysis is that the benzene reduction technologies assumed to be used are those which reduce benzene levels from the feed or product streams (the product stream is called “reformate”) of the reformer, the unit in the refinery which produces most of the benzene in gasoline.[3] Basing the cost of this program on reformer benzene reduction technologies is reasonable because the reformer contains the highest concentrations of benzene and reformate comprises a large portion of the gasoline pool. More importantly, essentially all the benzene reduction technologies which have been developed to date and used around the world are designed to reduce reformer benzene levels. Thus, reducing benzene from reformate would be expected to be the most cost-effective means for achieving benzene reductions. In some unique situations additional benzene reduction might be available from other refinery units. Despite considering the possibility for such reductions, we have not assumed this to be the case here. Should it occur, it would only be at refineries where such control would be more economical than reformate benzene control at other refineries – reducing the costs of the program, but also increasing uncertainty that the benzene reductions that are estimated to occur in each region of the country will actually occur. A detailed discussion on the technologies available for benzene control is discussed in Chapter 6 of the Regulatory Impact Analysis.

A number of benzene programs were considered for the final rulemaking. These include the proposed 0.62 vol% average benzene standard with an ABT program and several variants of the proposed benzene standard. We evaluated some of these alternative benzene standards with a second benzene standard called a maximum average standard. The maximum average standard would place an additional constraint on refiners beyond the average standard. Under this option, refiners would still be able to meet the average standard using credits; however, the maximum average standard would require them to meet or exceed the maximum average standard in each refinery before purchasing credits to show compliance with the average standard. The standard effectively limits the degree to which credits can be used to demonstrate compliance. For example, a refinery with a gasoline benzene level of 2 vol% and faced with a 1.3 vol% maximum average standard and a 0.62 vol% average standard under a nationwide ABT program would have to at least reduce its benzene level below 1.3 vol% to comply with this program. It could remain above the 0.62 volume percent standard and comply with the standard through the purchase of credits. However, its actual production would have to meet the 1.3 vol% maximum average limit. The addition of a maximum average standard would force several high cost refineries to take additional benzene control steps not required by the 0.62 vol% average standard alone. The addition of a maximum average standard would thus tend to increase the cost of a benzene program over a program without a maximum average standard.

We also evaluated a benzene standard without an ABT program. This type of benzene program would require that the benzene levels of every refinery be reduced down to the benzene standard. Because a number of refineries currently produce gasoline with very low benzene levels, the average benzene level of a benzene program without an ABT program would likely result in a national average benzene level that is lower than the standard (albeit far costlier, and with far more negative impact on individual refineries). We also modeled several air toxics control standards that would regulate total air toxics. Finally we modeled two different low RVP programs and a lower sulfur standard.

After the proposed rule, we eliminated any further consideration of a more stringent average gasoline sulfur standard, a low RVP standard, or any variant of a total air toxics standard. Therefore we limited our cost analysis for the final rule to various benzene programs above and below the proposed 0.62 vol% benzene standard, including variants with a maximum average standard. For the final rule, we adopted a gasoline benzene content standard of 0.62 vol% benzene with a maximum average standard of 1.3 vol%. The benzene standards evaluated for the final rule are summarized in Table 9.1-1 .

Table 9.1-1. Benzene Standards Modeled using Refinery-by-Refinery Model

Average Std.	Avg.-Max Std.	ABT Program
0.50	None	Yes
0.60	1.3	Yes
0.60	None	Yes
0.62	1.1	Yes
0.62	1.2	Yes
0.62	1.3	Yes
0.62	1.4	Yes
0.62	1.5	Yes
0.62	None	Yes
0.65	1.3	Yes
0.65	None	Yes
0.70	1.3	Yes
0.70	None	Yes
0.71	None	No

The final benzene levels and cost results for the benzene program and other benzene standards considered are reported by PADD. This allows one to view the potential impact of the benzene program on a regional basis. Moreover, since the PADD regions are the smallest geographical unit of analysis for the LP refinery modeling case studies, reporting the cost results for the benzene control cases also on a PADD-by-PADD basis allows a straightforward comparison to the LP refinery modeling results which are reported on a PADD-basis. Agreement of certain outputs between the refinery-by-refinery and LP models increases our confidence in the results of both.

9.1.2 Changes to the Cost Analysis since the Proposal

In deriving the cost estimate for the final rule, we identified and made a number of changes to the refinery modeling methodology used for the proposed rule. One of the primary changes was to base the future year fuel prices on the Annual Energy Outlook (AEO) 2006 instead of AEO 2005. Perhaps the most important difference between the two AEO studies is that the AEO 2006 projects a higher crude oil price of $47 per barrel for 2012, the year of the final rule analysis, compared to the crude oil price projected by AEO 2005, which was $27 per barrel. The primary difference caused by the higher crude oil price is that the cost of reduced gasoline supply, such as when benzene is extracted from gasoline, is higher when the removed benzene is replaced by other high octane petroleum compounds. AEO 2006 also projects higher natural gas prices as well.

Another change was to update the refinery modeling base year to 2004 from 2003 – the year used for the proposed rule analysis. The primary purpose for this change was to calibrate each refinery's gasoline benzene levels and gasoline volumes to the most recent year that we have information available. Each refinery's 2004 gasoline benzene level and volume is available from the RFG data base.

The final rule analysis treated natural gasoline differently in the refinery-by-refinery cost model compared to how it was treated in the proposed rule analysis. Natural gasoline contains 1.3 vol% benzene and we assumed for the proposed rule cost analysis that natural gasoline, and other benzene-containing streams, are blended directly into gasoline without being treated to reduce their benzene. For the final rule cost analysis, we assessed the feasibility for treating the benzene in natural gasoline as well as the other benzene containing gasoline streams (these other benzene-containing streams include, light straight run naphtha, light coker naphtha and light hydrocrackate). Of these streams, the only one that we identified that refiners would treat to reduce benzene with certainty is natural gasoline (see Chapter 6 of the RIA for a discussion of the feasibility for treating the benzene of these other streams). The reason why we are confident that refiners would treat the benzene in natural gasoline is because most refiners have rerouted natural gasoline to the front of the refinery and are feeding it into the atmospheric crude tower to facilitate the desulfurization of this stream to achieve compliance with the Tier 2 gasoline sulfur standard. As the benzene of natural gasoline is routed through the refinery, it will be treated by the isomerization unit, when the six carbon benzene compounds are rerouted around the reformer, or by extraction and benzene saturation which post-treat the benzene in the reformate. For some refineries which blend a lot of natural gasoline into their gasoline, this additional benzene reduction can be significant.

The refinery modeling case studies conducted for the final rule were conducted on an annual basis – which is different from the proposed rule, which was conducted on a summer basis. As we acknowleded in the proposed rule, assessing the cost of benzene reductions solely on a summer basis, which was done to allow the cost comparison with low RVP control, would likely lead to a slightly conservative cost estimate for benzene reductions. For example, recovering octane loss associated with benzene reduction is higher in the summer versus the winter. Thus, assessing the cost of benzene reductions on an annual basis is expected to more accurately estimate the cost of benzene reductions.

The cost analysis for the final benzene program excludes the participation of California refineries – which differs from how the analysis was conducted for the proposed rule. After the cost analysis was completed for the proposed rule, but before it was proposed, California state officials decided not to be a part of the Federal benzene program and the state has maintained this point of view. Not including California refineries in our cost analysis increases the cost of benzene control slightly because non-California refiners cannot take advantage of the low-cost benzene control credits that California refineries would provide them if they were included in the program.

In addition to the above changes to our cost analysis that we identified, we also made some adjustments that were based on public comments (from the American Petroleum Institute) and peer review comments we received on the cost analysis that we conducted for the proposal. Peer reviews on the refinery-by-refinery cost model were conducted by Jacobs Engineering and A Second Opinion.[4, 5] They both are refining industry consulting firms which also have consulted for EPA in the past. Both firms have conducted cost analyses on changes to fuel quality – Jacobs uses a refinery cost LP refinery model while A Second Opinion has used simpler cost estimation techniques. Based on the different experiences they each have in conducting cost analysis, each firm brings a different perspective to the peer review process.

As expected, both peer reviewers agreed with aspects of the refinery modeling and took issue with other aspects. Both reviewers found that the choices for benzene control technologies, including benzene precursor rerouting with and without isomerizing this stream, benzene saturation and benzene extraction, are sound choices for modeling the reduction in benzene levels. Both reviewers thought, contrary to our modeling, that any benzene precursor rerouting assumed to be occurring in the basecase would continue in the control case when benzene saturation is applied. Applying this approach would slightly reduce the cost of the program, but we believe a more conservative approach that results in deeper benzene reductions under the credit trading program is more appropriate, thus relieving the need for some of the benzene control by other refineries.

Both reviewers found that the calibration of each refinery's benzene level and gasoline volume to their actual levels and volumes is important for establishing a sound refinery-specific analysis, although one reviewer pointed to some anomalies in how a few specific refineries were calibrated. Some anomalies can be expected when attempting to calibrate individual refineries modeled using average gasoline blendstock production and quality information when their operations deviate significantly from the average. Thus, this is not unexpected and we did not make any changes to our methodology.

Jacobs commented that using the marginal cost of octane from the LP refinery model (also termed shadow values) might underestimate the cost of making up lost octane since the cost of the amount of additional octane needed might be greater than the marginal octane cost. Our analysis of the octane made available from the Renewable Fuels standard mandated by EPAct reveals that this octane entering into the gasoline pool would make up for the octane loss from this benzene program several times over, and should ensure that many increments of octane recovery could be made available at about the same price. Thus, we did not adjust our octane cost methodology for the final rule analysis.

One of the peer review comments we received from Jacobs was in response to our assumption that refiners assess what strategy they will take to reduce gasoline benzene levels based on their desire to minimize their dollars expended per barrel of benzene reduced (dollars expended includes capital amortized at 10% return on investment (ROI) after taxes). Jacobs countered stating that refiners assess how to move forward on a particular refining strategy solely on the desire to minimize their capital investments. We disagree with Jacob's statement. If minimizing capital investment was a refiner's sole goal, then refiners would not have invested in fluidized catalytic cracker (FCC) feed hydrotreating to reduce gasoline sulfur when lower capital cost FCC naphtha hydrotreating is also available. Similarly, refiners would not opt for hydrocrackers and would instead live with relative inflexibility of FCC units. However, we do understand a refiner's desire to limit their capital investments. We contacted two refining companies and asked them what payout they expect for their newly invested capital investments. The two refiners said that they move forward with their capital investments when they are better than 15% ROI. Thus for the final rule, we continued to assume that refiners assess benzene control technology based on their dollars expended per barrel of benzene reduced, but we amortized the capital investments involved based on the higher after-tax 15% ROI which values the cost of capital more than the lower ROI.

Jacobs and API, in its comments on the proposed rule, provided capital cost estimates for the benzene control technologies. We summarized our capital costs that we used for the proposed rule analysis and those by Jacobs and API in Table 9.1-2.[6]

Table 9.1-2 EPA Capital Costs used for the Proposed Rule Compared to Jacobs and API Capital Costs

	Reported/Estimated			**Adjustment to Standard Size and to 2004 Dollars**				**2004 Dollars**				
	Unit Size (K b/sd)	ISBL Cost ($MM)	$ Year	Scale Factor	Infl. Adj. (%)	Std Size (K b/sd)	ISBL Cost ($MM)	Off -Site Factor	ISBL + OSBL Cost $MM	Contingency	Total Capital Cost ($ MM)	Per Barrel Cost ($/bbl)
LSR Rerouting												
EPA (Abt)	15.0	7.69	2004	0.70	100%	15.0	7.69	12.0%	8.61		8.61	0.57
Jacobs Consult	20.0	9.10	2005	0.65	98%	15.0	7.41	50.0%	11.11		11.11	0.74
API (B&OB)	30.0	7.52	2Q 06	0.39	95%	15.0	5.45	70.2%	9.27	15%	10.66	0.71
Benzene Saturation												
EPA (Abt)												
Conv Saturation												
Reform Spltr	30.0	6.00	2003	0.70	107%	30.0	6.43	25.0%	8.04		8.04	
Saturation Unit	6.3	2.76	2003	0.65	107%	6.3	2.96	25.0%	3.70		3.70	
Total		8.76			107%	30.0	9.39	25.0%	11.74		11.74	0.39
CD Hydro	30.0	7.20	2003	0.70	107%	30.0	7.72	25.0%	9.65		9.65	0.32
Jacobs Consult												
Reform Spltr	20.0	9.10	2005	0.65	98%	30.0	11.62	50.0%	17.43		17.43	
Saturation Unit	9.1	10.12	2005	0.65	98%	13.7	12.91	75.0%	22.60		22.60	
Total		19.22		0.65	98%	30.0	24.53	63.9	40.03		40.03	1.33
API (B&OB)												
Reform Spltr	30.0	7.52	2Q 06	0.39	95%	30.0	7.14	70.2%	12.15	15%	13.97	
Saturation Unit	10.0	9.09	2Q 06	0.67	95%	10.0	8.62	70.2%	14.68	15%	17.68	
Total		16.61		0.67		30.0	15.76	70.2%	26.82		31.65	1.05
Benzene Extr												
EPA (ABT)												
Reform Spltr	30.0	6.00	2003	0.70	107%	30.0	6.43	25.0%	8.04		8.04	
Depentanizer	6.3	1.07	2003	0.70	107%	6.3	1.15	25.0%	1.43		1.43	
Sulfolane	5.4	19.00	2003	0.65	107%	5.4	20.37	40.0%	28.52		28.52	
Total	1.8	26.07		0.65	107%	1.8	27.95	35.9%	38.00		38.00	21.1
Jacobs Conslt												
Reform Spltr	20.0	9.10	2005	0.65	96%	16.2	7.77	50.0%	11.66		11.66	
Sulfolane	10.4	17.05	2005	0.65	96%	8.4	14.56	100.0%	29.11		29.11	
Total	1.0	26.16		0.65	96%	0.8	22.33	82.6%	40.77		40.77	48.54
API (B&OB)												
Aromatics Extr	20.4	134.63	2Q 06	0.67	95%	8.4	70.41				113.18	
Aromatics Extr	14.3	134.63		0.67	95%	5.9	70.41				113.18	19.25

Comparing our capital costs used in our proposed rule analysis to those by Jacobs and API we found that, for the most part, our capital costs were lower. We discovered that one general reason why our capital costs were lower is that the base year for our capital costs is several years ago, and capital costs have increased recently much faster than the rate of inflation. For each benzene control technology, we also compared other aspects of our capital costs, such as the offsite costs, to those used by Jacobs and API, and made additional changes to the capital cost information we used for the proposed rule to update them for our final rule cost analysis.

Our proposed light straight run rerouting capital costs are about 80 percent those of Jacobs and API. The inside battery limits (ISBL) portion of our LSR rerouting capital costs are the highest of the three for a similar sized unit, but our 12% offsite factor is much lower.[a] Our LSR rerouting offsite factor also seems low compared to the 25% offsite factor we assigned to reformate splitters, which is another distillation column and arguably should have a similar offsite factor. The offsite factor for Jacob's and API's LSR rerouting distillation column are much higher at 50% and 70%, respectively. However, we believe that these are too high for a distillation column. According to a presentation by Fluor engineers, the offsite factors for new process units in refineries range from 10% to 80%, with the average being 40%.[7] Distillation columns are simple refinery units that we expect would have lower offsite costs. Thus we don't believe that the higher offsite factor used by Jacobs is justified, and API's offsite factor seems extremely high. In addition to API's very high offsite factor, API also applies a 15% contingency factor. Contingency factors are usually reserved for estimates with significant uncertainty, not for well proven technologies. It appears that API is being excessively conservative in its cost estimate. After considering the different offsite factors, we decided to increase our LSR rerouting offsite factor to 25% to make it consistent with the offsite factor for reformate splitters.

Our proposed benzene saturation capital costs are about one third of those of Jacobs and API. In conducting our capital cost comparison, we compared our capital costs individually for each of the two units which comprise benzene saturation: the reformate splitter and the saturation unit. Reviewing our reformate splitter costs we identified that its ISBL costs are lower than API's and much lower than Jacobs'. After reviewing those costs, we found that our costs are indeed low – perhaps solely because they are older. Updating them with cost information from the year 2006, we increased our reformate splitter ISBL costs from $6.4 to $8.3 million for a 30,000 barrel per day unit expressed in 2004 dollars. As discussed above, our OSBL factor is 25% compared to Jacobs which is 50% and API which is 70%, along with a 15% contingency factor. As discussed above, we have a high level of confidence with our 25% offsite factor for distillation columns so we kept the same factor for reformate splitters.

Our proposed saturation unit capital costs are much lower than those by Jacobs and API. We identified two reasons for our lower costs. First, our ISBL and offsite costs were much lower than those by Jacobs and API. We reviewed our saturation unit ISBL cost and found that it was indeed low. We obtained more recent capital cost information and based our saturation unit ISBL capital costs on this new cost information, increasing them by about a factor of 2 ½. Again our saturation offsite factor was much lower than that used by Jacobs and API. As discussed above, the typical range for offsite costs is 10 to 70 percent. A benzene saturation unit is more complicated than a simple distillation column, but less complicated than fluidized catalytic cracker (FCC) or hydrocracker units, which would arguably have offsite costs at the higher end of this range. For this reason, we believe that the offsite factor for a benzene saturation unit should be about at the middle of the range for an offsite factor, so we assigned it a

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[a] Onsite costs are for the primary unit including the distillation column, heat exchangers, pumps, heaters, piping, valves and instrumentation. Offsite costs are for administration and control buildings, cooling tower, electrical substation and switchgear, water and waste treatment facilities, feedstock and product storage and loading and offloading, spare equipment kept onsite and catalysts. Normally refiners estimate offsite costs for each project which can vary from zero to a factor several times greater than the onsite costs. For national fuel control programs, cost estimation is averaged and a factor is used to indicate the fraction that offsite costs comprise of onsite costs. This factor is applied for all the technologies requiring capital investment and is expressed as a single onsite and offsite capital cost estimate.

40% offsite factor. We believe that our 40% factor is more appropriate than the higher offsite factors used by Jacobs and API.

The second reason why our proposed benzene saturation costs were lower is that our ratio of benzene saturation unit capacity to reformate splitter capacity was much lower compared to the same ratios used by Jacobs and API. Benzene saturation units are always of lower capacity than the reformate splitter because the reformate splitter concentrates the benzene into a single stream separate from the rest of the reformate. If at a refinery, the six, seven and eight carbon compounds are sent to the reformer, then the six carbon portion of reformate is likely to be on the order of 33% of the reformate, provided that the mix of hydrocarbons are proportional for each carbon number. However, most refiners also send nine carbon and even some higher carbon number hydrocarbons to the reformer in addition to the six, seven and eight carbon hydrocarbons. Thus, the six carbon hydrocarbons comprise 25% or less of the total mix of hydrocarbons. For our proposed rule cost analysis, our benzene saturation unit capacity was 21% of the reformate capacity, while Jacobs and API assigned the benzene saturation unit capacities which are 46% and 31% of the reformate splitter capacity, respectively. Since refiners usually send (or want the capacity to send) the nine and heavier hydrocarbons to the reformer, then it seems that the benzene saturation unit would only need to be sized to be about 25% of the reformate splitter capacity, depending on whether or not a safety factor is also necessary. Based on this reasoning, our assumption that the benzene saturation unit would be sized to be 21% of the reformate splitter capacity would be low. We contacted a vendor of benzene saturation technology to find out how they size their benzene saturation units relative to reformate splitters. They typically size their benzene saturation units to be 28% of the capacity of the reformate splitters. This relative benzene saturation unit capacity seemed reasonable based on the discussion above, and is only slightly lower than API's but much lower than Jacobs' which seems unnecessarily high. We changed the relative capacity of the benzene saturation unit for our analysis to be 28% of the reformate splitter.

Our proposed benzene extraction capital costs were also lower than Jacobs', but about the same as API's on a per-barrel basis. However, the API capital costs are for a BTX extraction unit which is larger and therefore enjoys a better economy of scale. For a similar sized unit, the per-barrel API capital costs would be $32 per barrel and therefore higher than ours at $21 per barrel. We made several changes to our benzene extraction costs. First, as stated above, we adjusted our reformate splitter ISBL capital costs higher for the benzene saturation unit and we applied those same adjustments to our reformate splitter capital costs for benzene extraction. We had included capital costs for a depentanizer, the purpose of which would be to ensure that no five-carbon hydrocarbons would be sent to the extraction unit. However, after further consideration we realized that that all reformers have a stripper that could be used to separate the five carbon hydrocarbon compounds from the heavier hydrocarbons in reformate. Thus, adding a depentanizer unit would be unnecessary, so we eliminated the depentanizer from our benzene extraction costs. Finally, we assessed our capital costs for the benzene extraction unit, the sulfolane unit. Our sulfolane unit ISBL capital costs are as high as or higher than those by Jacobs and API . Therefore we did not adjust them. The offsite factor that we assigned to the sulfolane unit was 40%, which is much lower than those used by Jacobs and API. Using the reasoning that we used above for estimating the offsite factor, we believe that the offsite factor should be higher than 40%. The offsite costs are usually very high for a benzene saturation unit because of the need for adding special benzene and extraction chemical storage, offloading facilities and the costly environmental controls necessary to control benzene fugitive emissions. The offsite costs for benzene extraction are usually higher than FCC and hydrocracker units which are other complex refinery units with high offsite factors. We therefore increased benzene extraction unit's offsite factor to 100% of the ISBL capital costs. The last variable in the extraction unit's costs is the relative capacity for the sulfolane unit compared to the reformate splitter. For the saturation unit capital costs, we concluded that the saturation unit capacity should be sized to be 28% of the reformate unit capacity. Since the reformate splitter will be creating the same benzene-rich stream for extraction as it would for saturation, we assigned the same relative ratio of extraction unit capacity to reformate splitter unit capacity, which is 28%. Again, Jacobs used a very conservative ratio for the benzene sulfolate extraction unit capacity compared to the capacity for the reformate splitter unit, which we believe is unjustified.

After making the above adjustments to our capital costs, we summarize our revised capital costs in Table 9.1-3 below, comparing them to the Jacobs and API capital costs. The values in Table 9.1-3 which are in bold are revised from the values presented in the proposed rule.[b]

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[b] After further reviewing the cost information for the benzene saturation technologies as we adopted the revised capital cost estimates into our refinery cost model, we realized that the differences in capital costs from literature between a Bensat unit and a CDHydro unit were greater than expected compared to how these technologies differ. To remedy this, we conservatively assigned CDHydro's capital costs to be the same as those as Bensat, as described in Section 9.2.3.

Table 9.1-3 Our Revised Capital Costs Compared to Capital Costs Provided by Jacobs and API (values in bold indicated that they were updated since the proposed rule)

	Reported/Estimated			**Adjustment to Standard Size and to 2004 Dollars**				**2004 Dollars**				
	Unit Size (K b/sd)	ISBL Cost ($MM)	$ Year	Scale Factor	Infl. Adj. (%)	Std Size (K b/sd)	ISBL Cost ($MM)	Off -Site Factor	ISBL + OSBL Cost $MM	Contingency	Total Capital Cost ($ MM)	Per Barrel Cost ($/bbl)
LSR Rerouting												
EPA (Abt)	15.0	7.69	2004	0.70	100%	15.0	7.69	**25.0%**	**9.61**		**9.61**	0.64
Jacobs Consult	20.0	9.10	2005	0.65	96%	15.0	7.41	50.0%	11.11		11.11	0.74
API (B&OB)	30.0	7.52	2Q 06	0.39	92%	15.0	5.45	70.2%	9.27	15%	10.66	0.71
Benzene Saturation												
EPA (Abt)												
Conv Saturation												
Reform Spltr	30.0	**8.79**	**2006**	0.70	**95%**	30.0	**8.34**	25.0%	**10.42**		**10.42**	
Saturation Unit	**8.4**	**8.67**	**2006**	0.65	**95%**	**8.4**	**8.22**	**40.0%**	**11.51**		**11.51**	
Total		17.46			**95%**	30.0	**16.56**	25.0%	**21.94**		**21.94**	**0.73**
CD Hydro	30.0	**5.86**	2003	0.70	**110%**	30.0	**6.44**	**40.0%**	**9.01**		**9.01**	**0.30**
Jacobs Consult												
Reform Spltr	20.0	9.10	2005	0.65	98%	30.0	11.62	50.0%	17.43		17.43	
Saturation Unit	9.1	10.12	2005	0.65	98%	13.7	12.91	75.0%	22.60		22.60	
Total		19.22		0.65	98%	30.0	24.53	63.9	40.03		40.03	1.33
API (B&OB)												
Reform Spltr	30.0	7.52	2Q 06	0.39	95%	30.0	7.14	70.2%	12.15	15%	13.97	
Saturation Unit	10.0	9.09	2Q 06	0.67	95%	10.0	8.62	70.2%	14.68	15%	17.68	
Total						30.0	15.76	70.2%	26.82		31.65	1.05
Benzene Extr												
EPA (ABT)												
Reform Spltr	30.0	**8.79**	**2006**	0.70	**95%**	30.0	**8.34**	25.0%	**10.42**		**10.42**	
Sulfolane	**8.4**	**25.20**	2003	0.65	110%	**8.4**	**27.73**	**100.0%**	**55.45**		**55.45**	
Total	1.8	**33.99**		0.65	107%	1.8	**36.07**	**82.7%**	**65.88**		**65.88**	**36.60**
Jacobs Conslt												
Reform Spltr	20.0	9.10	2005	0.65	96%	16.2	7.77	50.0%	11.66		11.66	
Sulfolane	10.4	17.05	2005	0.65	96%	8.4	14.56	100.0%	29.11		29.11	
Total	1.0	26.16		0.65	96%	0.8	22.33	82.6%	40.77		40.77	48.54
API (B&OB)												
Aromatics Extr	20.4	134.63	2Q 06	0.67	95%	8.4	70.41				113.18	
Aromatics Extr	14.3	134.63		0.67	95%	5.9	70.41				113.18	19.25

9.1.3 LP Refinery Modeling Methodology

Although the benzene control costs estimated for the final rule were estimated using the refinery-by-refinery cost model, certain inputs into that model were taken from the input tables or from the results of the refinery modeling output from the LP refinery model – hence its importance for the cost analysis. The information from the LP refinery model used in the refinery-by-refinery model included the average benzene content of the various streams which make up gasoline, the price of hydrogen, the cost for making up the octane-barrel loss of octane, and the price of gasoline. Certain refinery operations information from the LP refinery model was used for estimating the volume of gasoline produced in the refinery-by-refinery model, including the utilization factors of individual refinery units, and the percentage that straight run naphtha, FCC naphtha and hydrocrackate comprises of the feed volume of their respective units. The means for using the specific inputs from the LP refinery model discussed here in the refinery-by-refinery model are summarized below in the section discussing the refinery-by-refinery model methodology.

LP refinery models are detailed mathematical representations of refineries. They are used by individual refining companies to project how best to operate their refineries. They are also used by government agencies, such as EPA and DOE, as well as by refining industry associations and individual companies, to estimate the cost and supply impacts of fuel quality changes. LP refinery models have been used for these purposes for decades and a certain protocol has been established to conduct these studies. For estimating the cost and other impacts of a future gasoline quality standard, the refinery modeling work is conducted in three steps.

The first step in conducting an LP refinery modeling analysis is the development of a base case. The base case is a refinery modeling case that calibrates the refinery model based on actual refinery unit capacity and input and output data. The base year for this study was the year 2000. Because much of the information available for establishing the base case is only available for PADDs of refineries, the LP refinery modeling is conducted on a PADD-wide basis. Refinery capacity information from the Oil and Gas Journal is aggregated by PADD and entered into the LP refinery model.[8] The year 2000 feedstock volumes including crude oil, oxygenates, and gasoline blendstocks, were obtained from the Energy Information Administration and entered into each PADD's model. Similarly, year 2000 product volumes such as gasoline, jet fuel and diesel fuel, were obtained from EIA and entered into the cost model. The environmental and ASTM fuel quality constraints in effect by 2000 are imposed on the products. This includes the Reformulated Gasoline program and the 500 ppm highway diesel fuel sulfur standard. This information was input into the LP refinery cost model for each PADD and each PADD model was run to model the U.S. refinery industry for the year 2000, which is the base year. The gasoline quality for each PADD refinery model was then compared to the actual gasoline quality which is available from the RFG data base. Each model was calibrated to closely approximate the gasoline quality of each PADD.

The next step in modeling is the development of a reference case. The purpose of the reference case is to model the refining industry operations and cost in a future year, which is the year that the air toxics cases are modeled to be in effect (serving as a point of reference to the modeled air toxics cases for estimating costs). The benzene program was assumed to take effect in 2012. The reference case is created by starting with the 2000 base cases for each PADD and adjusting each base case to model the future year, accounting for the changes between the two years.

Two different types of adjustments were made to the base case refinery models to enable modeling the refining industry in 2012 for the reference case. First, the change in certain inputs such as product volumes and energy prices need to be accounted for. U.S. refinery gasoline, diesel fuel and jet fuel demand are projected by EIA to grow to meet increased demand.[9] This growth in demand is used to project refinery production for each PADD to meet that increased demand. This projected growth in U.S. refinery production is entered into the reference case version of the LP refinery model. Another adjustment is made to account for changes in energy prices which are projected by EIA for future years.

The second adjustment made to model the reference cases is the application of fuel quality changes. Environmental programs which have been implemented or which will largely be implemented by the time that the prospective benzene program would take effect were modeled in the reference case. These fuel quality changes include limits such as the 30 ppm average gasoline sulfur standard, and 15 ppm caps on highway and nonroad diesel fuel, in addition to the environmental programs which were already being modeled in the base case. Additionally, we also modeled the implementation of EPAct, which requires a large increase in the amount of ethanol to be blended into gasoline to comply with the renewable fuels standard (RFS). In its AEO 2006, EIA has projected that the volume of ethanol blended into gasoline will exceed the RFS required amounts, resulting in 9.6 billion gallons of ethanol blended into gasoline by 2012. Other provisions of EPAct that we modeled included a nationwide ban on MTBE and rescinding the RFG oxygenate standard.

The third step in conducting the LP refinery modeling was to run the various control cases. The control cases are created by applying a specific fuel control standard to each PADD reference case. The control cases are run with capital costs evaluated at a 15 percent rate of return on investment (ROI) after taxes. The refinery model output for each PADD is then compared to the reference case output and the changes in refining operations, fuel quality and costs are reviewed and reported. In the reported results the capital costs are adjusted to a 7 percent rate of ROI before taxes.

9.1.4 Summary of Refinery-by-Refinery Model Methodology

The methodology used for estimating costs with the refinery-by-refinery cost model has some similarities with the methodology used with the LP refinery cost model. Although the refinery-by-refinery cost model is a separate cost estimation tool, the means for using the mathematical representation of the benzene control technologies for estimating the cost and the final gasoline benzene level by reducing benzene levels is very similar. The principal difference is that the refinery-by-refinery cost model estimates the gasoline production and benzene level for each refinery, while the LP refinery model estimates the benzene levels of the aggregate gasoline produced by each PADD of refineries. As discussed above, the modeling of each refinery is important to understanding the impact of the ABT program on compliance and cost. However, attempting to model the refinery operations for each refinery has its own set of challenges. This section presents various steps used in our methodology for estimating the operations and benzene control costs for individual refineries.

The first step was to estimate year 2004 baseline operating conditions for each refinery. This involves estimating the volumes and benzene levels of the gasoline blendstocks that comprise each refinery's gasoline. As a final adjustment to our estimated gasoline volumes and benzene levels, we calibrate them against actual refinery gasoline volume and benzene levels. For seven refineries, we had gasoline blendstock volumes and benzene levels which the refining companies shared with us in our previous discussions with them for MSAT1 concerning air toxics control and during our discussions with refiners prior to the proposed rule. This specific refinery information provided to us was entered into the refinery-by-refinery model avoiding the need to estimate it.

The 2004 gasoline production volumes and refinery operating conditions were projected to 2012, the year that we modeled the cost for gasoline benzene control. We chose the year 2012 for modeling the cost of benzene reductions because it represented a midyear in the range of years that the benzene program is expected to phase in. The phase-in years range from 2007 to 2015 with the major benzene reductions expected to occur in 2015. Based on projections by the Energy Information Administration, gasoline demand is expected to increase by 12.5 percent between 2004 and 2012.[10]

The next step involves applying the various benzene control technologies as appropriate in each refinery. This allows us to make a cost estimate for using each benzene control technology in each refinery. The capital costs for installing the various benzene control technologies in each refinery were evaluated based on a 15 percent rate of return on investment (ROI) after taxes, but were adjusted post modeling to a 7 percent ROI before taxes for reporting the results. We also report the cost estimates based on capital costs amortized at 6 and 10 percent ROI after taxes, to represent the typical return on investments experienced by refiners. A key part of illustrating this step is a summary of the cost inputs for the various benzene control technologies. We also describe how the four benzene control strategies were utilized to meet the various benzene standards.

9.1.4.1 Estimating Individual Refinery Gasoline Blendstock Volumes

To calibrate each refinery to its current benzene levels and gasoline volumes, and to provide the best opportunity for estimating the cost and ultimate level of benzene control, it is necessary to understand the benzene levels and volumes of the various blendstocks which make up each refinery's gasoline. Information on the volumes and benzene levels of each gasoline blendstock contained in each refinery's gasoline is not publicly available, so it was necessary to estimate them. This is accomplished by adjusting published refinery unit capacity information to estimate the extent that each refinery unit is utilized, followed by a unit-specific analysis for estimating how each refinery unit produces material for blending into gasoline. After the unit-by-unit estimates are completed, we do an overall check by comparing our estimated gasoline volumes with actual gasoline volume. We force the estimated gasoline volumes to match the actual gasoline volume using a factor which adjusts the estimated gasoline volume of each refinery unit.

The Oil and Gas Journal publishes, and the Energy Information Administration reports, unit capacities for the principal refinery units for each refinery in the U.S.[11] [12] Information from these two sources was reviewed for the year 2004, the base year for the cost model, and the information judged best overall from the two sources was entered into the refinery-by-refinery cost model. This information was used as a first step in the process to estimate the volumetric contribution of each of the gasoline producing units to each refinery's gasoline pool. The units analyzed include coking, fluidized catalytic cracking (FCC), hydrocracking, alkylation, dimersol, polymerization, isomerization, reforming and aromatics extraction.

An initial assumption was made that each unit in each refinery is being operated at the percent of capacity for the respective unit's percent of operating capacity for the PADD of refineries being modeled by the LP refinery model. The initial percent of capacity utilization for each unit as estimated by the LP refinery model for 2004 and 2012 is presented in Table 9.1-4.

Table 9.1-4. Initial 2004 and 2012 Percent of Refinery Unit Capacity used in Refinery-by-Refinery Cost Model

		PADD 1	PADD 2	PADD 3	PADD 4 & 5 exCA
Crude	2004	101	94	97	89
	2012	103	97	100	98
Coking	2004	97	90	96	100
	2012	88	87	104	100
FCC	2004	94	97	95	100
	2012	96	97	96	111
Hydrocracker	2004	100	102	77	100
	2012	100	111	100	110
Isomerization	2004	98	100	100	103
	2012	98	72	100	100
Polymerization	2004	90	86	64	10
	2012	101	98	87	71
Alkylation	2004	100	92	71	89
	2012	103	96	75	95
Reforming	2004	88	82	85	85
	2012	93	82	96	72
Aromatics	2004	100	65	88	-
	2012	100	67	94	-

The estimates of refinery unit capacity utilized in Table 9.1-4 are a product of how the LP refinery model models the use of refinery units in each PADD of refineries. Normally, we would expect year 2004 (baseyear) refinery unit utilization to be 80 to 95 percent of listed capacity. For some units this is the case, but for many of the units this is not the case. There are two reasons for this. First, listed refinery unit capacity can be wrong. For past refinery modeling efforts, we have compared the listed unit capacity for specific refinery units between EIA and the Oil and Gas Journal and have seen significant differences between the two sources. We do not know which source is right, or if either of the sources is right. The second reason why there may be a discrepancy is because LP refinery models attempt to model PADDs of refineries based on average operating characteristics, which can vary substantially between refineries, and can vary between PADDs based on regional differences in how the units are being operated. If such average operating characteristics are not capturing the refining characteristics adequately, then this could lead to over and underestimating refinery unit utilization. Despite the occasional apparent anomaly in percent of operating capacity estimated by the LP refinery model, we chose to use the LP refinery model's estimated refinery utilization factors.

Estimating refinery unit capacity and utilization of that capacity may or may not translate directly into the gasoline blendstock volume produced by a specific refinery unit because some of the refinery units produce more than one refinery product or they may affect the density of the feedstock to that unit. How the refinery unit capacity and its utilization are used to estimate gasoline blendstock volume is described in detail for each major refinery unit.

For the polymerization and alkylation units listed in Table 9.1-4, the actual capacity of the unit coupled with its estimated utilization does establish the initial volume of gasoline blendstock volume produced by those units. For example, a particular refinery unit in PADD 1 might have a 10,000 barrel per day alkylation unit. Table 9.1-4 shows that the alkylation units in PADD 1 are estimated to be operating at 103 percent of its listed capacity in 2012, thus, alkylate production is projected to be 10,300 barrels per day at that refinery.

Other gasoline blendstocks require additional steps to estimate their volumes, including light straight run naphtha, FCC naphtha, coker naphtha and hydrocrackate. Each of these other gasoline blendstocks are produced based on a portion of the unit capacities for the units used to produce them. To illustrate the methodology used to estimate the volumes, we will use light straight run naphtha as an example. Light straight run naphtha is principally comprised of five carbon hydrocarbons which come directly from crude oil. Thus to model the volume of the light straight run naphtha, it was necessary to estimate the volume of crude oil as well as the percentage that light straight naphtha comprises of crude oil. The Oil and Gas Journal contains reported capacities of the atmospheric crude oil towers for each refinery. The reported crude oil tower capacity is adjusted using the percent of unit utilization estimates for the crude unit contained in Table 9.1-4 applying the same adjustment to each refinery in each PADD. These calculations provided us an estimate of the volume of crude oil processed by each refinery. The fraction of light straight run naphtha in each refinery's crude oil was estimated from the percentage that light straight run comprises of crude oil for each PADD in the LP refinery model. This percentage is based on the types and quality of crude oil processed by all the refineries in each PADD – information obtained from the Energy Information Administration.[13] The percentage that light straight run naphtha comprises of crude oil is applied to each refinery in the refinery-by-refinery cost model. As summarized below in Table 9.1-5, the volume of light straight run naphtha is estimated to be 4 to 5 percent of the crude oil volume processed depending on the PADD.

Light straight run has three possible different fates depending on the refinery. Except for PADD 2, a portion is designated to be sold into the petrochemicals market. For PADDs 1, 3, 4 and 5, although primarily in PADD 3, a portion of straight run naphtha is processed and sold to petrochemical companies which use the material to make other hydrocarbon compounds. EIA publishes the volume of naphtha which is sold into the petrochemicals market in each PADD.[14] Since no source of information is publicly available that specifies the volume of naphtha sold by each refinery to the petrochemicals market, the volume of light straight run naphtha sold into the petrochemicals market by each refinery was assumed to be proportional to the percentage that its crude oil processing capacity comprises of the total crude oil processing capacity in the PADD. After accounting for the volume of light straight run naphtha sold to the petrochemicals market, the balance of straight run naphtha is blended directly into gasoline for those refineries without an isomerization unit. For refineries with an isomerization unit, the volume of light straight naphtha not sent to the petrochemicals market is sent to the isomerization unit up to the capacity of that unit, and the balance is blended directly into gasoline.

The hydrocracker and coker units produce some light naphtha material which plays a role in blending up gasoline. The light naphtha material produced by the hydrocracker and coker are termed light hydrocrackate and light coker naphtha, respectively. The portion of the material processed by each of these units converted to light coker naphtha and light hydrocrackate is 5 percent for coker units across all the PADDs, and ranges from 23 to 32 percent for hydrocracker units depending on the PADD. Table 9.1-5 below summarizes the percentage of total material processed by these units into light naphtha.

The volume of isomerate, the product produced by the isomerization unit, is based on the feed to the isomerization unit up to its capacity. As described above, the volume of light straight run is estimated and that volume which is not assumed to be sold into the petrochemical markets is assumed to be sent to the isomerization unit. An additional source of feed to the isomerization unit, as described below, is a portion of the six carbon hydrocarbons which is estimated to be sent to the isomerization unit to calibrate a refinery's benzene levels. This is one of the strategies used by refiners to reduce their benzene levels today, although in a limited way since the refinery-by-refinery model estimates that 26 refineries in the U.S. in 2012 are sending their six carbon hydrocarbons to the isomerization unit. The six carbon hydrocarbons have priority to the light straight run which is sent to the isomerization unit. In all cases, the volume of isomerate produced by isomerization units is estimated to be 1.6 volume percent less than its feed.

The volume of reformate was estimated based on the feed to the unit as limited by each unit's capacity. The feed to the reformer comes from various sources depending on the refinery configuration. For virtually all refineries, part of the naphtha from the atmospheric crude tower is sent to the reformer. Those refineries with a hydrocracker or a coker will send part of the naphtha from these units to the reformer as well. The naphtha sent to the reformer from these various units is that portion that is heavier than the light naphtha which is either sent to the isomerization unit or blended directly to gasoline. This reformate feed naphtha contains the six, seven, eight and usually the nine carbon compounds from these various sources. In some cases, the six carbon compounds are separated from the rest of the reformate feedstock to reduce the benzene in the final reformate. As discussed above, this rerouted six carbon stream is either blended directly into gasoline or is sent to the isomerization unit for further benzene control. The volume of the feed to the reformer is estimated on a PADD basis and is based on fractions of the material processed in the atmospheric crude tower, hydrocracker and coker.

The fraction of crude oil that is fed to the reformer ranges from about 13 to 16 percent depending on the PADD. About 18 percent of the material processed in the coker unit is estimated to end up as feedstock to the reformer. Of the feed processed in the hydrocracker, a range of 30 to 50 percent is estimated to end up as feed to the reformer unit, depending on the PADD. The variance in the fraction of hydrocracker material sent to the reformer is due to the significant flexibility that the hydrocracker has for producing either gasoline or diesel fuel. In certain PADDs, such as PADD 4 and 5, there is a higher relative demand for diesel fuel compared to gasoline so there is a lower conversion to naphtha than in other PADDs. The product from the reformer experiences a volume decrease of about 18 percent relative to the volume of feed due to the conversion of straight chain and cyclical hydrocarbons to energy dense aromatics and other light products. This volume shrinkage and conversion to lighter products increases with the severity and thus the conversion of the reformer unit. All the refineries in each PADD are assumed to be operating their reformers at the same severity as estimated by the LP refinery model. For PADDs 1 through 5, the reformer severity in 2012 falls within a range of 92 to 96 research octane number RON. [c] This range of reformer severity is projected to be lower than the reformer severity common today because of the projected increase in ethanol use and the high octane that it provides.

The FCC unit contributes a substantial volume to gasoline. We estimated the utilization of each refinery FCC unit by adjusting the nameplate capacity of each unit using the utilization factors listed in Table 9.1-4. Like a number of other gasoline producing units, only a portion of the feedstock of the FCC unit is converted to naphtha. Again, we used PADD-average estimates used in the LP refinery model for estimating the portion of the FCC feed volume converted to naphtha. The conversion percentage to naphtha is affected by the conversion severity of the individual unit. The PADD-average conversion severity is estimated to be fairly consistent across the PADDs, so the portion of FCC feedstock converted to naphtha is quite consistent at about 55 to 57 percent.

Some gasoline blendstocks are purchased and blended into gasoline. The typically purchased gasoline blendstocks include natural gasoline, alkylate, isooctene and ethanol. We did not have information on the volume of these gasoline blendstocks purchased and blended into gasoline by each refinery, so we again relied on the information from EIA, which reports the consumption of these blendstocks on a PADD basis, and our contractor who estimated the volume of isooctene which will be available from the conversion of MTBE plants. Based on the work we conducted for the Renewable Fuels Proposed rule, we provided to our contractor the volume of ethanol projected to be used in each PADD. We assumed that each refinery in the PADD purchased a portion of the total amount of gasoline blendstocks purchased in that PADD in proportion to that refinery's crude oil consumption within the PADD.

Another impact on gasoline volume is the volume of aromatics extracted from gasoline. Refiners extract aromatics to comply with the RFG toxics standards and also to take advantage of the higher price of aromatics, such as xylene and benzene, earns over the price of gasoline. The volume of aromatics, including benzene, extracted from gasoline was initially based on the nameplate capacity of each refinery's extraction unit listed in the Oil and Gas Journal. Unlike other refinery units, the extraction unit capacity is based on the volume of aromatics produced instead of the unit's feed volume. This production volume is estimated based on the unit capacity and aromatics plant utilization estimated by the LP refinery model as summarized in Table 9.1-4. This strategy was effective for the few refineries in PADD 2 with extraction units because it resulted in estimated gasoline benzene levels which closely matched the actual benzene levels for those refineries. However, this method was ineffective at matching the level of benzene for individual refineries in PADDs 1 and 3. One reason why the calibration method did not work so well for the extraction units in PADDs 1 and 3 is because a number of the refiners there are likely purchasing reformate for other refineries and processing them in their extraction units. For those PADDs, the degree to which their extraction units were being utilized was based solely on the need to calibrate each refinery's benzene levels to match year 2003

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[c] The severity of reformers is measured by the research octane number (RON) of its product. RON together with motor octane number (MON) makes up the total octane ((R+M)/2) of any gasoline blendstock or the gasoline pool.

benzene levels. Each extraction unit had sufficient capacity to supply the needed extraction estimated, and when averaged across each PADD, this method did match the LP refinery model's estimated PADD utilization for extractions units reasonably well.

A series of inputs are made to the refinery-by-refinery cost model which are necessary to estimate the cost for certain aspects of the cost modeling. These inputs are from the LP refinery model and EIA.

As stated above, hydrogen is necessary to saturate the benzene in the isomerization reactor when the rerouted benzene precursors are sent there. Similarly, hydrogen is consumed when benzene is saturated in benzene saturation units. It is also necessary to assign a cost for the lost hydrogen production in the reformer when the benzene precursors are rerouted around the reformer. This lost hydrogen production or additional hydrogen consumption must be made up from somewhere. A price derived from the LP refinery model is assigned for the lost hydrogen production and/or that consumed for saturating benzene. The LP refinery estimates the cost for building new hydrogen plant capacity to provide more hydrogen. The cost for this hydrogen varies somewhat by the region of the country because the typical size of hydrogen plant usually built in each region varies, which affects the economies of scale for the installed capital. Hydrogen costs also tend to vary because the feedstocks to hydrogen plants, which is usually natural gas, also varies by region. To incorporate this variance in regional hydrogen costs, the hydrogen costs are estimated, and entered into the refinery-by-refinery cost model, by PADD. These hydrogen prices may be conservative as they do not consider the economies of scale of producing hydrogen from very large third party hydrogen producers. Conversely, these hydrogen costs may be optimistic as they were based on EIA energy price projections that are lower than today's energy prices; for example, crude oil prices are assumed to be $47 dollar per barrel.[15]

Another input made to the refinery model is a cost factor used for estimating the cost of lost octane. When benzene precursors are routed around the reformer, when benzene is saturated in a benzene saturation unit, or when benzene is extracted from gasoline, the octane of the resulting gasoline is reduced. Similarly, when the rerouted benzene precursors are sent to the isomerization unit, the natural benzene from crude oil which is in that stream is saturated and the high octane of the benzene is lost. However, this resulting low octane stream is then treated in the isomerization unit which offsets some of the lost octane. For all these cases, the cost for the net octane loss is accounted for by assigning an octane-barrel cost to the octane change. The octane-barrel cost is from the LP refinery model which, like for hydrogen, estimates a cost for making up lost octane. There is a regional variance in the type of octane producing units, in the economies of scale for designing and constructing these units and in prices for purchased high octane blendstocks which results in differences in the cost for making up octane loss by PADD. To account for the regional variance in octane costs, octane barrel costs are estimated, and entered into the refinery-by-refinery cost model, by PADD.

Gasoline prices are also a necessary input into the refinery-by-refinery cost model to account for the effects by these various benzene control technologies on changes in gasoline volume. Extracting benzene from gasoline and selling the benzene into the chemicals market will result in a small reduction in gasoline produced by the refineries estimated to use this technology. When the benzene precursors are routed around the reformer, the reduction in feedstock to the reformer will increase gasoline supply. This is because the cracking and aromatization reactions which occur in the reformer reduce the hydrocarbon volume. To account for the full cost of benzene control, it is necessary to account for the change in gasoline volume. This loss in gasoline volume supply is accounted for by multiplying the change in gasoline volume with the gasoline prices from EIA on a PADD basis.[16]

The various assumptions associated with estimating gasoline blendstocks and the volumes of purchased and sold blendstocks and cost factors in 2012 are summarized in Table 9.1-5.

Table 9.1-5. Information used with the Refinery-by-Refinery Cost Model (Projected Year 2012 Operating Conditions and Year 2004 dollars)

		PADD 1	**PADD 2**	**PADD 3**	**PADDs 4, 5**
Hydrogen Cost ($/foeb)		121	108	82	93
Octane Cost ($/oct-bbl)		0.28	0.20	0.30	0.27
RVP Cost ($/rvp-bbl)		0.36	0.26	0.25	0.28
Gasoline Price ($/bbl)		54	55	52	51
Light Straight Run Naphtha (% of Crude Oil)		4.5	5.0	4.4	4.4
Medium and Heavy Straight Run Naphtha (% of Crude Oil)		13.8	16.2	14.0	13.6
Reformate Severity (RON)		94.7	92.1	96.2	96.2
Average Reformate Yield (vol%)		82	83	82	81
Light Coker Naphtha (% of Unit Feed)		5	5	5	5
Medium and Heavy Coker Naphtha (% of Unit Feed)		18.4	18.4	18.4	18.4
Light Hydrocrackate (% of Unit Feed)		28.7	32.0	23.3	27.2
Medium and Heavy Hydrocrackate (% of Unit Feed)		35.4	43.4	50.2	33.3
FCC Naphtha (% of Feed)		56.6	56.9	54.9	56.4
Aromatics (% of Unit Capacity)		As necessary	0.62	As necessary	-
Inputs	Isooctene Purchased (Kbbl/d)	20	0	0	0
	Alkylate Purchased (Kbbl/d)	0	0	0	0
	Natural Gasoline (Kbbl/d)	0	48	117	35
	Ethanol (Kbbl/d)	73	203	150	59
Outputs	Naphtha to Petrochem. (Kbbl/d)	2	0	134	1
	Gasoline Blendstocks Kbbl/d)	0	0	0	8

Utility costs are also an input into the refinery-by-refinery cost model. The benzene reduction technologies consume natural gas, electricity and steam which contribute to the total cost of using these technologies. The consumption of the utilities is converted to per-gallon costs using average cost factors for the individual utilities. The utility costs are from EIA, although for the case of steam are calculated based on fuel oil costs, and are represented on a PADD basis.

Another input into the cost model is a cost factor used for adjusting the installed capital costs depending on the PADD in which the capital is being installed. Installing capital in refineries has been shown to vary geographically depending on the region in which the refinery is located. This difference in cost is primarily due to differences in contractor costs used for installing the costs in each region. Installing capital is cheapest in PADD 3 (Gulf Coast), and most expensive in PADDs 4 and 5 with capital costs 40 percent higher than in PADD 3.

Table 9.1-6 summarizes the various cost factors used in the refinery-by-refinery cost model by PADD.

Table 9.3-1. 2012 Cost Factors by PADD (2004 dollars)

	PADD 1	PADD 2	PADD 3	PADDs 4 & 5
Natural Gas $/foeb	48.3	43.0	32.9	37.0
Electricity $/kw-hr	0.069	0.044	0.056	0.057
Steam $/lb	0.010	0.0091	0.0070	0.0079
Capital Cost Adjustment Factors	1.25	1.15	1.00	1.40

9.1.4.2 Refinery Blendstock Benzene Levels

It is necessary to estimate the benzene levels of individual gasoline blendstocks to model the benzene levels of gasoline today and for estimating the benzene levels attainable by additions of benzene control technology. The benzene levels of individual gasoline blendstocks for each refinery were also not available so they were they were estimated using the average benzene levels in the LP refinery model. The benzene level of reformate was estimated using average reformate benzene levels adjusted for the PADD-average severity and also adjusted by the benzene characteristics of the type of reformer. As the severity of the reformer increases, it produces a greater concentration of benzene in reformate. The Oil and Gas Journal contains information on the type of reformer for each refinery in the U.S. The types of reformers are semi-regenerative (semi-regen) reformers, cyclical reformers, and continuous reformers. Semi-regen reformers operate the highest pressure of the three and as a result this type of reformer tends to crack more of the higher molecular weight aromatics to benzene, resulting in a higher benzene level in reformate. The second type of reformer is the cyclical reformer which operates at a lower pressure than semi-regen reformers, and therefore causes less cracking of heavier aromatic compounds to benzene. Continuous reformers are the lowest pressure reformers and as a result cause relatively little cracking of heavier aromatic compounds to benzene. The benzene level of heavy reformate varies based on presence of the heaviest portion of straight run naphtha, which are the nine carbon compounds. Depending on the refinery, the nine carbon hydrocarbons in straight run is either sent to the reformer, or is blended into jet fuel or diesel fuel. The inclusion of the nine carbon hydrocarbons in reformer feed depends on the gasoline volume calibration as described below. The inclusion of the nine carbon hydrocarbons in the feed to the reformer tends to lower the concentration of benzene in the heavy part of reformate. The assigned benzene content of gasoline blendstocks, including reformate, is summarized in Table 9.1-7.

Table 9.1-7. Estimated Benzene Content of Gasoline Blendstocks

	PADDs 1 – 5 including CA
Light Straight Run	1.10
Light Coker Naphtha	2.0
Light Naphtha (rerouted benzene precursors)	8.10
Natural Gasoline	1.30
Hydrocrackate	2.40
Alkylate	0.05
FCC Naphtha	0.80
Isomerate	0.20
Ethanol	0.05
Light Reformate (no benzene precursor rerouting)	9.8
Light Reformate (with complete benzene precursor rerouting)	0.90
Light Reformate (with benzene extraction)	0.58
Light Reformate (with benzene saturation)	0.39
Heavy Reformate – Semi-Regen (High Press.)	1.7-2.2
Cyclical (Medium Press.)	1.6-2.0
Continuous (Low Press.)	0.78-1.1
Heavy Reformate – High Press.	0.09 - 0.11
(with benzene Medium Press.	0.08 – 0.10
Extraction) Low Press.	0.040 – 0.050
Heavy Reformate – High Press.	0.07-0.09
(with benzene Medium Press.	0.06-0.08
Saturation) Low Press	0.03-0.04

9.1.4.3 Calibration of the Refinery-by-Refinery Cost Model

The gasoline volume and benzene levels in the refinery-by-refinery cost model were calibrated against actual gasoline volume and benzene levels.[17] Refiners report their conventional and reformulated gasoline volumes and benzene levels to EPA to comply with the reporting provisions of the Reformulated Gasoline program. The 2004 gasoline quality was used for calibrating the refinery model, which is consistent with the baseyear of the refinery-by-refinery cost model. However, we could not begin to estimate how the various gasoline blendstocks were used to blend up RFG and CG for those refineries which produce both, so we aggregated them together for each refinery and calibrated both the gasoline volume and benzene levels for each refinery's entire gasoline pool. Also, since most of the information used to develop the refinery-by-refinery cost model was from summertime refinery modeling runs from the LP refinery model, summertime gasoline volumes and benzene levels were used to calibrate the refinery-by-refinery cost model.

Two different adjustments were used to calibrate the gasoline volumes in the refinery-by-refinery cost model. The first adjustment increased or decreased the utilization of each gasoline producing unit to adjust the gasoline volume higher or lower, respectively. The second adjustment factor is applied when the gasoline volume is too high and it is used to reduce the amount of nine carbon straight run naphtha processed by the reformer. The default in the refinery model is that the nine carbon straight run naphtha is being sent to the reformer unit. Therefore, if the initial gasoline volume in the refinery-by-refinery cost model is higher than actual, adjustment factors are applied to decrease the utilization of each gasoline-producing unit and reduce the volume of nine carbon feedstock sent to the reformer unit, thus adjusting each refinery's estimated volume in the refinery-by-refinery cost model to equal the actual gasoline volume.

To show the effects of these volumetric calibrations on the PADD volumes, the calibrated crude oil consumption feed and the gasoline production volumes for each PADD are summarized in Table 9.1-8.

Table 9.1-8. Calibrated 2004 and Projected 2012 Consumption and Production Volumes for Crude Oil and Gasoline by PADD (kbbl/day)

	Year	**PADD 1**	**PADD 2**	**PADD 3**	**PADDs 4, 5**
Crude Oil Consumed (Kbbl/d)	2004	1590	3297	7537	1433
	2012	1574	3403	7789	1589
Gasoline Produced (Kbbl/d)	2004	841	1872	3741	652
	2012	879	2081	4148	718

The initial summertime benzene level of each refinery's gasoline estimated with the refinery-by-refinery model was also calibrated against the reported annual average benzene content of gasoline in 2004 from the RFG database. Unlike the straightforward adjustment used for calibrating gasoline volume, adjusting each refinery's benzene level required one or more of a series of different methods depending on the level of adjustment needed, the direction of the adjustment and the processing units in each refinery. If the benzene level for a refinery in the refinery-by-refinery cost model is higher than actual, and that refinery did not have a benzene extraction nor a benzene saturation unit, then an adjustment was made to bypass benzene precursors around the reformer. This is a likely strategy being employed today at refineries producing RFG. However, we are aware that some conventional gasoline-producing refineries are also using benzene precursor rerouting to comply with MSAT1. We therefore utilized this strategy to calibrate the benzene levels for refineries producing either RFG or conventional gasoline. If routing all the benzene precursors around the reformer did not lower the refinery benzene level sufficiently to match the actual benzene level, then an additional step was taken depending on the refinery. Refineries with isomerization units are assumed to route the rerouted benzene precursor stream to that unit to the extent necessary to reduce the benzene down to the actual level. The benzene levels of refineries without isomerization units are adjusted lower by applying an adjustment factor to straight run and FCC naphtha benzene levels, thus lowering the benzene content of each of these streams until the actual benzene level is achieved. If a refinery had a benzene saturation or extraction unit and its benzene level is too high, the straight run and FCC naphtha levels were adjusted lower until the actual benzene level is achieved.

If a refinery's initial benzene level in the refinery-by-refinery model is too low when compared to its 2004 actual benzene level, two different adjustments were made depending on the refinery's configuration. For a refinery without a benzene saturation unit or a benzene extraction unit, its benzene level is adjusted higher by adjusting the straight run and FCC naphtha benzene levels higher until the refinery's gasoline benzene level matched its actual benzene level. For a refinery with a benzene saturation unit or a benzene extraction unit, its gasoline benzene level is adjusted higher by reducing the utilization of its benzene saturation or its extraction unit until its refinery gasoline benzene level matched its actual benzene level.

In Table 9.1-9, the refinery-by-refinery 2004 PADD-average benzene levels are compared to the actual PADD-average benzene levels for 2004. We also show the projected PADD-average benzene levels for 2012.

Table 9.1-9 Refinery-by-Refinery Model 2004 Calibrated and 2012 Projected Benzene Levels by PADD versus 2004 PADD-actual Benzene Levels (vol%)

	Year	**PADD 1**	**PADD 2**	**PADD 3**	**PADDs 4, 5**
Actual Benzene Levels	2004	0.67	1.26	0.85	1.68
Refinery-by-Refinery Benzene Levels	2004	0.68	1.23	0.84	1.58
	2012	0.66	1.10	0.85	1.44

9.2 Cost Inputs for the Benzene Control Technologies

To estimate the cost of reducing refinery benzene levels, it was necessary to identify the cost inputs of the identified benzene control technologies. This information was obtained from vendors of these benzene control technologies or from the literature. This information was updated from the proposed rule reflecting the detailed analysis we conducted to update the capital costs. Information is presented for routing benzene precursors around the reformer, routing that rerouted benzene precursor stream to an isomerization unit, and installing either of two reformer post-treat technologies, which are benzene saturation and benzene extraction.

9.2.1 Benzene Precursor Rerouting

Routing benzene precursors around the reformer requires that a refinery add a naphtha splitter distillation column, or modify an existing column, to make a distillation separation between the six carbon and seven carbon hydrocarbons. As discussed in the RIA Section 6.2 above presenting our assessment of the feasibility of complying with this rulemaking, in a refinery where most of the benzene precursors are not currently being routed around the reformer, the naphtha splitter would need to be added or modified to be able to make a fairly clean cut between the six and seven carbon molecules. Making this cut efficiently is important in separating as much of the six carbon compounds (which include benzene) from the rest of the heavy straight run naphtha as possible, so that the seven carbon and heavier straight run hydrocarbons can continue to be sent to the reformer. A new unit would require the addition of a new naphtha splitter distillation column. Modifying the naphtha splitter distillation column involves increasing the height of the existing column and adding additional distillation trays or replacing the distillation tower with a taller unit. The naphtha splitter modification would also mean that the utility demands of that unit would increase. Conversely, the utility demands of the reformer decreases as the six carbon compounds are withdrawn from that unit. The estimated capital cost and increased utility costs for adding a naphtha splitter to facilitate routing benzene precursors around the reformer is summarized in Table 9.2-1.[18] We also summarized the utility demands of the reformer in Table 9.2-2 because this information is used to calculate the reduced utility demands when the benzene precursors are withdrawn from that unit.[19]

Table 9.2-1. Cost Inputs for Rerouting Benzene Precursors (2004 dollars)

Capital Costs – onsite and offsite ($MM)	9.6
Capital Cost Unit Size (bbl/day feedstock)	15,000
Catalyst ($/bbl)	0.01
Natural Gas (foeb/bbl)	0.010
Electricity (kwh/bbl)	2.80

Table 9.2-2. Cost Inputs and Light Gas Outputs for the Reformer (Severity 95 RON 2004 dollars)

Catalyst Cost ($/bbl)	0.354
Fuel Gas (foeb/bbl)	0.044
Electricity (kwh/bbl)	2.6
Steam (lb/bbl)	75
Hydrogen (foeb/bbl feed)	0.036
Plant Gas (foeb/bbl feed)	0.029
Propane (bbl/bbl feed)	0.036
Isobutane (bbl/bbl feed)	0.017
Butane (bbl/bbl feed)	0.028

9.2.2 Isomerizing Rerouted Benzene Precursors

Sending the rerouted benzene precursors to an existing isomerization unit is another technology identified for further reducing gasoline benzene levels. The rerouted benzene precursor stream contains naturally occurring benzene from crude oil. The isomerization unit saturates the benzene in this stream, causing a further reduction in gasoline benzene levels. The saturation occurs in the isomerization reactor which is designed to convert straight chain compounds to branched chain compounds. So while the isomerization unit reduces the octane of this stream by saturating benzene, it also offsets some of the octane loss by producing branched chain compounds from the saturated benzene. The isomerized six carbon stream is estimated to have an octane value of 77.4 (R+M)/2, compared to a similar octane value for the rerouted benzene precursor stream before it. Many refineries have isomerization units today and for this analysis, refiners are assumed to only rely on these existing units at their present capacity for benzene reductions and not build a new isomerization unit nor increase an existing unit's capacity.[d] In this analysis the rerouted benzene precursors are sent to the isomerization unit which has been treating five carbon hydrocarbons. If the isomerization unit does not have sufficient capacity to treat the volume of both the five and six carbon hydrocarbons, the preference is given to benzene reduction and treating the six carbon hydrocarbons, and the five carbon hydrocarbons are removed as necessary to make room for the six carbon hydrocarbons.

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[d] Isomerizing straight run naphtha increases its vapor pressure. Many refiners today are vapor pressure limited and face having to substantially cut its gasoline production volume if its gasoline were to increase in vapor pressure. Since we do not know which refineries are in this situation, we assume that additional isomerization capacity beyond that already present in the refinery would not be tolerated.

Therefore, for some refineries the increased utility costs for treating the rerouted benzene precursors is based on the capacity of the isomerization unit instead of the total volume of five and six carbons hydrocarbons fed to the unit, since some of the five carbon hydrocarbons are backed out of the unit. Table 9.2-3 shows cost figures used in modeling isomerization of rerouted benzene precursors.[20]

Table 9.2-3. Cost Inputs for Sending the Rerouted Benzene Precursors to an Isomerization Unit (2004 dollars)

Catalyst ($/bbl)	0.25
Hydrogen (foeb/bbl)	0.002
Natural Gas (foeb/bbl)	0.009
Plant Gas (bbl/bbl)	-0.024
Electricity (kwh/bbl)	0.90
Steam (lb/bbl)	50

9.2.3 Benzene Saturation

Benzene saturation is another technology which reduces the benzene content of gasoline. The advantage that benzene saturation has for benzene reduction is that it treats the naturally occurring benzene as well as the benzene formed in the reformer. The benzene formed in the reformer includes the benzene formed from the cracking of heavy aromatics to benzene as well as that formed by the conversion of six carbon hydrocarbons. The benzene saturation technology involves the addition of a distillation column called a reformate splitter and then the benzene-rich stream is sent to a benzene saturation unit.

The distillation column creates a benzene rich stream which prevents other aromatics, such as toluene, from being sent to the benzene saturation unit. Keeping the toluene and xylenes out of the benzene saturation unit preserves the octane level of the seven carbon and heavier reformate. Based on information we received from vendors who are experts on benzene saturation technology, the reformate splitter is typically optimized to capture 96% of the benzene, while only capturing 1% of the toluene. We programmed our refinery-by-refinery cost model so that the reformate splitter captures benzene and toluene consistent with this information. For those refineries estimated to be currently routing some or all of the benzene precursors around the reformer, for modeling the cost of benzene saturation, those benzene precursors are sent to the reformer before the costs of applying benzene saturation are estimated.

The benzene-rich stream is sent to the benzene saturation unit. In the benzene saturation reactor, hydrogen is reacted with benzene which converts the benzene to cyclohexane. There are two benzene saturation technologies. One is called Bensat and is licensed by UOP. This technology maintains the reformate splitter and benzene saturation units as separate discrete units. The other benzene saturation technology is licensed by CDTech and is called CDHydro. The CDHydro technology combines the distillation column and benzene saturation reactor together into a single unit. The advantage of this approach is that it eliminates the need for the second unit, potentially lowering the capital costs. A review of the capital cost inputs of the two benzene saturation technologies shows much lower capital costs. When we considered the difference in capital costs, the CDHydro capital costs seemed much lower than expected considering the efficiency provided by the combined units. For this reason, we assigned the CDHydro unit the same capital costs as the conventional benzene saturation unit. For both benzene saturation technologies, the capital costs are scaled using a 0.65 scaling factor which increases the per-barrel capital costs for smaller extraction units than the standard size, and decreases the per-barrel capital costs for larger extraction units than the standard size. The capital and utility costs and scaling factor used for both Bensat and CDHydro are summarized in Table 9.2-4.[21] [22] [23]

Table 9.2-4. Cost Inputs for Benzene Saturation (2004 dollars)

Inputs	Bensat	CDHydro
Capital Cost – onsite and offsite ($MM)	20.9	20.9
Capital Cost Unit Size (bbl/day feedstock)	8,400	8,400
Capital Cost Scaling Factor	0.65	0.65
Hydrogen (foeb/bbl)	0.046	0.046
Natural Gas (foeb/bbl)	-	0.016
Electricity (kwh/bbl)	2.5	0.80
Steam (lb/bbl)	197	-

As discussed below in the summary of costs, benzene saturation is the highest cost benzene control technology modeled for this final rulemaking. The primary reason for this is that after processing the straight run naphtha in the reformer to create the benzene for blending into gasoline as high octane blendstock, this process converts it back to a low octane blendstock. The process is desirable from the standpoint that it achieves deeper benzene reductions and its cost is acceptable for larger refineries that can take advantage of their better economies of scale.

9.2.4 Benzene Extraction

Benzene extraction is the final benzene reduction technology used in our cost analysis for estimating benzene control costs. Benzene extraction physically and chemically separates benzene from the rest of the hydrocarbons, and then concentrates the benzene into a form suitable for sale into the chemicals market. Since this process results in a benzene product stream which must be transported to a buyer, a refiner is unlikely to choose this technology unless there is economical access to a benzene market.

The first step involved in benzene extraction is the separation of a benzene rich stream from the rest of the reformate using a reformate splitter. To maximize the removal of benzene with this technology, any benzene precursor rerouting that is occurring in the basecase is eliminated prior to costing out this technology, allowing the removal of naturally occurring benzene. Not only does this further reduce the benzene in the final gasoline, it improves the cost effectiveness of benzene extraction by improving the economies of scale for the benzene extraction unit. The benzene-rich stream off the reformate splitter is sent to an extraction unit which separates the aromatic compounds from other hydrocarbons contained in the benzene-rich stream using a chemical extraction agent. While the intent is to have benzene as the only aromatic in the benzene-rich stream, in reality some toluene is also contained in that stream as well. For this reason, a very precise distillation step is conducted concurrently on the product that produces a pure chemical grade benzene product. The desire would be to send only benzene and no toluene to the benzene extraction unit, however, this would require an unreasonably large and expensive reformate splitter. Thus, we used the same assumption used for benzene saturation, which is that 96% of the benzene and 1% of the toluene is captured by the reformate splitter. The concentration process of benzene for the petrochemicals market also assumes the use of a clay treater.

The total capital costs for benzene extraction include the capital costs for the installation of a reformate splitter, a benzene extraction unit and the associated distillation hardware which concentrates the benzene, including a clay treater. The capital costs for the benzene extraction unit assumes that the extraction and distillation step occur in one step, which is called extractive distillation. For new benzene extraction units, additional capital costs are incurred for the installation of benzene storage and loading equipment. The capital costs for new extraction units are scaled exponentially using a 0.65 scaling factor. The capital costs for revamped extraction units are not scaled which provides the same per-barrel capital costs regardless of the size of the expansion.[e] Utility costs are incurred for operating the benzene extraction units. Table 9.2-5 contains the capital and utility cost inputs to the refinery-by-refinery cost model for benzene extraction.[24]

Table 9.2-5. Cost Inputs for Benzene Extraction (2004 dollars)

Capital Costs – onsite and offsite ($MM)	65.9
Capital Cost Unit Size* (bbl/day product)	1800
Capital Cost Scaling Factor	0.65
Catalyst ($/bbl)	0.354
Natural Gas (foeb/bbl)	0
Electricity (kwh/bbl)	9.4
Steam (lb/bbl)	1271

* Capital Cost is based on the volume of benzene produced.

A refiner with an extraction unit in one of their refineries has informed us that they frequently extract the benzene from benzene-rich reformate streams provided by other U.S. refineries as well as streams from abroad. This helps offset the high capital costs associated with these units. Because of the high capital costs, other refiners are hesitant to install an extraction unit, but have sufficient octane production capacity to sell benzene-rich reformate to a neighboring refinery which does extract benzene. For our year 2004 basecase analysis, we have deduced that several refineries without an extraction unit or a benzene saturation unit, but with already very low benzene levels (which cannot be easily explained on other bases), are selling benzene-rich reformate to a neighboring refinery with an extraction unit. For modeling the cost of additional benzene control, we also assume that refineries which already have an extraction

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[e] Typically, the capital costs for revamping an existing refinery unit are not scaled. They are not scaled because small expansions to existing refinery units require the redesign of only a part of an existing refinery unit to realize the usually small increase in production capacity. This is in contrast to very small grassroots units of the same volume as the expansion which requires the design and construction of every piece of equipment involved in the unit being designed. Thus the small grassroots unit needs to be scaled to capture the higher capital costs while the capital costs of revamps are estimated consistent with the per-barrel costs of a full sized unit.

unit would process the benzene rich reformate of other refineries to comply with the benzene program.

9.3 Benzene Market and Prices

Benzene which is generated by benzene extraction and sold into the chemicals market is an important output from the refinery-by-refinery cost model. The economics for benzene extraction are partially dependent on the revenue earned through the sale of chemical grade benzene. To understand the production and demand for benzene and the projected price of benzene, we purchased Chemical Market Associates Incorporated (CMAI) 2004 report entitled the World Benzene Analysis.[25] The CMAI report lists the benzene producers and consumers worldwide and analyzes the economics of benzene production.

Benzene is produced to sell into the chemicals market by 8 different types of benzene production processes. These include extraction from reformers and pyrolysis gasoline at refineries and petrochemical plants, selective toluene disproportionation, paraxylene coproduction, toluene hydrodealkylation and extraction from coke oven naphtha. Except for the production of benzene from coke ovens, the rest of the benzene is sourced from crude oil. The World and U.S. production volumes of benzene for 2002, the most recent year that complete information is available from the CMAI report, are summarized in Table 9.3-1.

Table 9.3-1. 2002 Benzene Supply by Source for U.S. and the World (thousand metric tons)

	Reformate	Pygas	Toluene Disprop.	Selective Toluene Disprop.	Paraxylene Coprod.	Toluene Hydrodealk	Coke Oven	Toluene Transalk.	Imports	Total
U.S.	3,527	2,086	149	810	529	317	163	0	929	8510
World	13,213	12,699	353	1171	1458	2202	1266	980	-	33,342

The benzene production figures show that extraction from reformate is currently a primary source of benzene in the U.S. and the rest of the world. This suggests that if refiners extract benzene from reformate, they will be able to and sell the concentrated benzene into the chemicals market. We considered this information below when we estimated the impact on benzene price when additional benzene is extracted from gasoline.

The chief uses for benzene are to use it as a feedstock to produce ethylbenzene, cumene, nitrobenzene, and cyclohexane. Ethylbenzene is used to produce styrene which is a precursor for producing polystyrene. Cumene is used to produce phenol and acetone. Benzene is also reacted to nitrobenzene which is an intermediate in the chain of reactions used for producing urethane. The World and U.S. consumption volumes of benzene by demand market for 2002 from the CMAI report are summarized in Table 9.3-2.

Table 9.3-2. 2002 Benzene Demand by Target Chemical for U.S. and the World (thousand metric tons)

	Ethyl-Benzene	Cumene	Nitrobenzene	Cyclohexane	Chloro-Benzene	Alkylbenzene	Maleic Anhyd.	Exports	Total
U.S.	4050	2291	752	964	131	144	0	27	8450
World	18,201	5872	2200	4257	585	1144	583	-	33,487

Additional information which is useful to consider when projecting the price of benzene is the historical benzene price. Like all hydrocarbons sourced from crude oil, the price of benzene is susceptible to changes in crude oil and other energy prices which complicates the process of projecting the price of benzene. To diminish the effect that changes in energy prices have on benzene prices, we compared the price of benzene to the price of gasoline which would likely be affected in the same way by energy prices as benzene, thus reducing the effects of energy prices as a variable. Also, it is the relative price of benzene to gasoline which established the economics of extracted benzene. Since the proposal, we contacted CMAI and they provided us with more recent benzene and gasoline price information than that contained in their 2004 report.[26] The U.S. historical prices for benzene, gasoline and the difference between them for the nine years prior to 2005 are summarized in Table 9.3-3.

Table 9.3-3. Historical U.S. Benzene Price

Year	Benzene Price ($/bbl)	Gasoline Price ($/bbl)	Benzene Price above Gasoline Price ($/bbl)
1996	40.95	25.02	15.93
1997	42.00	24.60	17.40
1998	33.78	17.39	16.38
1999	36.36	21.79	14.57
2000	57.75	34.99	22.76
2001	42.71	30.83	11.89
2002	49.98	30.28	19.70
2003	64.68	36.67	28.01
2004	120.94	49.16	71.78
2005	121.75	67.47	54.71

The price of benzene dropped in 2001 both absolutely and relative to the price of gasoline. This decrease in price is attributed to a decrease in demand associated with a recession experienced by the U.S. and other parts of the world. Since 2001 the price has tracked upward through 2004 consistent with increasing demand as the economies of many countries have emerged from recession. Between 2001 and 2003, benzene demand increased by about 15 percent in the U.S., and about 10 percent for the whole world. This large increase in demand has tightened up the benzene market thus resulting in the increasing benzene price since 2001. This demand increase continued in 2004 with a sharp increase in benzene price relative to gasoline prices. Benzene prices remained about the same in 2005, but gasoline prices increased therefore decreasing benzene's relative price compared to gasoline's price.

CMAI used its economic model to project the benzene market in the medium term during the future years from 2006 through 2015. CMAI starts by establishing a basecase which was based on the information on the benzene market in 2005. CMAI then projects the benzene market based on anticipated supply, demand and energy prices. The benzene supply which CMAI considers in its cost model includes existing benzene production capacity and announced and planned new benzene plant construction. The future benzene demand is estimated based on historical demand, the projected U.S. and world economic conditions, and on the anticipated changes in the chemical markets which use benzene as a feedstock. After conducting its benzene market review, CMAI made a series of conclusions. In its 2004 report, CMAI projected that World benzene and U.S. benzene demand would increase annually at a very robust rate of 3.8 and 2.4 volume percent, respectively. Imports which satisfied just more than 10 percent of U.S. demand in 2003, is expected to be flat and even decline in the out years. CMAI explains that the robust world benzene demand coupled with new benzene production, which is expected to be slow coming on line, will result in continued high benzene prices in 2007. As additional benzene production capacity comes on line, benzene prices are expected to come down to more moderate levels. The projected energy prices which CMAI uses in its economic model are nearly identical with those used by EIA, thus making the two analyses consistent in this regard. Table 9.3-4 summarizes the projected benzene and gasoline prices obtained from CMAI's 2005 benzene market projections through 2015. For 2011 through 2015, CMAI provided their projected benzene prices, but not the gasoline prices. We projected the gasoline prices for 2011 through 2015 using the crude oil prices provided by CMAI using the relationship of crude oil prices to gasoline prices from the previous years.

Table 9.3-4. Projected U.S. Benzene/Gasoline Price Differential

Year	Crude Oil Price ($/bbl)	Benzene Price ($/bbl)	Gasoline Price ($/bbl)	Benzene Price above Gasoline Price ($/bbl)
2007	69	128	79	50
2008	57	102	65	37
2009	52	93	59	35
2010	48	87	55	33
2011	47	85	54	32
2012	48	87	55	32
2013	50	88	56	32
2014	51	90	58	33
2015	52	93	60	34

The CMAI model estimates that the price of benzene in 2007 will be $50 higher than gasoline assuming that crude oil prices will stay high through 2007. CMAI projects that the price of crude oil will decline after 2007. As the projected crude oil price declines, both gasoline and benzene prices are also expected to decline resulting in benzene's price above gasoline to decrease to about $32 per barrel above the price of gasoline. CMAI's projected crude oil price is

$48 per barrel in 2012, which is consistent with the crude oil price assumed for our refinery modeling.

There may be a concern that the additional benzene that would be extracted from gasoline and sold into the chemical benzene market in response to this rulemaking could depress the benzene price below that projected by CMAI. To address this concern we used the projected volume of benzene extracted from gasoline by the refinery-by-refinery model to evaluate the impact of the additional benzene supply on benzene price. The refinery-by-refinery cost model projects that about 12,500 barrels per day, which is 192 million gallons per year, of benzene would be extracted from gasoline and sold to the petrochemical market under the benzene program assuming that it took effect in 2012.

Table 9.3-3 above shows that the U.S. demand for chemical grade benzene in 2002 was 8450 metric tons, which is equivalent to 2529 million gallons. Based on an annual growth rate of 2.4 percent, the U.S. demand for benzene is expected to be 3,000 million gallons in 2010 and is expected to grow to 3,130 million gallons in 2011. Thus, the increase in U.S. benzene demand from 2010 to 2011 is projected to be 130 million gallons. We expect the extraction of benzene would occur over several years due to the effect of the ABT program. Therefore, the increased production of chemical grade benzene due to extraction would be smaller than the annual growth over the several years that the program phases in and no significant impact on benzene price would be expected. Even if all of the benzene extraction capacity were to be installed in a single year resulting in all 192 million gallons of benzene coming into the benzene market in one year, the benzene production market could rebalance by the reduced processing of toluene into benzene, the highest cost process for producing benzene. The toluene would remain in the gasoline pool helping to maintain the octane and volume lost by benzene extraction. Finally, refining and petrochemical market experts who evaluated the effect of the benzene extraction expected to occur in response to the Reformulated Gasoline Program came to a similar conclusion despite the large volume of benzene extracted back then.[27] [28] While we don't expect a significant impact on benzene price, we rounded the incremental benzene price down to $30 dollars higher than gasoline. This incremental benzene price is slightly lower than CMAI's projected incremental price to account for a small decrease in benzene price caused by the increased benzene supply caused by this rulemaking.

9.4 Refinery Modeling of Benzene Control Scenarios

For modeling the benzene program, we addressed the costs and benzene impacts of the maximum average standard first. Refineries that the model estimates would be above the maximum average standard are assumed to put in the most cost-effective benzene reduction technology which the model shows would get them below the maximum average standard. Under the ABT program, the benzene control units that the model adds to meet the maximum average standard are assumed to be operated to achieve the maximum possible amount of benzene reduction. The benzene reductions associated with meeting the maximum average standard may or may not be sufficient for meeting the average standard depending on how stringent the maximum average standard is relative to the average standard. If additional benzene reduction is necessary, it is achieved in the cost model consistent with the methodology used to achieve benzene reductions under the average standard only.

If additional benzene reductions are needed after application of the maximum average standard, or if we were not modeling a maximum average standard, we modeled benzene reductions to meet the average benzene standard. The national ABT program optimizes the benzene reduction by allowing the refining industry to collectively choose the most cost-effective means of benzene reduction. In the refinery-by-refinery modeling, this is accomplished by ranking the benzene reduction technology available to each refinery and over all the refineries in order from lowest to highest in benzene reduction cost-effectiveness. Then refineries are chosen to implement benzene reduction refinery-by-refinery from the lowest to the next lowest in benzene control cost-effectiveness until the sum of the technologies and refineries chosen results in the U.S. gasoline being produced meeting the benzene program being modeled, giving credit to refineries already below the proposed benzene standard.

For the benzene control cases we modeled that do not include an ABT program, all the refineries that are below the standard are assumed to maintain their current benzene level, while the refineries with benzene levels above the standard are assumed to take the necessary steps to reduce their benzene levels down to the standard. If the model shows that capital investments need to be made to achieve the necessary benzene reduction, we assumed the installation of a full sized unit is installed to treat the entire stream being treated, but assumed further that the unit is only operated to the extent necessary to meet the applicable standard.

9.5 Evaluation of the Refinery-by-Refinery Cost Model

As described in the Overview Portion of this section, the refinery-by-refinery cost model was evaluated to assess its viability by comparing its cost output to the cost output of the LP refinery cost model. The LP refinery cost model is a good tool for comparison because it has been used for many years on many different cost studies subjecting it to extensive peer-review.

We evaluated the benzene program with the LP refinery model to estimate the energy and supply impacts of the benzene program. We specified the mix of benzene control technologies that the refinery-by-refinery cost model estimates will be used in each PADD to comply with the benzene program. We trust the refinery-by-refinery cost model’s choice of benzene control technologies because of its ability to estimate benzene control costs for each refinery and choose the best mix of benzene control technologies across the refining industry. Because we matched the benzene control technologies and final benzene levels in each PADD a close match in control costs between the two models would confirm that the refinery-by-refinery cost model is sound in its construction. Comparing the cost output of the two cost models, the LP refinery cost model produced very similar costs compared to the refinery-by-refinery cost model, which corroborates the refinery-by-refinery cost model. Table 9.5-1 summarizes the cost output and estimated benzene levels for the two refinery modeling analyses.

Table 9.5-1. Comparison of PADD and National Costs and Benzene Levels for the Benzene Program (2003 dollars, 7% ROI before taxes)

		PADD 1	PADD 2	PADD 3	PADDs 4 & 5	U.S. Average
Refinery-by-Refinery Cost Model	Cost (cents/gal)	0.15	0.34	0.16	0.91	0.27
	Bz Level (vol%)	0.52	0.63	0.61	0.78	0.62
LP Refinery Cost Model	Cost (cents/gal)	0.16	0.27	0.14	0.92	0.24
	Bz Level (vol%)	0.52	0.63	0.61	0.76	0.62

9.6 Refining Costs

This subsection summarizes the estimated costs of the benzene program as well as the other benzene standards considered for this final rulemaking. The estimated cost for the 0.62 vol% benzene standard with 1.3 maximum average standard and ABT program is summarized first, including the sensitivity cases described above. We next summarize the estimated cost for the same and higher and lower average benzene standards, with and without various maximum average standards or which models a benzene program without an ABT program. We adjust our costs from 2004 dollars back to 2003 dollars to make our costs consistent with the gas can and vehicle costs. To make this cost adjustment we used a 0.97 inflation cost factor from the Department of Labor webpage.

The capital costs estimated by the refinery-by-refinery cost model do not include the capital costs associated with hydrogen production and octane recovery. For this reason we believe that the capital costs estimated by the refinery-by-refinery cost model are low. We compared the capital cost estimate by the LP refinery cost model, which includes the hydrogen and octane capital costs, and found them to be about 20 percent higher than those estimated by the refinery-by-refinery cost model. For all the capital cost estimates for all the benzene programs evaluated by the refinery-by-refinery cost model, we adjusted them higher by 20 percent.

9.6.1 Cost of the Benzene Program

The refinery-by-refinery cost model was used to estimate the cost of the benzene program, which puts in place a 0.62 vol% average benzene standard with a 1.3 maximum average standard and an ABT program. For each of the refineries which produce gasoline, the methodology described above was applied to estimate the cost of reducing the benzene levels. The projected use of the benzene technologies in the refinery-by-refinery cost model is affected by the nature of the stringency of the benzene reduction program being modeled. The refinery-by-refinery cost model indicates that benzene precursor rerouting alone is the most cost effective benzene control technology, followed by routing the benzene precursors to an isomerization unit and extraction. Benzene saturation is the least cost-effective benzene control technology, but as the benzene control stringency is increased, for reasons of technical feasibility benzene saturation replaces benzene precursor rerouting with or without isomerization as the means for achieving benzene reductions. We assume that the ABT program would be fully utilized with credit trading occurring freely within and between refining companies.

The fully phased-in 0.62 vol% benzene standard with 1.3 maximum average standard and ABT program is estimated to cost 0.27 cents per gallon averaged over all U.S. gasoline and with capital costs amortized at 7% ROI before taxes. The total capital cost is estimated to be $1110 million; the total annual cost including amortized capital costs is $330 million/yr estimated in the year 2012.

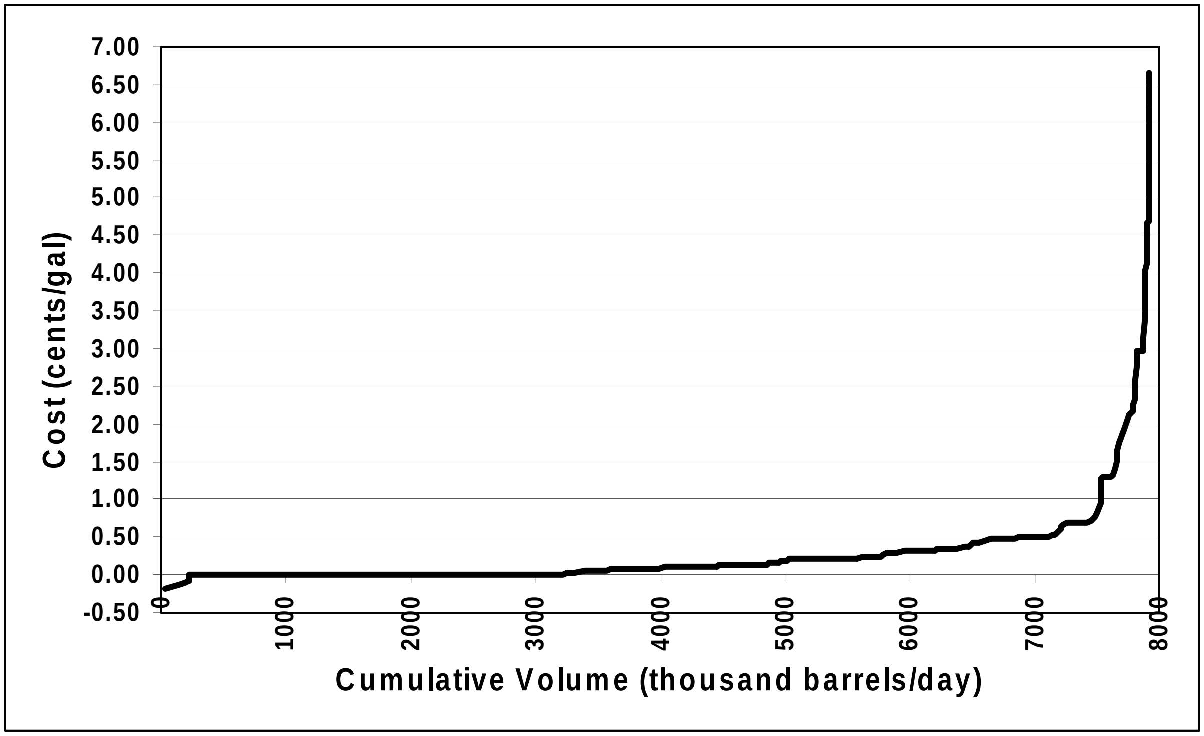
The 0.27 cents per gallon average cost is calculated by amortizing the costs over all U.S. produced gasoline including that gasoline volume with benzene levels already at or below 0.62 vol%. When the costs are averaged only over the portion of U.S gasoline which is expected to be reduced in benzene, the fully phased-in benzene program is expected to cost 0.40 cents per gallon. For those refineries which are projected to take some action to reduce their benzene levels, the average capital and total annual operating cost per refinery is $14 million and $4.2 million, respectively. These estimated costs for the benzene program are summarized in Table 9.6-1.

Table 9.6-1. Estimated Costs of the Fully Phased in Benzene Program Evaluated in 2012 (2003 dollars, 7% ROI before taxes)

All Refineries	Number of Refineries	104
	Total Capital Cost ($ million)	1110
	Total Annual Cost ($ million/year)	330
	Per-Gallon Cost (cents/gallon)	0.27
Refineries Reducing Their Gasoline Benzene Levels	Number of Refineries	79
	Capital Cost per Refinery ($ million)	14
	Operating Cost per Refinery ($ million/year)	4.2
	Per-Gallon Cost (cents/gallon)	0.40

Reporting the average per-gallon costs in the above table does not provide any indication of the range in costs that we project would occur in different refineries. The costs vary by refinery for a variety of reasons. First, some refineries experience no cost because either the gasoline produced by those refineries is already below the benzene standards, or (with respect to the 0.62 vol% average benzene standard), our modeling shows that these refineries would experience lower costs by simply purchasing credits. Another reason why refineries are projected to experience differing costs is due to the range in technologies that they would use and the extent of benzene reduction achieved by them. The final reason why these refineries are projected to experience differing costs is due to the different refinery economies of scale and cost inputs in different refining regions. Figure 9.6-1 summarizes the projected per-gallon costs by refinery plotted against the cumulative volume of gasoline produced. The figure shows that we project costs to be low for most refineries, representing most of the gasoline production in the country; a relatively few higher-cost refineries contribute significantly to the higher average cost of the program.

Figure 9.6-1. U.S. Refinery Per-Gallon Costs for the Benzene Program (2003 dollars, 7% ROI before Taxes)



To comply with the benzene program, we expect that all of the control technologies discussed above would be utilized. Of the 79 refineries expected to take steps to reduce their gasoline benzene levels, 17 are expected to route all of the benzene precursors around the reformer, and 28 are expected to send that rerouted stream to their isomerization unit. Of the refineries which take steps to lower their gasoline benzene levels by treating reformate, 16 would install a grassroots benzene extraction unit or revamp their existing extraction units while the another 18 would install benzene saturation units. We project that 52 refineries will continue to produce gasoline with benzene levels greater than the 0.62 vol% average standard and will choose to purchase credits to comply with that standard. Including the refineries with benzene levels currently below 0.62, we project that there will be a total of 50 refineries that will produce gasoline with benzene levels at 0.62 or lower and will generate credits for sale to other refineries.

Finally, based on our modeling, we project that 26 refineries will not take steps to reduce their gasoline benzene levels to comply with the 0.62 and 1.3 vol% benzene standards.

While the estimated per-gallon costs are very low, there is a range in costs depending on the area of the country (again primarily reflecting the degree of benzene reductions as well as the ability to extract and sell the extracted benzene). The estimated costs in PADDs 1 and 3 are lowest due to the expected use of extraction (with sale of the recovered benzene). The estimated benzene control costs are higher for the rest of the PADDs because extraction was not assumed to be an option due to lack of benzene markets. The average per-gallon benzene control costs for each PADD are summarized in Table 9.6-2.

Table 9.6-2. Per-Gallon Costs by PADD for the Benzene Program (cents/gal; 2003 dollars; 7% ROI before taxes)

PADD 1	PADD 2	PADD 3	PADD 4	PADD 5 except CA
0.15	0.34	0.16	0.69	1.11

In each PADD, the average costs in Table 9.6-2 represent a wide range in costs across the refineries in the PADD. However, the nature of the cost range varies in each PADD based on the factors described above. Figure 9.6-2 depicts the estimated per-gallon costs by refinery in each PADD plotted against the cumulative gasoline production.

Figure 9.6-2. U.S. Refinery Per-Gallon Costs by PADD for the Benzene Program (2003 dollars, 7% ROI before Taxes)

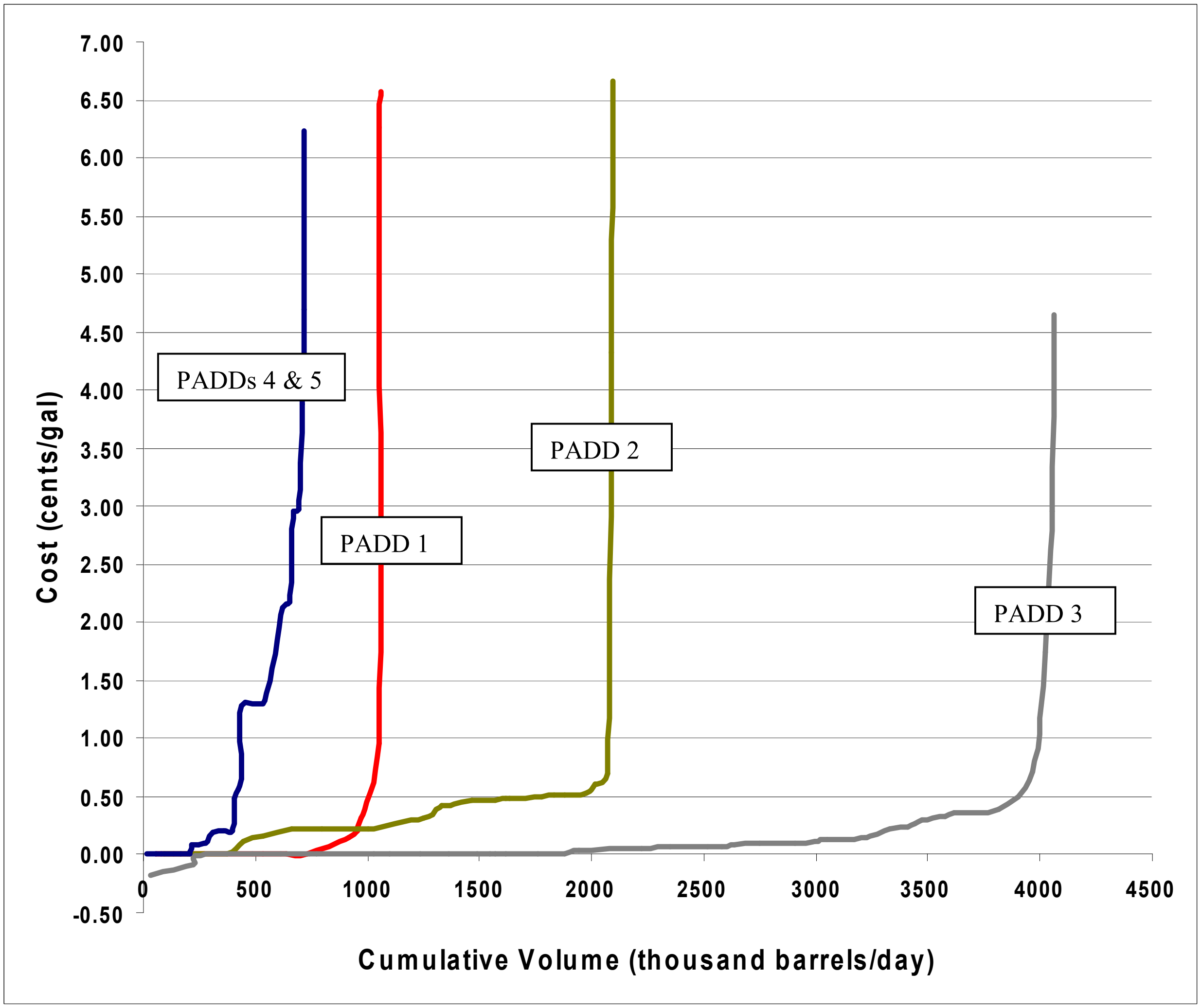


Figure 9.6-2 shows a significant range in costs by the refineries in each PADD. Costs for most refineries in PADDs 1 and 3 are similar with most costs being incurred through extraction which results in near zero (and in a few cases slightly less than zero) costs, as well as zero costs for refineries which do not need to take any action due to already low gasoline benzene levels. Most of the refineries in PADDs 4 and 5 face higher costs, and these costs are significantly higher than the costs for most refineries in the other PADDs due to the generally smaller refineries there and the inability to use extraction. The refinery costs in PADD 2 are more moderate for most of the refineries than those in PADDs 4 and 5, but still more severe than the costs for most of the refineries in PADDs 1 and 3.

In each PADD there are smaller-sized refineries which the model predicts would need to comply with the maximum average standard using benzene saturation, resulting in high per-gallon costs. The costs for these refineries are high because of their poorer economies of scale. The model does not attempt to apply other means likely to be available to these refineries for avoiding these high per-gallon costs. We believe that these refiners can avoid resorting to benzene saturation and their associated high per-gallon costs by installing a reformate splitter. The reformate splitter is a relatively low capital and operating cost unit that would allow them to remove a benzene-rich stream from the rest of their reformate, resulting in a final gasoline blend that would be in compliance with the maximum average standard. The benzene-rich stream can be sold to another refinery with gasoline benzene levels below the cap standard and so can absorb this small benzene-rich volume. This sort of trading is similar to the credit trading program, except that actual benzene is being traded instead of paper credits.[f]

The rule also includes hardship provisions, available to all refineries, to address extreme hardship situations. The model assumes full compliance without hardship relief, and so may overstate costs for this reason as well.

Our refinery modeling analysis projects that the ABT program will effectively result in a phase-in of the benzene program from 2007 through early 2015. Starting in mid-2007 we believe that using simple operational changes refiners will take the opportunity to achieve modest benzene reductions to generate early credits. We project that these actions taken in mid-2007 will result in a reduction of the average U.S. gasoline benzene level from 1.00 to 0.81 volume percent at an average cost of 0.04 cents per gallon averaged over all U.S. gasoline.

To take full advantage of the flexibility provided to refiners by the ABT program to delay more expensive capital investments, refiners are expected to make additional early benzene reductions to generate more early credits, requiring modest investments in capital. Because of the time it takes to assess, design and install the capital equipment, we believe that these additional early benzene reductions will not occur until the beginning of 2010. These benzene reductions are expected to further reduce the average benzene level of U.S. gasoline to 0.74 volume percent and cost 0.05 cents per gallon averaged over all U.S. gasoline. Refiners are expected to make $324 million of capital investments to achieve this benzene reduction. In 2011 when the 0.62 vol% average benzene standard takes effect, we do not anticipate any further reduction in benzene because we project that the refining industry will be able to comply using early credits.

In mid-2012, when refineries with high benzene levels need to comply with the 1.3 volume percent maximum average standard, we anticipate that U.S. gasoline benzene levels will decline further, to 0.73 vol% benzene and cost an additional 0.04 cents per gallon averaged over all U.S. gasoline. Refiners are expected to make another $153 million in capital investments to comply with the 1.3 vol% maximum average standard which takes effect in mid-2012. Although the early credit use period terminates at the end of 2013, refiners will be able to further delay their most expensive capital investments by using standard credits (which will have been accruing since the start of 2011).[g] Because we expect that refiners will first use their early credits, the standard credits will be banked and will start to be used in 2014 to show compliance

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[f] Uncertainties in how trading of actual benzene barrels would occur precluded our modeling the cost of this option. For example, we could not anticipate which refiners would be willing to accept this benzene-rich stream which affects its transportation costs.

[g] Early credits generated or obtained and ultimately used by small refiners may be used through 2017. However, these credits will not affect the overall implementation timeline discussed here.

with the 0.62 vol% average benzene standard. Our analysis suggests that the U.S. refining industry will be able to delay their highest capital investments until May 2015 when the standard credits accumulated since the beginning of 2011 run out. Small refiners must meet the 1.3 vol% maximum-average standard beginning of July 2016 so they also will be reducing their gasoline benzene levels to that standard or below.[h] Small refiners are expected to add an additional 0.01 cents per gallon averaged over all U.S. gasoline when reducing their gasoline benzene levels to comply with their average and cap standards, although the average U.S. gasoline benzene levels do not appear to change due to rounding. This additional benzene reduction is estimated to incur an additional $26 million in capital investments. The nonsmall refiners are projected to fully complete the transition in May 2015 bringing the average gasoline pool down to 0.62 vol% benzene, and incurring a 0.13 cents per gallon cost averaged over all U.S. gasoline and $608 million in capital investments. The estimated cost savings of both the early and ongoing aspects of the ABT program are summarized above in Section 6.5.5.12 where the impacts of the ABT program are discussed.

We estimated the stream of total annual compliance costs for the U.S. refining industry complying with the benzene program from 2007 to 2035, including the phase-in of the ABT program. We used the per-gallon program costs to refiners in 2012 throughout the phase-in period as well as the fully phased-in program, multiplying these estimated costs times the projected gasoline demand by the Energy Information Administration (EIA) contained in the Annual Energy Outlook (AEO) 2006. Since the EIA projections end at 2030, we used the annual average growth rate over the years 2025 to 2030 to extrapolate the growth in demand to 2035. The stream of projected gasoline consumption volume and the total annual costs for complying with the benzene program are summarized in Table 9.6-3.

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[h] Our analysis included values for small additional costs and emission reductions based on an assumption that the start date for the 1.3 maximum average standard for small refiners would be 2015. Since the final rule sets this date as July 2016, our 2015 results are slightly over-estimated.

Table 9.6-3. Stream of Total Compliance Costs for the Benzene Program (2003 dollars, 7% ROI before Taxes)

Year	Gasoline Volume (million gallons)	Cost (c/gal)	Total Program Cost (million dollars)
2007	123,719	0.02	28
2008	125,315	0.04	49
2009	127,311	0.04	50
2010	129,705	0.09	101
2011	132,233	0.09	104
2012	134,362	0.11	133
2013	136,224	0.13	164
2014	137,953	0.13	166
2015	139,683	0.27	363
2016	141,412	0.27	379
2017	143,142	0.27	384
2018	144,871	0.27	388
2019	146,733	0.27	393
2020	148,463	0.27	398
2021	150,059	0.27	402
2022	151,656	0.27	406
2023	153,119	0.27	410
2024	154,582	0.27	414
2025	156,179	0.27	419
2026	157,775	0.27	423
2027	159,504	0.27	427
2028	161,234	0.27	432
2029	162,830	0.27	436
2030	164,560	0.27	441
2031	166,156	0.27	445
2032	167,885	0.27	450
2033	169,632	0.27	455
2034	171,397	0.27	459
2035	173,180	0.27	464

9.6.2 Cost of Alternative Benzene Programs

We used the refinery-by-refinery cost model to estimate the cost of other potential benzene standards. This includes analyses of different maximum average benzene standards, different averaging standards, and benzene standards with and without ABT programs.

Table 9.6-4 contains a summary of the national average per-gallon costs and aggregate capital and total annual costs for maximum average benzene standards which range from 1.1 to 1.5 vol% benzene and average benzene standards which range from 0.50 to 0.71 vol%, with and without an ABT program. The 0.50 vol% average benzene standard represents the most stringent benzene standard technically feasible with maximum reformate control assuming that either benzene extraction or benzene saturation would be used. For comparison, we also modeled an average standard of 0.71 vo% benzene, but without the full ABT program. Each refinery would have to average 0.71 vol% benzene across its own gasoline batches with no ability to average or trade across refineries, or bank credits. This benzene standard is projected to result in a national average benzene level which would equal the 0.62 vol% benzene standard with full ABT – thus it is an interesting case to study relative to the benzene program. However, the refinery model estimates that two refineries would not be able to achieve the 0.71 vol% benzene standard based on reformate benzene control alone, thus it is not a perfect comparison.

Table 9.6-4. Cost of Other Benzene Standards (2003 dollars, 7% ROI before taxes)

Average Benzene Std. (vol %)	ABT Program	Max-Avg Std. (vol %)	Actual In-Use Benzene Level (vol %)	Per-Gallon Cost (cents/gal)	Total Annual Cost ($ million/yr)	Aggregate Capital Cost ($ million)
0.50	Yes	None	0.50	0.74	900	2140
0.60	Yes	1.3	0.60	0.31	380	1250
0.60	Yes	None	0.60	0.30	360	1180
0.62	Yes	1.1	0.62	0.34	410	1120
0.62	Yes	1.2	0.62	0.30	360	1070
0.62*	Yes	1.3	0.62	0.27	330	1110
0.62	Yes	1.4	0.62	0.26	320	1100
0.62	Yes	1.5	0.62	0.25	300	1070
0.62**	Yes	None	0.62	0.24	290	1120
0.65	Yes	1.3	0.65	0.21	250	950
0.65	Yes	None	0.65	0.18	220	960
0.70	Yes	1.3	0.70	0.16	190	740
0.70	Yes	None	0.70	0.11	140	510
0.71***	No	None***	0.62	0.51	620	1670

* Final Rule

** Proposed Rule

*** The 0.71 volume percent benzene standard we modeled could also be thought of being a maximum average standard, because without an ABT program, each refinery would have to meet this level with actual production on an annual average basis.

Our refinery model analysis shows that the reduced flexibility of adding a maximum average benzene standard increases the cost of benzene control over a benzene control program without a maximum average standard. We estimate that the reduced flexibility will require some refiners to install a benzene saturation unit instead of routing the benzene precursors around the reformer or sending that rerouted stream to an isomerization unit and procuring credits to make up the remaining shortfall. As the table shows, these additional actions by some refiners and the associated cost increases will not affect the in-use benzene level, which will be driven by the 0.62 vol% average standard regardless of the level of maximum average standard.

The benefit to the program of the 1.3 vol% maximum average standard is the increased certainty that the benzene reductions projected by our modeling will in fact be achieved nationwide, especially the significant reductions projected in areas that currently have the highest benzene levels. Implementing a maximum average standard lower than 1.3 vol% would increase the number of refineries that need to install the more expensive benzene reduction equipment. This would diminish the value of the flexibility provided by the ABT program by requiring an increasing number of refineries to make expenditures in benzene control that could otherwise be smaller or avoided entirely, thereby increasing the overall costs of the program. Conversely, a maximum average standard greater than 1.3 vol% would require progressively fewer refineries to take action to reduce their benzene levels. This would in turn provide less assurance that actual benzene levels would be broadly achieved and would undermine the greater degree of geographic uniformity in benzene reductions achieved by the 1.3 vol% standard.

The 0.71 vol% benzene standard without the ABT program, which results in the same national average gasoline benzene level as the benzene program, is estimated to cost almost two times more than the benzene program. Without any ABT program, this standard offers the least amount of flexibility compared to the benzene program. The lack of flexibility of this benzene standard results in a larger share of benzene reductions occurring through benzene saturation, the most expensive benzene control technology.

We plotted the projected per-gallon costs for each refinery producing gasoline (from lowest to highest cost) versus the cumulative volume of gasoline across the refineries producing gasoline for several benzene programs of interest. Figure 9.6-3 shows the per-gallon costs for the final benzene program and a program with the same standard, but without a maximum average standard. We also included a plot of the 0.50 vol% benzene standard which represents maximum reformate benzene control technically achievable (albeit at significant higher national cost, and with significant adverse economic impact on individual refineries).

Figure 9.6-3.
Cost Comparison between Final Benzene Standards and Two Other Options
(2003 dollars, and 7% ROI before taxes)

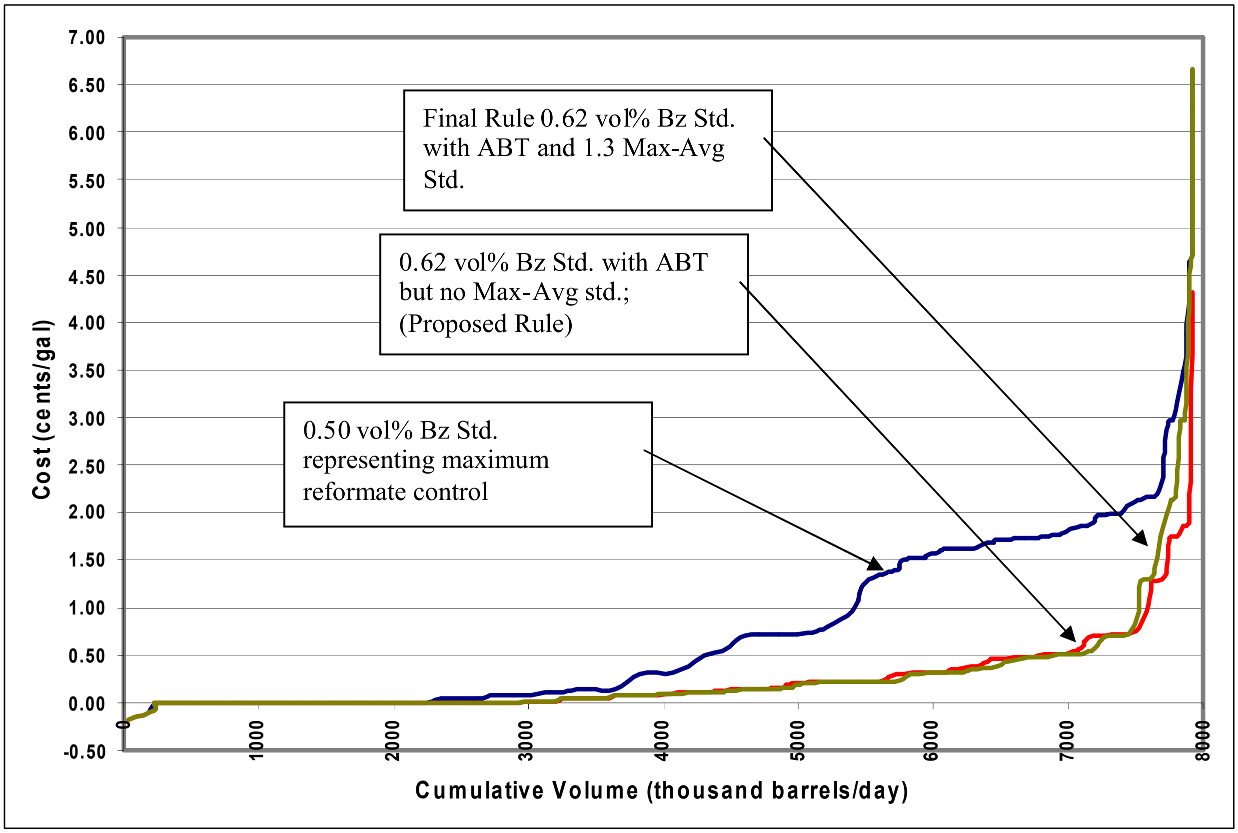


Figure 9.6-3 shows that for nearly half the volume of gasoline, the costs for benzene control are zero or near zero, and for a few extraction refineries even negative. The model projects that the addition of the maximum average standard will require a small number of refineries to adopt more expensive benzene control strategies. Comparing the proposed and final programs, the final rule benzene program would cause 16 refineries to exceed 1 cent per-gallon compliance cost compared to 8 refineries that would exceed 1 cent per gallon without a maximum average standard. The 0.50 vol% benzene standard would be much more expensive in this regard as it is estimated to cause about 60 refineries to exceed 1 cent per gallon in compliance costs. Although it is difficult to determine this from the above figure, the refinery with the highest cost of compliance under the final benzene program is estimated to incur about a 6.5 cents per gallon cost (same for the 0.50 vol% standard) while under the benzene program without the maximum average standard the refinery with the highest cost of compliance would be about 4 cents per gallon.

Table 9.6-5 below summarizes the number refineries which install or adopt each of the four different types of benzene control technologies for:

- the final benzene program (0.62 vol% average benzene standard with 1.3 maximum average standard and ABT program,

- a 0.62 vol% benzene standard program with ABT program, but no maximum average standard (proposed rule),

- a 0.71 vol% benzene standard without an ABT program which results in a 0.62 vol% average benzene level in gasoline, and

- a 0.50 vol% benzene standard with ABT program (maximum reformate benzene control).

Table 9.6-5. Projected Number and Type of Benzene Control Technologies Installed for the Final Benzene Standards and Other Options

	Routing Benzene Precursors Around Reformer	Sending Rerouted Benzene Precursors to Isom Unit	New and Revamped Benzene Extraction Units	Benzene Saturation
Final Rule 0.62 vol% avg Bz std with 1.3 Max-Avg std and ABT program	17	28	16	18
0.62 avg Bz std with ABT Program , no max-avg std (proposed rule)	19	28	17	8
0.71avg Bz std, No ABT Program; 0.62 vol% in-use	1	12	25	52
0.50 avg Bz std with ABT (maximum reformate benzene control)	0	0	63	24

Adding a maximum average standard or eliminating the ABT program altogether is projected to result in a different pattern of benzene reduction across the country. Refineries which we project will find it economically advantageous to realize only minor benzene reductions and to primarily purchase credits to comply with the average benzene standard are primarily located in PADD 4 and PADD 5. The refineries which we project will generate credits under the ABT program are primarily located in PADDs 1 and 3. The model assumes perfect trading of credits, so if an alternate program is projected to increase benzene reductions in one area, the model would project that this increase would be offset by decreased benzene reductions in other areas. For example, as shown in Table 9.6-6, the model projects that adding a 1.3 vol% maximum average standard should result in significant additional benzene reductions in PADDs 4 and 5 and a small increased reduction in PADD 1, all of which would appear to be offset by small decreases in benzene reductions in PADDs 2 and 3.

We note that the design of the refinery model and its inherent trading assumptions is such that we can be much more certain that large projected changes will actually occur than we can about small projected changes. Thus, while we are confident that adding the 1.3 vol% maximum average standard will result in greater benzene reductions in PADDs 4 and 5 than would a program without the 1.3 vol% standard, we cannot be certain that the small changes projected for PADDs 1, 2, and 3 will occur or occur in the ways that the model projects. In addition to this uncertainty about small modeled changes in benzene, some refiners may behave differently than the model predicts. For example, it is not unlikely that some refiners in PADDs 2 and 3 will choose to “over-comply” with the 0.62 vol% average standard (to provide a greater margin of safety for compliance) regardless of the state of the benzene credit market. Yet the model would tend to project that these refiners would reduce benzene levels as little as necessary. Thus, the projected benzene levels achieved in PADDs 2 and 3 under a 0.62 vol% benzene standard without a maximum average standard may well be achieved (or even exceeded) under the final rule program with a maximum average standard if refiners choose to comply with a safety margin. Table 9.6-6 summarizes the estimated benzene level by PADD for several different benzene programs that would result in the same nationwide benzene level, but differing gasoline benzene profiles because of the addition of the maximum average standard. We also show the pattern of benzene control across the country for the 0.50 vol% benzene standard with ABT program.

Table 9.6-6. Comparison of the 2004 and Modeled Gasoline Benzene Levels by PADD for the Final Benzene Program and Other Options (vol% benzene)

	PADD 1	PADD 2	PADD 3	PADD 4	PADD 5 excluding CA	U.S. Average
Current Benzene Levels	0.67	1.26	0.85	1.56	1.80	1.00
Final Rule 0.62 vol% avg Bz std with 1.3 Max-Avg std and ABT program	0.52	0.63	0.61	0.90	0.69	0.62
0.62 vol% avg Bz std with 1.1 Max-Avg std and ABT program	0.55	0.61	0.63	0.83	0.55	0.62
0.62 vol% avg Bz std with 1.5 Max-Avg std and ABT program	0.52	0.63	0.60	0.90	0.82	0.62
0.62 avg Bz std with ABT Program No Max-Avg (Proposed Rule)	0.53	0.61	0.60	0.94	0.88	0.62
0.71 avg Bz std, No ABT Program*	0.53	0.70	0.59	0.71	0.70	0.62
0.50 avg Bz std with ABT (maximum reformate benzene control)	0.50	0.45	0.52	0.53	0.48	0.50

* The cost analysis shows that 2 refineries would not be able to meet a 0.71 vol% benzene standard. These two refineries would need to achieve the 0.71 vol% standard by reducing benzene levels in another gasoline stream.

To gain a sense of the relative benzene levels among all U.S. refineries, we plotted the individual refinery benzene levels projected to result from several of the benzene programs with average national benzene levels of 0.62 vol% benzene. A review of the refinery-by-refinery output shows that the benzene levels of the refineries in PADD 4 and PADD 5 (excluding California) are most likely to remain above the average standard with a nationwide ABT program in place. The plots of the refinery benzene levels against cumulative gasoline production for all U.S. refineries, and for all refineries in PADDs 4 and 5 (excluding California), are contained in Figure 9.6-4, and Figure 9.6-5, respectively.

Figure 9.6-4. U.S. Final Rule Benzene Levels Compared to Benzene Levels for 2004 and Other Control Options

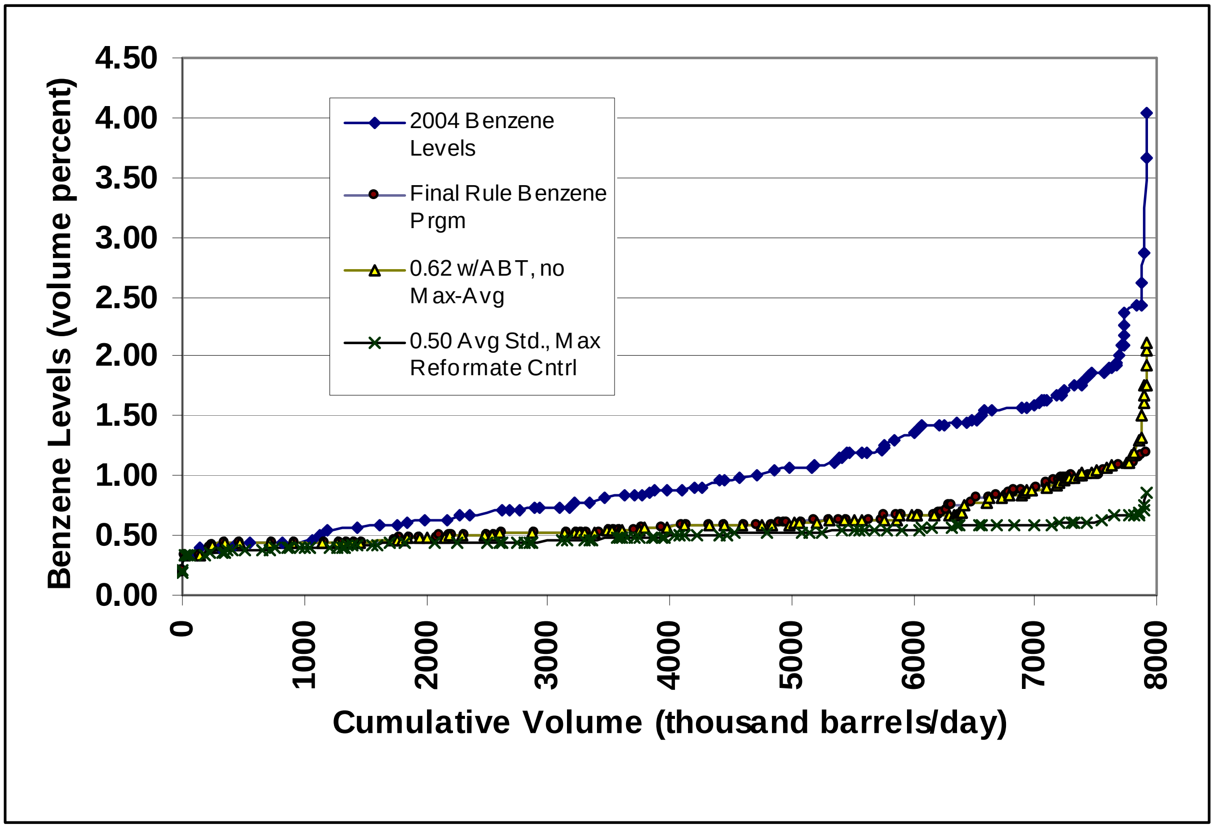
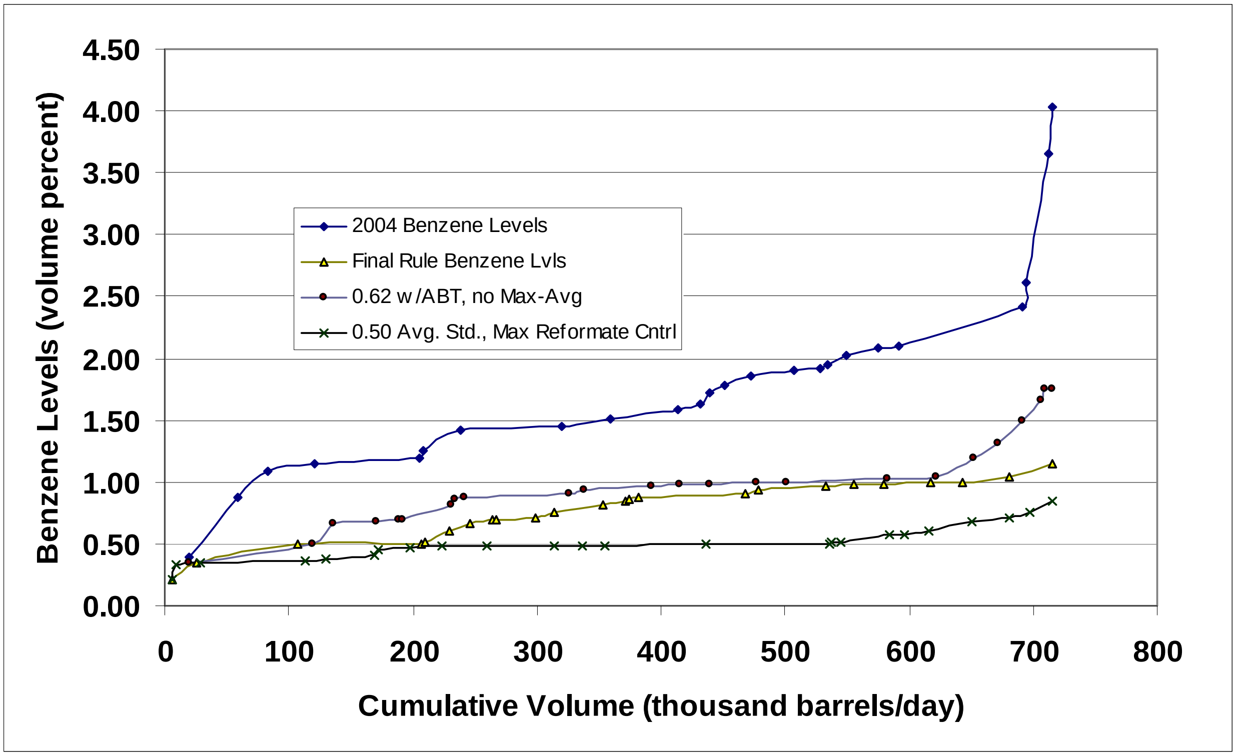


Figure 9.6-5. PADD 4 and 5 Estimated Final Rule Benzene Levels Compared to Benzene Levels for 2004 and Other Control Options



All of the benzene standards represented in Figure 9.6-4 and Figure 9.6-5 would realize substantial benzene reductions in all parts of the country compared to today's benzene levels. As the benzene control standard is tightened or as flexibility is reduced, the curve for gasoline benzene levels becomes flatter.

9.6.3 Costs Used to Estimate Price Impacts of the Benzene Program

In Chapter 13 of the RIA, we estimate the increase in gasoline prices for the benzene program. To facilitate that analysis, certain cost information was obtained from the refinery-by-refinery cost model and presented to the contractor conducting that analysis. The cost information provided is consistent with specific macroeconomic principles that form the basis for estimating price impacts.

When modeling macroeconomic effects, the price in any market can be assumed to be based on the cost for the last, highest cost increment of supply which meets demand. We do not know which refineries are the highest cost producers of gasoline, so we have estimated three different cost breakpoints to capture the costs experienced by these price setter refineries. For the first set of costs provided, we assumed that the highest cost gasoline producers also experience the highest benzene control costs. The refinery-by-refinery cost model estimates the compliance cost for individual refineries so we simply sorted through the list of individual refinery costs and picked the highest cost of compliance in each PADD, which is the market area we chose to use for evaluating price effects.

We developed other cost information to capture other ways that this program could impact prices. Perhaps, the price setting refineries are not experiencing the maximum benzene control costs, or maybe they are affected by other factors. Refineries produce in a wide range of markets. Since the products are produced from the same feedstock with limited flexibility for changing the product slate, market prices for individual products are not independent of each other. Being the highest cost producer for one product does not mean they are the highest cost producer for all products, and market prices won't necessarily reflect their costs. To capture these other possible market effects, two other sets of cost information are provided to our contractor for estimating price effects.

The second set of costs we developed is based on the maximum variable costs experienced in each PADD. These costs do not include the capital costs and could also represent another situation based on claims made by the representatives of the oil industry. They have said that after complying with the 500 ppm highway diesel fuel sulfur standard, the price increase in highway diesel fuel after that rule went into effect did not support their recovering their capital costs. We could not confirm this claim, but providing the maximum variable costs would attempt to model this situation.

For the third set of costs, we provided the average cost of compliance in each PADD. Since the highest benzene control costs may not necessarily correlate to the refineries with the highest overall gasoline production costs this case simply assumes the highest cost gasoline producer experiences average benzene control costs. Estimating the average cost of compliance for the fuel consumed is more complicated because the gasoline consumed in any area is a function of the imports and transfers into the PADD as well as the gasoline produced there. The methodology for how we generated average compliance costs for the gasoline consumed in a PADD from the average costs for the gasoline produced in a PADD is summarized in the RIA Section 6.1.2. Tables 9.6-7,8 and 9 summarize gasoline consumption volumes and average per-gallon consumption costs and per-gallon maximum total and maximum variable costs for each PADD for estimating the price impacts of the benzene program.

Table 9.6-7. Summary of Yearly Volumes and Potential Price Increases by PADD for the Benzene Program Based on Average Total Costs (2003 dollars, 7% ROI before taxes)

	PADD 1		PADD 2		PADD 3		PADD 4		PADD 5 except CA	
Year	Gasoline Consumption (million gals)	Cost (c/gal)	Gasoline Consumption (million gals)	Cost (c/gal)	Gasoline Consumption (million gals)	Cost (c/gal)	Gasoline Consumption (million gals)	Cost (c/gal)	Gasoline Consumption (million gals)	Cost (c/gal)
2004	49,193	0	38,790	0	20,615	0	4542	0	7918	0
2005	49,517	0	39,045	0	20,751	0	4572	0	7971	0
2006	50,274	0	39,642	0	21,068	0	4642	0	8092	0
2007	50,923	0.008	40,154	0.053	21,340	0.013	4702	0.019	8197	0.004
2008	51,734	0.014	40,793	0.091	21,680	0.022	4777	0.033	8327	0.007
2009	52,707	0.014	41,560	0.091	22,088	0.022	4867	0.033	8484	0.007
2010	53,734	0.027	42,370	0.194	22,518	0.042	4962	0.099	8649	0.035
2011	54,599	0.027	43,052	0.194	22,881	0.042	5042	0.099	8788	0.035
2012	55,355	0.051	43,649	0.308	23,198	0.075	5111	0.213	8910	0.140
2013	56,058	0.048	44,203	0.227	23,492	0.065	5176	0.227	9023	0.244
2014	56,761	0.048	44,757	0.227	23,787	0.065	5241	0.227	9137	0.244
2015	57,464	0.147	45,311	0.307	24,081	0.154	5306	0.501	9250	0.997
2016	58,167	0.147	45,866	0.307	24,376	0.154	5371	0.501	9363	0.997
2017	58,869	0.147	46,420	0.307	24,670	0.154	5436	0.501	9476	0.997
2018	59,626	0.147	47,016	0.307	24,987	0.154	5506	0.501	9598	0.997
2019	60,329	0.147	47,571	0.307	25,282	0.154	5571	0.501	9711	0.997
2020	60,978	0.147	48,082	0.307	25,554	0.154	5631	0.501	9815	0.997
2021	61,626	0.147	48,594	0.307	25,826	0.154	5691	0.501	9920	0.997
2022	62,221	0.147	49,063	0.307	26,075	0.154	5745	0.501	10,015	0.997
2023	62,816	0.147	49,531	0.307	26,324	0.154	5800	0.501	10,111	0.997
2024	63,464	0.147	50,043	0.307	26,596	0.154	5860	0.501	10,215	0.997
2025	64,113	0.147	50,554	0.307	26,868	0.154	5920	0.501	10,320	0.997
2026	64,816	0.147	51,109	0.307	27,162	0.154	5985	0.501	10,433	0.997
2027	65,518	0.147	51,663	0.307	27,457	0.154	6050	0.501	10,546	0.997
2028	66,167	0.147	52,174	0.307	27,729	0.154	6110	0.501	10,651	0.997
2029	66,870	0.147	52,728	0.307	28,023	0.154	6175	0.501	10,764	0.997
2030	67,519	0.147	53,240	0.307	28,295	0.154	6235	0.501	10,868	0.997
2031	68,221	0.147	53,794	0.307	28,589	0.154	6299	0.501	10,981	0.997
2032	68,931	0.147	54,354	0.307	28,887	0.154	6365	0.501	11,095	0.997
2033	69,648	0.147	54,919	0.307	29,187	0.154	6431	0.501	11,211	0.997
2034	70,373	0.147	55,491	0.307	29,491	0.154	6498	0.501	11,328	0.997
2035	71,105	0.147	56,068	0.307	29,798	0.154	6566	0.501	11,445	0.997

Table 9.6-8. Summary of Yearly Volumes and Potential Price Increases by PADD for the Benzene Program Based on Maximum Total Costs
(2003 dollars, 7% ROI before taxes)

	PADD 1		PADD 2		PADD 3		PADD 4		PADD 5 except CA	
Year	Gasoline Consumption (million gals)	Cost (c/gal)	Gasoline Consumption (million gals)	Cost (c/gal)	Gasoline Consumption (million gals)	Cost (c/gal)	Gasoline Consumption (million gals)	Cost (c/gal)	Gasoline Consumption (million gals)	Cost (c/gal)
2004	49,193	0	38,790	0	20,615	0	4542	0	7918	0
2005	49,517	0	39,045	0	20,751	0	4572	0	7971	0
2006	50,274	0	39,642	0	21,068	0	4642	0	8092	0
2007	50,923	0.026	40,154	0.243	21,340	0.323	4702	0.609	8197	0.334
2008	51,734	0.026	40,793	0.243	21,680	0.323	4777	0.609	8327	0.334
2009	52,707	0.026	41,560	0.243	22,088	0.323	4867	0.609	8484	0.334
2010	53,734	0.189	42,370	0.473	22,518	0.424	4962	0.176	8649	0.334
2011	54,599	0.189	43,052	0.473	22,881	0.424	5042	0.176	8788	0.334
2012	55,355	5.67	43,649	3.54	23,198	4.10	5111	2.46	8910	3.37
2013	56,058	5.67	44,203	3.54	23,492	4.10	5176	2.46	9023	3.37
2014	56,761	5.67	44,757	3.54	23,787	4.10	5241	2.46	9137	3.37
2015	57,464	5.80	45,311	5.89	24,081	4.10	5306	5.62	9250	4.29
2016	58,167	5.80	45,866	5.89	24,376	4.10	5371	5.62	9363	4.29
2017	58,869	5.80	46,420	5.89	24,670	4.10	5436	5.62	9476	4.29
2018	59,626	5.80	47,016	5.89	24,987	4.10	5506	5.62	9598	4.29
2019	60,329	5.80	47,571	5.89	25,282	4.10	5571	5.62	9711	4.29
2020	60,978	5.80	48,082	5.89	25,554	4.10	5631	5.62	9815	4.29
2021	61,626	5.80	48,594	5.89	25,826	4.10	5691	5.62	9920	4.29
2022	62,221	5.80	49,063	5.89	26,075	4.10	5745	5.62	10,015	4.29
2023	62,816	5.80	49,531	5.89	26,324	4.10	5800	5.62	10,111	4.29
2024	63,464	5.80	50,043	5.89	26,596	4.10	5860	5.62	10,215	4.29
2025	64,113	5.80	50,554	5.89	26,868	4.10	5920	5.62	10,320	4.29
2026	64,816	5.80	51,109	5.89	27,162	4.10	5985	5.62	10,433	4.29
2027	65,518	5.80	51,663	5.89	27,457	4.10	6050	5.62	10,546	4.29
2028	66,167	5.80	52,174	5.89	27,729	4.10	6110	5.62	10,651	4.29
2029	66,870	5.80	52,728	5.89	28,023	4.10	6175	5.62	10,764	4.29
2030	67,519	5.80	53,240	5.89	28,295	4.10	6235	5.62	10,868	4.29
2031	68,221	5.80	53,794	5.89	28,589	4.10	6299	5.62	10,981	4.29
2032	68,931	5.80	54,354	5.89	28,887	4.10	6365	5.62	11,095	4.29
2033	69,648	5.80	54,919	5.89	29,187	4.10	6431	5.62	11,211	4.29
2034	70,373	5.80	55,491	5.89	29,491	4.10	6498	5.62	11,328	4.29
2035	71,105	5.80	56,068	5.89	29,798	4.10	6566	5.62	11,445	4.29

Table 9.6-9. Summary of Yearly Volumes and Potential Price Increases by PADD for the Benzene Program Based on Maximum Operating Costs (2003 dollars)

	PADD 1		PADD 2		PADD 3		PADD 4		PADD 5except CA	
Year	Gasoline Consumption (million gals)	Cost (c/gal)	Gasoline Consumption (million gals)	Cost (c/gal)	Gasoline Consumption (million gals)	Cost (c/gal)	Gasoline Consumption (million gals)	Cost (c/gal)	Gasoline Consumption (million gals)	Cost (c/gal)
2004	49,193	0	38,790	0	20,615	0	4542	0	7918	0
2005	49,517	0	39,045	0	20,751	0	4572	0	7971	0
2006	50,274	0	39,642	0	21,068	0	4642	0	8092	0
2007	50,923	0.026	40,154	0.243	21,340	0.323	4702	0.609	8197	0.334
2008	51,734	0.026	40,793	0.243	21,680	0.323	4777	0.609	8327	0.334
2009	52,707	0.026	41,560	0.243	22,088	0.323	4867	0.609	8484	0.334
2010	53,734	0.096	42,370	0.351	22,518	0.342	4962	0.609	8649	0.334
2011	54,599	0.096	43,052	0.351	22,881	0.342	5042	0.609	8788	0.334
2012	55,355	4.56	43,649	3.02	23,198	3.41	5111	2.01	8910	2.75
2013	56,058	4.56	44,203	3.02	23,492	3.41	5176	2.01	9023	2.75
2014	56,761	4.56	44,757	3.02	23,787	3.41	5241	2.01	9137	2.75
2015	57,464	4.56	45,311	4.42	24,081	3.41	5306	4.27	9250	3.34
2016	58,167	4.56	45,866	4.42	24,376	3.41	5371	4.27	9363	3.34
2017	58,869	4.56	46,420	4.42	24,670	3.41	5436	4.27	9476	3.34
2018	59,626	4.56	47,016	4.42	24,987	3.41	5506	4.27	9598	3.34
2019	60,329	4.56	47,571	4.42	25,282	3.41	5571	4.27	9711	3.34
2020	60,978	4.56	48,082	4.42	25,554	3.41	5631	4.27	9815	3.34
2021	61,626	4.56	48,594	4.42	25,826	3.41	5691	4.27	9920	3.34
2022	62,221	4.56	49,063	4.42	26,075	3.41	5745	4.27	10,015	3.34
2023	62,816	4.56	49,531	4.42	26,324	3.41	5800	4.27	10,111	3.34
2024	63,464	4.56	50,043	4.42	26,596	3.41	5860	4.27	10,215	3.34
2025	64,113	4.56	50,554	4.42	26,868	3.41	5920	4.27	10,320	3.34
2026	64,816	4.56	51,109	4.42	27,162	3.41	5985	4.27	10,433	3.34
2027	65,518	4.56	51,663	4.42	27,457	3.41	6050	4.27	10,546	3.34
2028	66,167	4.56	52,174	4.42	27,729	3.41	6110	4.27	10,651	3.34
2029	66,870	4.56	52,728	4.42	28,023	3.41	6175	4.27	10,764	3.34
2030	67,519	4.56	53,240	4.42	28,295	3.41	6235	4.27	10,868	3.34
2031	68,221	4.56	53,794	4.42	28,589	3.41	6299	4.27	10,981	3.34
2032	68,931	4.56	54,354	4.42	28,887	3.41	6365	4.27	11,095	3.34
2033	69,648	4.56	54,919	4.42	29,187	3.41	6431	4.27	11,211	3.34
2034	70,373	4.56	55,491	4.42	29,491	3.41	6498	4.27	11,328	3.34
2035	71,105	4.56	56,068	4.42	29,798	3.41	6566	4.27	11,445	3.34

9.6.4 Projected Fuel Supply and Energy Impacts of the Benzene Program

EPA has evaluated the potential impact on U.S. fuel supply of the benzene program. As discussed in detail elsewhere in this chapter, refiners are expected to utilize a variety of approaches to control benzene. Other than extraction these do not impact gasoline production appreciably. Extraction physically removes benzene from the refinery reformate stream, usually for sale into the petrochemical market. In extracting benzene, the volume of reformate available for gasoline production is reduced.

We estimate that in response to the benzene program, refiners will extract about 12,500 barrels of benzene per day, or 192 million gallons per year, when the benzene program is fully phased-in. Because benzene has a slightly higher energy density than gasoline (about 7 percent higher), the projected extracted benzene is equivalent to about 13,375 barrels per day of gasoline, or about 0.1 percent of U.S. gasoline production. However, we believe that the net effect on gasoline supply of the rule will be far less, potentially zero.

This increase in extraction of benzene from gasoline is expected to occur with or without the benzene program. Using CMAI's estimate of a 2.4 percent annual growth in benzene demand, we expect that U.S. demand for benzene will increase by 600 million gallons from 2007 to 2015, the years that the benzene program is expected to phase-in. Assuming that reformate extraction continues to supply about 40 percent of the supply, then reformate extraction is expected to supply about 250 million gallons additional benzene over the 8 year program phase-in period. Thus, increased reformate extraction expected to occur to meet increased benzene demand would exceed the projected benzene extraction expected to occur to comply with the benzene program, provided that the benzene extraction occurs throughout the entire phase-in period. If all the benzene extraction occurs to comply with the benzene program in a single year, then the increased benzene supply would be greater than two times the yearly increase in total benzene demand.

Even if all the projected benzene extraction occurs in a single year, the benzene market could adjust to rebalance both the benzene market and the gasoline supply. Selective toluene disproportionation and toluene hydrodealkylation are benzene production technologies which are higher benzene production cost technologies. These two marginal benzene production processes would likely reduce their benzene production which would rebalance the benzene supply/demand market. Presuming that these two benzene production processes temporally reduce their output to rebalance benzene supply, the toluene would presumably stay in the gasoline pool and the effect on gasoline supply would be minimal.

Projected Energy Impacts of the Benzene Program

We used the LP and refinery-by-refinery models to estimate the changes in energy use that would result from the implementation of the benzene program.[29] For this analysis, we used the refinery-by-refinery model to select the range of technologies we believe would be likely to be used across the industry by PADD in 2012, both with and without a benzene program. We then used the resulting array of technologies as input data for the LP model. This data then became the starting point for runs of the LP model, which we used to produce estimates of the net change in energy use due to increased refinery processing and changes to inputs into the refinery. In these runs, the LP model maintains the same volume of gasoline production in the reference and control cases. The model makes up the loss of gasoline volume due to benzene extraction by assuming additional purchases of crude oil. To the extent that this benzene extraction would be made up by swapping gasoline blendstocks or by increases to refinery intermediate streams that could then be used to produce gasoline, this analysis is somewhat conservative. Table 9.6-10 presents the results of the energy use evaluation.

Table 9.6-10. Estimated Changes in Energy Use (2012)
(in Thousands of Fuel Oil Equivalent Barrels per Day (Kfoeb/d)

	PADD 1	**PADD 2**	**PADD 3**	**PADDs 4&5 (except CA)**	**All PADDs (except CA)**
Refinery Process Energy Use					
Total Benzene Control-Related	0.4	2.0	3.4	2.1	8.0
Light Naphtha Splitting	-0.1	1.1	0.1	-0.1	1.1
Reforming	0.2	-0.6	0.6	0.4	0.6
Isomerization	0	-0.5	0	0.1	-0.5
Benzene Saturation	0	0.2	0.3	0.9	1.5
Benzene Extraction	0.4	1.1	1.9	0	3.4
Hydrogen Production	-0.2	0.8	0.5	0.8	1.8
All Other	-0.2	0.5	0.2	-0.1	0.4
Net Process Energy Change	**0.2**	**2.5**	**3.6**	**2.0**	**8.3**
% Change in Process Energy	*0.2*	*0.9*	*0.4*	*1.8*	*0.6*
Net Total Energy Change	**0.9**	**3.2**	**5.1**	**3.4**	**12.7**
% Change in Total Energy	*0.05*	*0.09*	*0.06*	*0.21*	*0.08*

As shown in the table, our modeling projects that increases refinery process energy (fuel, steam, and electricity) would contribute most to the total change in energy use (8.3 of the total increase of 12.7 Kfoeb/d). This process energy increase would represent about 0.6 percent of all energy used in refinery processes. When all energy involved in refining crude oil is considered, including the energy in crude oil and other feedstocks, we project that the benzene program would increase overall energy use by refineries by less than 0.1 percent.

Of the nationwide increase in process energy, most would be due to processes directly related to benzene control (8 of 8.3 Kfoeb/d). Benzene extraction would be the largest contributor to this process energy increase (3.4 of 8.3 Kfoeb/d). It is important to note as discussed above that the increase in benzene production through greater extraction, and thus the increase in energy used in this process, would likely occur regardless of whether the benzene program was in place. Thus, the increase in energy used to extract benzene could be attributed to meeting the increased demand for benzene rather than attributed to the benzene program. (Projected increases in energy use due to the other benzene-related processes would be appropriately attributed to the benzene program.)

The variation in energy impacts from PADD to PADD shown in the table results from the expected differences in the technological approaches refiners would pursue in different parts of the country, as discussed in Chapter 6. For example, for PADDs 2, 4, and 5, we do not expect that the benzene program would result in an increase in benzene extraction, and thus the table shows no increase in energy for this process. However, we project that the largest energy increases in PADD 1 and PADD 3 would be due to increased benzene extraction. (Refiners in these regions would be near benzene markets and would tend to invest in benzene extraction equipment.) Overall, we project that PADD 3 would contribute a significant portion of the nationwide increase in energy use because of its very large production volume as well as because of its reliance on extraction. PADDs 4 and 5 provide a significant portion of the energy demand despite the lower gasoline production in these two PADDs because of the large reduction in benzene levels in these two PADDs.

9.7 Refinery Industry Cost Study

The American Petroleum Institute (API) conducted its own refinery modeling study to evaluate the cost of benzene control.[30] The API study, conducted by Baker and O'Brien Incorporated, analyzed the cost of three different benzene programs, and these were Case A: a 0.60 vol% average benzene standard and 0.90 per-gallon cap standard applicable to RFG, and a 0.95 average vol% benzene standard and 1.30 per-gallon cap standard applicable to CG, but no credit trading program; Case B: a 0.60 vol% average benzene standard and 0.90 per-gallon cap standard applicable to both RFG and CG, but no credit trading program; and Case C: a 0.60 vol% average benzene standard for both CG and RFG with no cap standard and with a credit trading program.[i] API made some very conservative assumptions regarding credit generation and use for Case C. API assumed that when credits are being generated that each refinery will hold onto 10 percent of the generated credits as a safety margin which resulted in a lower benzene level than that required.

The API study also assumed that MTBE is no longer blended into the U.S. gasoline pool, that the Tier 2 gasoline sulfur program is fully implemented, that the renewable fuels standard is implemented resulting in 7 billion gallons of ethanol blended into the gasoline pool and that MSAT1 is still in effect. The three cases modeled by API are summarized in Table 9.7-1. We also included the final U.S. gasoline pool benzene levels for the base case and each case in the last column of the table. We adjusted the benzene levels to exclude California gasoline because it is not assumed to be regulated by the API refinery modeling study consistent with our analysis.

Table 9.7-1. Summary of the Three Refinery Modeling Case Studies by API

	Gasoline Pool	Avg Std	Cap Std	Credit Trading	Benzene Level (vol%)
Basecase	Total Pool	-	-	-	1.00
Case A	RFG	0.60	0.90	No	0.70
	CG	0.95	1.30		
Case B	RFG	0.60	0.90	No	0.52
	CG	0.60	0.90		
Case C	RFG	0.60	None	Yes	0.56
	CG	0.60	None		

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[i] In the refinery modeling report, Baker and O'Brien states that the benzene program modeled for Case C is a 0.60 vol% benzene standard, and that credits are calculated based on benzene reductions below that value. However, in its comments to the proposed rule summarizing the results of its refinery modeling study, API stated that it modeled a 0.62 vol% average benzene standard with a 0.02 vol% compliance margin. It appears that API was trying to adapt its refinery modeling cost study to mirror the proposed standard, but that the refinery modeling study actually modeled a 0.60 benzene control standard. For the purposes of our review of the API study we will assume that the modeled standard was the 0.60 vol% benzene standard, not a 0.62 vol% benzene standard as indicated in its comments.

The types of benzene control technologies modeled in the API study include modifying the cutpoints to remove benzene precursors from reformer feed, build or expand benzene saturation units, expand aromatics extraction units, and build or expand pentane/hexane isomerization units. These are the same technologies that we used in our cost study, except that API did not allow refineries to install grassroot extraction units. Similar to our study, API did allow refineries with aromatics extraction units to expand their units to extract the aromatics from the gasoline of other refineries, although in our study we only assumed the extraction of benzene, not xylene and toluene – the other aromatic compounds that can be extracted from gasoline.

The total costs for each of the refinery modeling cases analyzed by API were summarized in their report. The API refinery modeling report did not calculate the per-gallon costs so we made the necessary calculations based on the total annual capital costs provided by API which are based on a 10 percent return on investment (ROI). We summarize those costs and adjust them to a 7 percent ROI – the basis for how we express the per-gallon costs – to express the API costs on the same basis as ours. The total annual costs, per-gallon and adjusted per-gallon costs for each case are summarized in Table 9.7-2.

Table 9.7-2. Total and Per-Gallon Costs for API's Refinery Modeling Study

Case #	Total Cost ($MM/yr)	2012 Gasoline Volume (Kbbl/day)	Investment (Million dollars)	Per-Gallon Cost (c/gal)	Capital Charge 10% after tax ROI ($MM/yr)	Capital Charge 7% before tax ROI ($MM/yr)	Adjusted Per-Gallon Cost (c/gal)
A	1286	8365	899	1.00	151	97	0.96
B	1660	8365	1737	1.29	293	188	1.21
C	1431	8365	1476	1.12	246	158	1.05

Of the four cases modeled by API, Case C is the closest to our final benzene program, thus we will compare API's cost estimate for that case to our estimated benzene program costs. It is immediately apparent that there is a large difference in estimated cost between our estimated cost, which is 0.27 cents per gallon, compared to API's Case C, which is 1.05 cents per gallon. We identified numerous reasons for the most of the difference in cost.

One of the most important differences between the two cost estimates is that API assumed a much larger benzene reduction than our study. The starting benzene level for the API study was 1.0 vol% benzene. After control, the API study assumed a slightly more stringent benzene standard – modeling a 0.60 vol% average standard instead of a 0.62 vol% average benzene standard - and a much more conservative approach to how refiners use credits. API assumed that credits would not be traded freely, but instead that refining companies would hold onto 10 percent of their credits in case they have a future problem with their benzene control unit. Due to the more stringent benzene standard and the 10 percent credit margin, the API study estimated that the U.S. refining industry would average 0.56 vol% benzene compared to our 0.62 vol% benzene control level. From the base case to the final benzene level, the API study analyzed a 0.44 vol% benzene reduction. However, our study estimated the impacts of a 0.33

vol% benzene reduction. The API study estimated a 33 percent greater benzene reduction than that analyzed in our analysis.

EPA does not believe that refiners will find it necessary to consistently and significantly overcomply with the 0.62 vol% average benzene standard and hold onto a significant amount of credits as assumed by API. This is because this benzene standard is an average standard, not a cap standard, and can be met by the accumulation of gasoline batches with benzene levels higher or lower than the standard. Thus, if a refinery tended to produce gasoline with lower or higher gasoline benzene levels over the first part of the year, the operations could be adjusted to balance out the gasoline benzene levels for the rest of the year. Also, our program includes several provisions which give refiners significant flexibility for compliance with average benzene standard. For example, refiners could overcomply slightly with the standard early on in the program's implementation and hold onto the credits for up to five years before they expire. If a refinery's benzene control unit goes down, the refiner would be able to use those accumulated credits, the refiner could purchase credits from other refineries, or the refiner could create a benzene reduction deficit at that refinery and make it up the deficit following year. With this degree of flexibility, there will be little need for a refining company to control its refineries' benzene level on an ongoing basis at a lower level than the standard to have a substantial supply of credits on hand. Even if they did feel the need to accumulate some benzene credits, the company could do so the first year, but then would not likely do so for each year after since the first year's credits would be sufficient for the next five years. For these reasons, we believe that the overcompliance modeled by API is unnecessary.

The second reason why the API estimated costs are higher than our estimates is that API used a more restrictive assumption with respect to benzene extraction – a more cost-effective benzene control technology than benzene saturation which was the principal benzene control technology relied upon by the API study. API assumed that no new grassroots benzene extraction capacity would be installed in the future, but that existing extraction units could be expanded. We agree that existing units will likely be expanded. However, we also believe that new grassroots extraction units will be installed as well. Our premise is supported by CMAI projections of a continued robust benzene market in the future with benzene priced higher than its historical margin above gasoline. CMAI estimates a benzene price which is $30/bbl higher than gasoline, which is higher than its historical margin. Higher benzene price margins will provide an incentive to refiners to add grassroots benzene extraction units, even in areas where benzene markets have been smaller. For example, one refiner has indicated to us that if the proposed gasoline benzene standard was to be finalized, it would install a grassroots benzene extraction unit at one of its refineries in the Midwest, where the benzene market is currently small. This is a strong indicator that new grassroots benzene extraction units will also be installed on the Gulf and East Coasts, where benzene markets are already strong.

API's cost of aromatics extraction is likely to be higher than our extraction costs because of the differences in benzene prices. For the final rule, we used the most recent CMAI benzene price projection, which prices benzene at $30/bbl above that of gasoline. API used an incremental benzene price of $20 per barrel above that of gasoline, which is what we used for the proposed rule. A likely primary reason for CMAI's higher incremental benzene price is that CMAI is assuming a higher future crude oil price.

The third reason why the API benzene control costs are higher than ours is the very large difference in octane control costs. For both studies, the cost associated with the octane loss that occurs through the use of the various benzene control technologies is accounted for by assigning a dollar per octane-barrel cost to the octane loss. However, API's costs for restoring octane are about an order of magnitude higher than the octane recovery costs that we are projecting. The octane costs used by API and those we use are summarized in Table 9.7-3.

Table 9.7-3. Octane Costs used in the API and EPA Benzene Cost Studies ($/octane-barrel)

	PADD 1	PADD 2	PADD 3	PADD 4	PADD 5
API	2.19	2.11	1.83	2.14	2.58
EPA	0.28	0.20	0.30	0.27	0.27

The octane costs used by API are high because API used the rack price differential between premium and regular grade gasoline as summarized by the Energy Information Administration. Using the rack price differential between premium and regular grade gasoline results in high octane costs because they reflect a significant amount of profit. For example, the cost difference to produce premium gasoline is usually only a few cents per gallon more than for producing regular grade gasoline, yet refiners and marketers usually charge 20 to 30 cents per gallon higher price for premium gasoline at retail. Much of this marked up price appears at the rack price differential between regular and premium grades of gasoline. A review of octane prices shows that the rack price differential between premium and regular grade gasoline is 50% higher then when estimating octane cost using bulk prices. Bulk prices are closer to the actual costs incurred by refiners with respect to the cost of octane. However, our linear programming cost analysis shows that refinery octane costs are much lower than bulk prices.

Another reason why the API octane costs are higher than ours is because they used the premium-regular grade gasoline price differential for the summer of 2005, when the octane costs are likely higher than in the future due to the very large volume of ethanol that is expected to enter the gasoline market by then under the Renewable Fuels Standard. In addition to the large volume of ethanol, ethanol has very high octane (115 (R + M)/2) which contributes to the large impact on octane costs. The large impact that ethanol will have on octane costs is reflected in the octane costs that we use in our analysis.

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CHAPTER 10: Portable Fuel Container Costs

This chapter presents a detailed analysis of the projected average portable fuel container (PFC) costs related to meeting new emissions standards, which would require the use of “best available controls.” These costs have been developed based on industry information, discussions with manufacturers (including confidential business information concerning technology costs), and engineering judgment. These costs include variable costs for improved materials used in manufacturing PFCs (including improved spouts), and fixed costs for research and development, tooling, and certification. Finally, this chapter presents estimated fuel savings and aggregate nationwide costs for PFCs.

10.1 Methodology

The following technology characterization and cost figures reflect our current best judgment based on engineering analysis, information from manufacturers, and the published literature. The analysis includes manufacturer markups to the retail level.

Costs of control typically include variable costs (for incremental hardware costs, assembly costs, and associated markups) and fixed costs (for tooling, R&D, and certification). Variable costs are marked up at a rate of 29 percent to account for PFC manufacturers' overhead and profit.[1] To account for additional warranty costs associated with a change in technology, we have added 5 percent of the incremental variable cost. We estimated a range of costs for different size PFCs and also an average per container cost based on the approximate sales weighting of the three PFC sizes.[A] All costs are in 2003 dollars.

We are not projecting any additional R&D costs associated with the new EPA PFC standards. Manufacturers have developed and are continuing to develop control technologies in response to the California (and other state) programs. EPA’s program is very similar to the California program and we believe the most likely approach for manufacturers will be to use the technologies developed for state programs nationwide. Manufacturers will incur the R&D costs even in the absence of EPA emissions standards. Further, the permeation barriers available are very well understood within the industry. Therefore, we believe manufacturers will use these same technologies for their nationwide product lines and will not incur significant new R&D costs due to an EPA program.

We estimate that tooling and certification costs will be incurred one year prior to production, on average. These fixed costs were increased by seven percent to reflect the time value of money over the one year period. The fixed costs then were recovered over the first five years of production at a rate of seven percent.

10.2 Costs for Permeation Control

Multi-layered designs

[A] PFC sales for 1,2, and 5 gallon containers are weighted at 33%, 33%, and 34% of total sales, respectively.

Manufacturers have indicated that most are likely to switch to multi-layer designs to meet permeation requirements. For this analysis, we considered a PFC design with a material composition of 3% ethylene vinyl alcohol (EVOH) at $3.50/lb, 4% adhesive layer at $1/lb and the remainder HDPE.[2] This resulted in materials costs ranging from $0.29 to $0.58 for 1 to 5 gallon containers, with an average materials cost of $0.41.[B]

In some cases, blow-molding machines can be retrofitted for multi-layer operation. The total cost of such a retrofit, including supporting equipment, would be about $1,000,000 per machine. In other cases, a new blow-molding machine would be required. A machine that could blow-mold multi-layer tanks would approximately double the price of the blow-molding machine. For this analysis, we use a machine cost increase of $2,000,000, including all molds and related set-up. For our analysis, we've projected that half the machines would be retrofit and half would be new, for an average cost of about $1,500,000 per machine. Our analysis uses an average total annual production of 350,000 blow-molded tanks per machine and an amortization of the capital costs over 5 years. This results in an average fixed cost per container of $1.12. Adding the fixed costs to the variable costs described above gives an average per container cost for multi-layered cans of about $1.53.

Non-continuous Barrier Platelets

Manufacturers may reduce permeation from blow-molded PFCs by blending in a low permeation material such as EVOH with the HDPE. This is typically known by its trade name, Selar. The EVOH in the plastic forms non-continuous barrier platelets in the PFC during blow-molding that make it harder for fuel to permeate through the walls of the tank. Using this approach, no changes should be necessary in the blow-molding equipment, so the costs are based on increased material costs. We used 10 percent EVOH, which costs about $3-4 per pound, and 90 percent HDPE, which costs about $0.65-0.75 per pound. This equates to a price increase of about $0.35 per pound. The increased cost for PFCs would range from $0.69 to $1.38, with an average cost increase of $1.00 per container.

Fluorination

We have also estimated costs for fluorination since some PFC manufacturers have used this approach to meet current California standards. Our surface treatment cost estimates are based on price quotes from a company that specializes in this fluorination.[3] We estimate that PFC costs would range from $0.86 to $3.30, with an average cost of $1.84. These prices do not include the cost of transporting the PFCs; we estimated that shipping, handling and overhead costs would be an additional $0.30 per PFC.[4]

10.3 Spout Costs

Manufacturers will need to move from a simple pouring spout to an automatic closing spout in order to meet evaporative emissions standards. The automatic closing spouts would include a spring closing mechanism. For this analysis, we estimated an average variable cost

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[B] This analysis was done using container weights of 1.5, 2.0, and 3.0 pounds for 1,2, and 5 gallon containers, respectively.

increase for spouts of about $0.85 including assembly costs, based on discussions with PFC manufacturers. We have also estimated $200,000 for tooling per 1 million spouts. This results in a fixed cost for tooling of about $0.05 per spout, for a total spout cost of $0.90. The spout costs would not likely vary by PFC size.

10.4 Certification Costs

Manufacturers will need to integrate the emission control technology into their designs and there will be some engineering and clerical effort needed to submit the required information for certification. We expect that in the early years, PFC manufacturers will perform durability and permeation testing for certification. They will be able to carry over this data in future years and to PFCs that are made of similar materials and have the same permeation control strategy regardless of PFC size.

Manufacturers will need to run certification testing for their PFCs and then submit the data and supporting information to EPA for certification. Based on the current approach used by manufacturers, we've estimated that each manufacturer will contract out testing at a cost of about $7,500 per manufacturer. We've included an additional cost of $5,000 for staff time for the certification process, for a total certification cost of $12,500 per manufacturer.

To calculate a per PFC certification cost, we calculated a total industry cost for certification of $125,000 and spread this cost over industry-wide sales of 26,000,000 units. As with other fixed costs, we amortized the cost over five years of sales to calculate per unit certification costs. Due to the large sales volumes, the analysis results in an average per can cost for certification of less than one cent.

10.5 Per Container Total Costs

We based our cost analysis on costs associated with multi-layer PFCs. We believe most manufacturers will continue down the path of using this technology since it is robust, has well-understood emissions performance, and appears to have the lowest cost once the capital costs are recovered. Other options for permeation barriers have similar overall costs, especially in the near term. If manufacturers select a different permeation barrier approach such as non-continuous barrier platelets or fluorination, tooling costs would be lower, but would be offset by higher variable costs. Our estimated per container costs are shown in Table 10.5-1. The weighted average costs would be $2.69. These costs are similar to cost data shared with us by manufacturers on a confidential basis.

Table 10.5-1. Costs per PFC

	1 gallon	2 gallon	5 gallon
Variable costs - Permeation Barrier - Spout	 $0.22 $0.85	 $0.28 $0.85	 $0.44 $0.85
Total Variable Costs	$1.07	$1.13	$1.29
Total Variable costs w/ OEM Mark-up and warranty	$1.40	$1.48	$1.69
Tooling	$1.17	$1.17	$1.17
Certification	Less than $0.01	Less than $0.01	Less than $0.01
Total	$2.57	$2.65	$2.86

Costs are well understood due to the experience manufacturers have had previously with permeation emissions control technologies and with the California PFC program. We are estimating costs based on the likely technology path manufacturers will take to meet the standards. Costs could be somewhat higher or lower if manufacturers use a different mix of control technologies or use multiple technologies across their product lines. Other sources of potential uncertainty include whether costs might be lower on a nationwide basis due to economies of scale or due to additional learning by the manufacturers.

10.6 Costs for PFCs Complying with State Programs

The above costs are for currently uncontrolled PFCs. Some states have adopted PFC programs, based on the original California program which took effect in 2001.[C] The original California program contained permeation requirements that would be significantly less stringent than the standards considered in this cost analysis (about a 50 percent emission reduction compared to an 80 to 90 percent emission reduction). Because the standards considered in this cost analysis are more stringent than those currently in place in states with programs, we have estimated costs associated with the difference. For purposes of the cost analysis, we have estimated that the costs associated with meeting the state programs would be half those for the permeation requirements considered here, resulting in a cost difference of $0.77 per container.

Although there technically is a difference in stringency between current state programs and the potential EPA requirements and we are including costs associated with the difference, it is unlikely that these costs would be realized. California has adopted revised program requirements that are essentially equivalent to those being considered by EPA. Manufacturers are in the process of incorporating more robust permeation controls in response to the new California program. Manufacturers would want to avoid carrying two different products and would likely use the more robust permeation controls in all states with programs. Also, in the absence of an EPA program, states would likely adopt the new California requirements eventually.

[C] Delaware, Maine, Maryland, Pennsylvania, New York, Connecticut, Massachusetts, New Jersey, Rhode Island, Vermont, Virginia, Washington DC, Ohio, New Hampshire, and Texas

10.7 Gasoline Savings

The emissions reductions due to reduced evaporative losses and reduced spills from PFCs filled with gasoline translate into gasoline savings. As described in Chapter 2, we have estimated the annual HC reductions due to new standards. By dividing the tons reduced by the number of PFCs in use with gasoline we can estimate the annual tons reduction per PFC. In 2015, after the program is fully implemented, we estimated that there would be 88,023,896 PFCs in use with gasoline nationwide and that those cans would be responsible for about 202,347 tons of HC reduction. We can then translate the tons reduction per can per year (0.002 tons, or 4.1 pounds) to gallons using a fuel density of six lbs/gallon (for lighter hydrocarbons which evaporate first). We used an average life of five years for PFCs and used a discount rate of seven percent to estimate total average undiscounted and discounted fuel savings per PFC, provided below. We calculated the savings using $1.52 per gallon of gasoline.[5] These savings would offset the cost of the PFC controls.

Table 10.7-1. Average Gasoline Savings Over Life of PFC

HC reduced (pounds)	20.5
Fuel Savings (gallons)	3.4
Undiscounted Savings	$5.17
Discounted Savings	$4.24

10.8 Annual Total Nationwide Costs and Fuel Savings

The above analyses provide incremental per unit PFC cost estimates. Using these per unit costs and projections of future annual sales, we have estimated total aggregate annual costs. The aggregate costs are presented on a cash flow basis, with hardware and fixed costs incurred in the year the PFCs are sold and fuel savings occurring over the life of the PFC. To project annual sales into the future, we started with an estimated 26 million PFCs sold nationwide in 2002 and then grew sales by two percent per year.[6,7] The resulting sales estimates for select years are shown in Table 10.8-1 below. To estimate sales in states with and without existing PFC programs, we projected that 39 percent of overall sales would be in states with existing PFC programs. This estimate is based on current estimated PFC populations by state provided in Chapter 2 of the RIA.

Table 10.8-1. Projected Annual PFC Sales

	2009	2015	2020	2030
Projected sales	29,866,000	33,634,000	37,134,000	45,267,000

For total fuel savings, we used the nationwide HC reductions estimated in Chapter 2 of the RIA and the methodology described above to convert to gallons of fuel saved nationwide, and then to savings in dollars. We estimate that fuel savings ramp up as new PFCs replace old ones and would more than offset the aggregate costs in the long term, for an overall savings. Table 10.8-2 presents the results of this analysis. As shown in the table, aggregate costs start out at about $58 million and then drop to $33 million in 2014 when the fixed costs have been recovered. Fuel savings start out at about $15 million per year and reach $101 million in 2014. After 2014, increases in costs and savings are due to PFC sales and population growth.

As noted above, fixed costs due to certification and tooling are expected to actually be incurred on average one year prior to the start of the program. We estimate that the total fixed costs in that year would be about $107 million.

Table 10.8-2. Annual Nationwide PFC Costs and Fuel Savings

Calendar Year	Variable Costs	Fixed Costs	Total Costs	Fuel Savings	Net Cost
2008	0	0	0	0	0
2009	$ 30,194,245	$ 27,875,926	$58,070,171	$15,346,933	$42,723,237
2010	$ 30,798,130	$ 27,875,926	$58,674,056	$30,693,867	$27,980,189
2011	$ 31,414,092	$ 27,875,926	$59,290,018	$48,298,000	$10,992,018
2012	$ 32,042,374	$ 27,875,926	$59,918,300	$65,901,627	-$5,983,327
2013	$ 32,683,222	$ 27,875,926	$60,559,148	$83,505,760	-$22,946,612
2014	$ 33,336,886	$ -	$33,336,886	$101,109,387	-$67,772,501
2015	$ 34,003,624		$34,003,624	$102,522,480	-$68,518,856
2016	$ 34,683,696		$34,683,696	$103,935,898	-$69,252,201
2017	$ 35,377,370		$35,377,370	$105,349,189	-$69,971,819
2018	$ 36,084,918		$36,084,918	$106,762,481	-$70,677,563
2019	$ 36,806,616		$36,806,616	$108,175,772	-$71,369,156
2020	$ 37,542,748		$37,542,748	$109,589,064	-$72,046,316
2021	$ 38,293,603		$38,293,603	$111,056,401	-$72,762,798
2022	$ 39,059,475		$39,059,475	$112,523,738	-$73,464,263
2023	$ 39,840,665		$39,840,665	$113,991,075	-$74,150,410
2024	$ 40,637,478		$40,637,478	$115,458,412	-$74,820,934
2025	$ 41,450,228		$41,450,228	$116,925,749	-$75,475,522
2026	$ 42,279,232		$42,279,232	$118,393,086	-$76,113,854
2027	$ 43,124,817		$43,124,817	$119,860,423	-$76,735,606
2028	$ 43,987,313		$43,987,313	$121,327,760	-$77,340,447
2029	$ 44,867,059		$44,867,059	$122,795,097	-$77,928,038
2030	$ 45,764,401		$45,764,401	$124,262,434	-$78,498,034
2031	$ 46,679,689		$46,679,689	$125,675,726	-$78,996,037
2032	$ 47,613,282		$47,613,282	$127,089,018	-$79,475,735
2033	$ 48,565,548		$48,565,548	$128,502,309	-$79,936,761
2034	$ 49,536,859		$49,536,859	$129,915,601	-$80,378,742
2035	$ 50,527,596		$50,527,596	$131,328,892	-$80,801,296

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Chapter 11: Cost per Ton of Emissions Reduced

We have calculated the cost per ton for the rule based on the net present value of all costs incurred and all emission reductions generated from 2009 out to 2030. The time window is meant to capture both the early period of the program when there are a small number of compliant vehicles and portable fuel containers (PFCs) in use, and the later period when there is nearly complete turnover to compliant vehicles and PFCs. For the fuel benzene standards, which begin in 2011, the cost per ton estimates include costs and emission reductions that will occur from all vehicles and nonroad engines fueled with gasoline, PFCs, and gasoline distribution. We have also calculated the cost per ton of emissions reduced in the year 2030 using the annual costs and emissions reductions in that year alone. This number represents the long-term cost per ton of emissions reduced. All costs are in 2003 dollars.

To calculate the cost per ton for each pollutant reduced under the program, we divided the net present value of the annual costs by the net present value of the annual emissions reductions. We have not attempted to apportion costs across these various pollutants for purposes of the cost per ton calculations since there is no distinction in the technologies, or associated costs, used to control the pollutants. Instead, we have calculated costs per ton by assigning all costs to each individual pollutant. If we apportioned costs among the pollutants, the costs per ton presented here would be proportionally lowered depending on what portion of costs were assigned to the various pollutants. Results are presented using both a 3 percent and 7 percent discount rate.

This analysis uses the aggregate costs presented in Chapters 8 through 10 for vehicles, fuels, and PFCs as well as the emissions reductions presented in Chapter 2. In Section 11.1 through 11.3 we present the cost per ton estimates for vehicles, fuels, and PFCs separately. In Section, 11.4, we present the cost per ton estimates for the combined rule.

11.1 Cost per Ton for Vehicle Standards

We are establishing new cold temperature NMHC standards for light-duty vehicles, including medium-duty passenger vehicles. The new standard will be phased in from 2010 through 2015. As discussed in Chapter 8, we are projecting costs for R&D and facilities upgrades. For our cost estimates, we projected that these fixed costs would be recovered over the first five years of production for R&D and the first ten years of production for facilities upgrades. We are not projecting any variable costs, so after the first ten years of production, the overall annualized costs for the new standards are reduced to $0. For vehicles, we are establishing NMHC standards which would also VOC-based toxics including benzene. We are also expecting direct PM reductions due to the new NMHC standards. We have estimated NMHC, total MSATs, benzene, and PM emissions reductions associated with the cold temperature NMHC standards, as provided in Chapter 2. We have interpolated to estimate the emissions reductions for intermediate years not modeled. The annualized costs and emissions reduction estimates in tons for 2009 through 2030 are provided in Table 11.1-1 below.

Table 11.1-1 Aggregate Annualized Vehicle Costs and Emissions Reductions

Calendar Year	Cost	NMHC Reduction (tons)	Benzene Reduction (tons)	MSAT Reduction (tons)	PM Reduction (tons)
2009	$0	0	0	0	0
2010	$11,118,971	151,748	7,939	51,987	1,414
2011	$11,772,829	185,655	9,665	63,136	2,544
2012	$12,535,232	219,562	11,391	74,285	3,675
2013	$13,297,635	253,470	13,118	85,433	4,806
2014	$13,406,181	287,377	14,844	96,582	5,937
2015	$12,860,869	321,284	16,570	107,731	7,068
2016	$12,207,011	362,900	18,675	121,586	7,984
2017	$11,444,608	404,516	20,781	135,441	8,899
2018	$10,682,205	446,131	22,886	149,297	9,815
2019	$10,573,659	487,747	24,992	163,152	10,730
2020	$0	529,363	27,097	177,007	11,646
2021	$0	564,703	28,891	188,789	12,424
2022	$0	600,043	30,685	200,570	13,201
2023	$0	635,383	32,479	212,352	13,979
2024	$0	670,723	34,273	224,134	14,756
2025	$0	706,063	36,067	235,916	15,534
2026	$0	741,402	37,861	247,697	16,311
2027	$0	776,742	39,655	259,479	17,089
2028	$0	812,082	41,449	271,261	17,866
2029	$0	847,422	43,243	283,042	18,644
2030	$0	882,762	45,037	294,824	19,421

We have calculated the costs per ton using the net present value of the annualized costs of the program from 2009 through 2030 and the net present value of the annual emission reductions through 2030. We have also calculated the cost per ton of emissions reduced in the year 2030 using the annual costs and emissions reductions in that year alone. This number represents the long-term cost per ton of emissions reduced. As noted above, we have calculated costs per ton by assigning all costs to each individual pollutant. The results for each pollutant are provided in Table 11.1-2.

Table 11.1-2. Vehicle Aggregate Cost per Ton and Long-Term Annual Cost Per Ton ($2003)

	Discounted Lifetime Cost per ton at 3%	Discounted Lifetime Cost per ton at 7%	Long-Term Cost per Ton in 2030
NMHC	$14	$18	$0
Benzene	$270	$360	$0
Total MSATs	$42	$54	$0
Direct PM	$650	$870	$0

11.2 Cost Per Ton for Fuel Benzene Standard

We are adopting a new benzene fuel content standard which will go into effect in 2011. We have estimated the costs and benzene reductions for the new standards, which are provided in Chapters 9 and 2, respectively. Table 11.2-1 provides the estimated annualized aggregate costs and emissions reductions associated with the standard through 2030. The cost per ton estimates include costs and emission reductions that will occur from all vehicles and nonroad engines fueled with gasoline, as well as reductions from PFCs and gasoline distribution.

Table 11.2-1 Aggregate Annualized Fuels Costs and Benzene Reductions

Calendar Year	Cost	Benzene Reduction (tons)
2011	$354,384,659	18,095
2012	$360,089,040	17,975
2013	$365,080,373	17,855
2014	$369,715,182	17,735
2015	$374,349,992	17,615
2016	$378,984,801	17,616
2017	$383,619,610	17,616
2018	$388,254,420	17,617
2019	$393,245,753	17,617
2020	$397,880,563	17,618
2021	$402,158,848	17,821
2022	$406,437,134	18,023
2023	$410,358,896	18,226
2024	$414,280,657	18,428
2025	$418,558,943	18,631
2026	$422,837,229	18,833
2027	$427,472,038	19,036
2028	$432,106,847	19,238
2029	$436,385,133	19,441
2030	$441,019,943	19,643

The cost per ton of benzene reductions for fuels are shown in Table 11.2-2 using this same methodology as noted above.

Table 11.2-2. Fuel Benzene Aggregate Cost per Ton and Long-Term Annual Cost Per Ton ($2003)

	Discounted Lifetime Cost per ton at 3%	**Discounted Lifetime Cost per ton at 7%**	**Long-Term Cost per Ton in 2030**
Benzene	$22,400	$23,100	$22,500

11.3 Cost Per Ton for PFCs

We are adopting an HC standard for PFCs that will go into effect beginning in 2009. The estimated costs for the standard, and gasoline fuel savings, are presented in Chapter 10 and the emissions reductions are provided in Chapter 2. The new HC standard will also reduce VOC-based toxics including benzene. The stream of annualized costs, gasoline fuel savings, and emissions reduction estimates in tons for HC, benzene, and total MSATs for PFCs are provided in Table 11.3-1.

Table 11.3-1 Aggregate Annualized Portable Fuel Container Costs and Emissions Reductions

Calendar Year	Cost	Fuel Savings	HC Reduction (tons)	Benzene Reduction (tons)	MSAT Reduction (tons)
2009	$58,070,171	$15,346,933	30,290	100	2,590
2010	$58,674,056	$30,693,867	60,580	200	5,179
2011	$59,290,018	$48,298,000	95,325	294	8,149
2012	$59,918,300	$65,901,627	130,069	389	11,120
2013	$60,559,148	$83,505,760	164,814	483	14,090
2014	$33,336,886	$101,109,387	199,558	578	17,060
2015	$34,003,624	$102,522,480	202,347	672	17,357
2016	$34,683,696	$103,935,898	205,137	681	17,596
2017	$35,377,370	$105,349,189	207,926	690	17,835
2018	$36,084,918	$106,762,481	210,715	700	18,075
2019	$36,806,616	$108,175,772	213,505	709	18,314
2020	$37,542,748	$109,589,064	216,294	718	18,553
2021	$38,293,603	$111,056,401	219,190	728	18,801
2022	$39,059,475	$112,523,738	222,086	737	19,050
2023	$39,840,665	$113,991,075	224,982	747	19,298
2024	$40,637,478	$115,458,412	227,878	756	19,546
2025	$41,450,228	$116,925,749	230,775	766	19,795
2026	$42,279,232	$118,393,086	233,671	776	20,043
2027	$43,124,817	$119,860,423	236,567	785	20,291
2028	$43,987,313	$121,327,760	239,463	795	20,539
2029	$44,867,059	$122,795,097	242,359	804	20,788
2030	$45,764,401	$124,262,434	245,255	814	21,036

Table 11.3-2 provides estimated cost per ton for both overall HC reductions, overall MSAT reductions, and for benzene reductions. As with vehicles, we have calculated costs per ton by assigning all costs to each individual pollutant. If we apportioned costs among the pollutants, the costs per ton presented here would be proportionally lowered depending on what portion of costs were assigned to the various pollutants. The cost per ton estimates are presented

with and without gasoline fuel savings. Where the fuel savings outweigh the costs, the table presents cost per ton as $0, rather than calculating a negative value that has no clear meaning.

Table 11.3-2. PFC Aggregate Cost per Ton and Long-Term Annual Cost Per Ton ($2003)

	Discounted Lifetime Cost per ton at 3%	Discounted Lifetime Cost per ton at 7%	Long-Term Cost per Ton in 2030
HC without fuel savings	$240	$270	$190
HC with fuel savings	$0	$0	$0
Total MSATs without fuel savings	$2,800	$3,100	$2,200
Total MSATs with fuel savings	$0	$0	$0
Benzene without fuel savings	$74,500	$82,900	$56,200
Benzene with fuel saving	$0	$0	$0

11.4 Cost Per Ton for the Overall Proposal

The cost per ton estimates for each individual program are presented separately in the sections and tables above, and are part of the justification for each of the programs. For informational purposes, we also present below the cost per ton for the three programs combined. For MSATs and benzene, we have estimated overall costs by summing the cost shown above for fuels, vehicles, and PFCs, including gasoline fuel savings. For MSAT and benzene reductions, we have accounted for the interaction between reduced fuel benzene content due to the new standard and the reductions in benzene that are provided by the vehicle and PFC standards. These emissions reduction estimates are provided in Chapter 2. For HC, we have added the costs and HC reductions shown above for vehicles and PFCs, including fuel savings. Tables 11.4-1 and 11.4-2 provide the streams of costs and emissions reductions in tons for benzene and HC, respectively.

Table 11.4-1 Aggregate Annualized Overall Costs, and Benzene and MSAT Emissions Reductions*

Calendar Year	Cost Including Fuel Savings	Benzene Reduction (tons)	MSAT Reduction (tons)
2009	$42,723,237	100	2590
2010	$39,099,160	8,139	57,166
2011	$377,149,506	26,708	88,034
2012	$366,640,945	28,327	101,951
2013	$355,431,396	29,946	115,869
2014	$315,348,863	31,565	129,786
2015	$318,692,004	33,206	140,837
2016	$321,939,611	35,117	154,730
2017	$325,092,399	37,028	168,623
2018	$328,259,062	38,938	182,517
2019	$332,450,256	40,849	196,410
2020	$325,834,247	42,760	210,303
2021	$329,396,050	44,588	234,411
2022	$332,972,871	46,415	234,613
2023	$336,208,485	48,243	246,667
2024	$339,459,723	50,070	258,721
2025	$343,083,421	51,898	270,775
2026	$346,723,375	53,725	282,828
2027	$350,736,432	55,553	294,882
2028	$354,766,400	57,380	306,936
2029	$358,457,095	59,208	318,990
2030	$362,521,909	61,035	330,844

* includes fuels, vehicles, and portable fuel containers

Table 11.4-2 Aggregate Annualized Overall Costs and HC Emissions Reductions*

Calendar Year	Cost Including Fuel Savings	HC Reduction
2009	$42,723,237	30,290
2010	$39,099,160	212,328
2011	$22,764,847	280,980
2012	$6,551,906	349,631
2013	-$9,648,977	418,284
2014	-$54,366,320	486,935
2015	-$55,657,987	523,631
2016	-$57,045,190	568,036
2017	-$58,527,211	612,442
2018	-$59,995,358	656,847
2019	-$60,795,497	701,252
2020	-$72,046,316	745,657
2021	-$72,762,798	783,893
2022	-$73,464,263	822,129
2023	-$74,150,410	860,365
2024	-$74,820,934	898,601
2025	-$75,475,522	936,837
2026	-$76,113,854	975,073
2027	-$76,735,606	1,013,309
2028	-$77,340,447	1,051,545
2029	-$77,928,038	1,089,781
2030	-$78,498,034	1,128,017

* includes vehicles and gas cans

Table 11.4-3 provides the estimated combined cost per ton estimates for benzene, MSATs and HC. The HC estimates are reported as $0 because the gasoline fuel savings from PFCs offsets the combined costs of the vehicle and PFC programs.

Table 11.4-3. Overall Aggregate Cost per Ton and Long-Term Annual Cost Per Ton ($2003)

	Discounted Lifetime Cost per ton at 3%	Discounted Lifetime Cost per ton at 7%	Long-Term Cost per Ton in 2030
Benzene for fuels, vehicles, and PFCs combined	$8,200	$8,600	$5,900
Total MSATs for fuels, vehicles, and PFCs combined	$1,700	$1,800	$1,100
HC for vehicles and PFCs combined	$0	$0	$0

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Chapter 12: Cost-Benefit Analysis

12.1 Overview

Mobile sources are significant contributors to hazardous air pollutant emissions ("air toxics") across the country 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. 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. The final MSAT standards will help correct this market failure.

EPA is required by Executive Order (E.O.) 12866 to estimate the benefits and costs of major new pollution control regulations. Accordingly, the analysis presented here attempts to answer three questions: (1) what are the physical health and welfare effects of changes in ambient particulate matter (PM) resulting from direct PM emission reductions related to the cold temperature standards? (2) what is the monetary value of the changes in effects attributable to the final rule? and (3) how do the monetized benefits compare to the costs? It constitutes one part of EPA’s thorough examination of the relative merits of this regulation. At the same time, EPA notes that this analysis is for purposes of Executive Order 12866, rather than for purposes of showing that the final rule satisfies the requirements of section 202(l)(2) of the Act. That provision requires that emission reductions of mobile source air toxics be reduced to the greatest amount achievable with available technologies, considering cost among other factors. Section 202(l)(2) thus does not require a weighing of costs and benefits in determining what standards are achievable, and EPA did not do so in determining what standards to adopt.

This chapter reports EPA’s analysis of a subset of the public health and welfare impacts and associated monetized benefits to society associated with the final standards. In terms of emission benefits, we expect to see significant reductions in mobile source air toxics (MSATs) from the vehicle, fuel and PFC standards; reductions in VOCs (an ozone and $PM_{2.5}$ precursor) from the cold temperature vehicle and PFC standards; and reductions in direct $PM_{2.5}$ from the cold temperature vehicle standards. When translating emission benefits to health effects and monetized values, however, we have chosen to quantify only the PM-related benefits associated with the cold temperature vehicle standards.

We estimate that the final standards will reduce cancer and noncancer risk from reduced exposure to MSATs (as described in Chapter 3). However, we do not translate this risk reduction into benefits. We also do not quantify the benefits related to ambient reductions in ozone or $PM_{2.5}$ due to the VOC emission reductions that will occur as a result of the final standards. We describe in more detail below why these benefits are not quantified.

The analysis presented in this chapter uses a methodology generally consistent with benefits analyses performed for the recent analysis of the Clean Air Interstate Rule (CAIR) standards and the Clean Air Nonroad Diesel Rule (CAND).[1,2] For this reason, the current chapter avoids repeating this information and refers to the appropriate sections of each RIA. The benefits analysis relies on two major components:

1) Calculation of the impact of the cold temperature vehicle standards on the national direct PM emissions inventory for two future years (2020 and 2030).[A]
2) A benefits analysis to determine the changes in human health, both in terms of physical effects and monetary value, based on a PM benefits transfer approach that scales CAND results (see Section 12.2.).

A wide range of human health and welfare effects are linked to the emissions of direct PM and its resulting impact on ambient concentrations of $PM_{2.5}$. Potential human health effects associated with $PM_{2.5}$ range from premature mortality to morbidity effects linked to long-term (chronic) and shorter-term (acute) exposures (e.g., respiratory and cardiovascular symptoms resulting in hospital admissions, asthma exacerbations, and acute and chronic bronchitis [CB]). Welfare effects potentially linked to PM include materials damage and visibility impacts.

Table 12.1-1 summarizes the annual monetized health and welfare benefits associated with the cold temperature standards for two years, 2020 and 2030. The $PM_{2.5}$ benefits are scaled based on relative changes in direct PM emissions between this rule and the proposed Clean Air Nonroad Diesel (CAND) rule.[B] As explained in Section 12.2.1 of this chapter, the $PM_{2.5}$ benefits scaling approach is limited to those studies, health impacts, and assumptions that were used in the proposed CAND analysis. As a result, PM-related premature mortality is based on the updated analysis of the American Cancer Society cohort (ACS; Pope et al., 2002). However, it is important to note that since the CAND rule, EPA's Office of Air and Radiation (OAR) has adopted a different format for its benefits analysis in which characterization of the uncertainty in the concentration-response function is integrated into the main benefits analysis. Within this context, additional data sources are available, including a recent expert elicitation and updated analysis of the Six-Cities Study cohort (Laden et al., 2006). Please see the PM NAAQS RIA for an indication of the sensitivity of our results to use of alternative concentration-response functions.

The analysis presented here assumes a PM threshold of 3 $\mu g/m^3$, equivalent to background. Through the RIA for CAIR, EPA's consistent approach had been to model premature mortality associated with PM exposure as a nonthreshold effect; that is, with harmful effects to exposed populations modeled regardless of the absolute level of ambient PM concentrations. This approach had been supported by advice from EPA's technical peer review panel, the Science Advisory Board's Health Effects Subcommittee (SAB-HES). However,

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[A] We consider two future years for analysis (2020 and 2030). Gas can, vehicle, and fuels controls will be fully implemented by 2020. However, for vehicles, the in-use fleet will not be fully turned over to vehicles meeting the new standards by 2020. Therefore, we have analyzed 2030 to represent a more fully turned over fleet.

[B] Due to time and resource constraints, EPA scaled the final CAND benefits estimates from the benefits estimated for the CAND proposal. The scaling approach used in that analysis, and applied here, is described in the RIA for the final CAND rule.[2]

EPA's most recent $PM_{2.5}$ Criteria Document concludes that "the available evidence does not either support or refute the existence of thresholds for the effects of PM on mortality across the range of concentrations in the studies," (p. 9-44).[3] Furthermore, in the RIA for the PM NAAQS we used a threshold of 10 $\mu g/m^3$ based on recommendations by CASAC for the Staff Paper analysis. We consider the impact of a potential, assumed threshold in the PM-mortality concentration response function in Section 12.6.2.2 of the RIA.

Table 12.1-1. Estimated Monetized PM-Related Health Benefits of the Final Mobile Source Air Toxics Standards: Cold Temperature Controls

	Total Benefits[a, b, c] (billions 2003$)	
	2020	**2030**
Using a 3% discount rate	$3.3 + B	$6.3 + B
Using a 7% discount rate	$3.0 + B	$5.7 + B

[a] Benefits include avoided cases of mortality, chronic illness, and other morbidity health endpoints. PM-related mortality benefits estimated using an assumed PM threshold at background levels (3 $\mu g/m^3$). There is uncertainty about which assumed threshold to use and this may impact the magnitude of the total benefits estimate. For a more detailed discussion of this issue, please refer to Section 12.6.2.2 of the RIA.

[b] For notational purposes, unquantified benefits are indicated with a "B" to represent the sum of additional monetary benefits and disbenefits. A detailed listing of unquantified health and welfare effects is provided in Table 12.1-2 of the RIA.

[c] Results reflect the use of two different discount rates: 3 and 7 percent, which are recommended by EPA's *Guidelines for Preparing Economic Analyses*[4] and OMB Circular A-4.[5] Results are rounded to two significant digits for ease of presentation and computation.

This chapter specifically assesses the direct PM-related benefits of the cold temperature vehicle standards. Other standards in this rulemaking, such as the cold temperature vehicle and PFC standards, will also reduce the national emissions inventory of precursors to ozone, such as VOCs. Exposure to ozone has been linked to a variety of respiratory effects including hospital admissions and illnesses resulting in school absences. In addition, recent analyses (reflected in the 2006 Ozone Criteria Document for the current ozone review cycle under section 109(d) of the Act) provide evidence that short-term ozone exposure is associated with increased premature mortality independent of exposure to PM. Ozone can also adversely affect the agricultural and forestry sectors by decreasing yields of crops and forests. Although ozone benefits are typically quantified in regulatory impact analyses, we do not evaluate them for this analysis.

We estimate that there will be demonstrable VOC reductions as a result of the cold temperature vehicle standards. However, we assume that these emissions will not have a measurable impact on ozone formation since the standards seek to reduce VOC emissions at cold ambient temperatures and ozone formation is primarily a warm ambient temperature issue. There will, however, likely be benefits associated with VOC emission reductions resulting from the PFC standards. In Chapter 3, we discuss that the ozone modeling conducted for the PFC standards results in a net reduction in the average population-weighted ozone design value metric measured within the modeled domain (37 Eastern states and the District of Columbia). The net improvement is very small, however, and will likely lead to negligible monetized benefits. We therefore do not estimate ozone benefits for the PFC standards due to the magnitude of this change and the uncertainty present in the modeling. Instead, we acknowledge that this analysis may underestimate the benefits associated with reductions in ozone precursor emissions achieved by the various standards, and we will discuss them qualitatively within this chapter.

The VOC reductions resulting from the cold temperature vehicle standards and PFC standards will also likely reduce secondary $PM_{2.5}$ formation. However, we did not quantify the impacts of these reductions on ambient $PM_{2.5}$ or estimate any resulting benefits. As described further below, we estimated PM benefits by scaling from a previous analysis, and this analysis did not examine the relationship between VOC reductions and ambient PM. As a result, we did not quantify PM benefits associated with this rule's VOC reductions, and we acknowledge that this analysis may therefore underestimate benefits.

There will also be significant reduction in emissions of mobile source-related air toxics with the final standards in place (including benzene, 1,3-butadiene, formaldehyde, acetaldehyde, acrolein, naphthalene, and other toxic air pollutants). While there will be substantial benefits associated with air toxic pollutant reductions, notably with regard to reductions in exposure and risk (see Chapter 3), we do not attempt to extrapolate this risk reduction to monetize those benefits. This is primarily because available tools and methods to assess air toxics risk from mobile sources at the national scale are not adequate for extrapolation to 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; these tools are discussed in Chapter 3). 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.[6] While EPA has since improved the tools, there remain critical limitations for estimating incidence and assessing monetized benefits of reducing mobile source air toxics.

In addition to inherent limitations in the tools for national-scale modeling of air quality and exposure, there is a lack of epidemiology data for air toxics in the general population. Therefore, we must rely on health endpoints estimated from occupational or animal exposure studies. There are several limitations in our ability to quantify and value changes in incidence of health effects. For the MSATs of greatest concern, we are currently unable to estimate cessation lag, which is the time between reduction in exposure and decline in risk to "steady state level." We have not resolved the analytical challenges associated with quantifying partial lifetime probabilities of cancer for different age groups or estimating changes in survival rates over time. In addition, we are currently unable to estimate the premium people are willing to pay to avoid cancer. There is also no data on the cost of treating leukemia cases and little data on how to value non-fatal leukemias. Given all the limitations in our ability to develop incidence estimates and to monetize willingness to pay or treatment costs, a quantitative benefits analysis for benzene would not be meaningful or informative. We continue to work to address these limitations, and we are exploring the feasibility of a quantitative benefits assessment for air toxics through a benzene case study as part of the revised study of "The Benefits and Costs of the Clean Air Act" (also known as the "Section 812" report).[C] In this case study, we are attempting to monetize the benefits of reduced cancer incidence, specifically leukemia, and are not addressing other cancer or noncancer endpoints.

Table 12.1-2 lists the full complement of human health and welfare effects associated with PM, ozone and air toxics, and identifies those effects that are quantified for the primary estimate and those that remain unquantified because of current limitations in methods or available data.

Table 12.1-2. Human Health and Welfare Effects of Pollutants Affected by the Final MSAT Standards

Pollutant/Effect	Quantified and Monetized in Base Estimates[a]	Unquantified Effects - Changes in:
PM/Health[b]	Premature mortality based on cohort study estimates[c] 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) Respiratory symptoms (asthmatic population) Infant mortality	Premature mortality: short-term exposures[d] Subchronic bronchitis cases Low birth weight Pulmonary function Chronic respiratory diseases other than chronic bronchitis Nonasthma respiratory emergency room visits UVb exposure (+/-)[e]
PM/Welfare		Visibility in Southeastern Class I areas Visibility in northeastern and Midwestern Class I areas Household soiling Visibility in western U.S. Class I areas Visibility in residential and non-Class I areas UVb exposure (+/-)[e]

[C] The analytic blueprint for the Section 812 benzene case study can be found at http://www.epa.gov/air/sect812/appendixi51203.pdf.

Pollutant/Effect	**Quantified and Monetized in Base Estimates**[a]	**Unquantified Effects - Changes in:**
Ozone/Health[f]		Premature mortality: short-term exposures[g] Hospital admissions: respiratory Emergency room visits for asthma Minor restricted-activity days School loss days Asthma attacks Cardiovascular emergency room visits Acute respiratory symptoms Chronic respiratory damage Premature aging of the lungs Nonasthma respiratory emergency room visits UVb exposure (+/-)[e]
Ozone/Welfare		Decreased outdoor worker productivity Yields for: - Commercial forests - Fruits and vegetables, and - Other commercial and noncommercial crops Damage to urban ornamental plants Recreational demand from damaged forest aesthetics Ecosystem functions UVb exposure (+/-)[e]
MSAT Health[h]		Cancer (benzene, 1,3-butadiene, formaldehyde, acetaldehyde, naphthalene) 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) Neurotoxicity (n-hexane, toluene, xylenes)
MSAT Welfare[h]		Direct toxic effects to animals Bioaccumulation in the food chain Damage to ecosystem function Odor

[a] Primary quantified and monetized effects are those included when determining the primary estimate of total monetized benefits of the final standards.

[b] In addition to primary economic endpoints, there are a number of biological responses that have been associated with PM health effects including morphological changes and altered host defense mechanisms. The public health impact of these biological responses may be partly represented by our quantified endpoints.

[c] Cohort estimates are designed to examine the effects of long term exposures to ambient pollution, but relative risk estimates may also incorporate some effects due to shorter-term exposures (see Kunzli, 2001 for a discussion of this issue).[7]

[d] While some of the effects of short-term exposure are likely to be captured by the cohort estimates, there may be additional premature mortality from short-term PM exposure not captured in the cohort estimates included in the primary analysis.
[e] May result in benefits or disbenefits. See Section 12.5.3. for more details.
[f] In addition to primary economic endpoints, there are a number of biological responses that have been associated with ozone health including increased airway responsiveness to stimuli, inflammation in the lung, acute inflammation and respiratory cell damage, and increased susceptibility to respiratory infection. The public health impact of these biological responses may be partly represented by our quantified endpoints.
[g] EPA sponsored a series of meta-analyses of the ozone mortality epidemiology literature, published in the July 2005 volume of the journal Epidemiology, which found that short-term exposures to ozone may have a significant effect on daily mortality rates, independent of exposure to PM. EPA is currently considering how to include an estimate of ozone mortality in its benefits analyses.
[h] The categorization of unquantified toxic health and welfare effects is not exhaustive.

Figure 12.1-1 illustrates the major steps in the PM benefits analysis. Given the change in direct PM emissions modeled for the cold temperature vehicle standards, we use a benefits transfer approach to scale PM benefits estimated for the CAND analysis (see Section 12.2 for a description of the scaling approach). For the CAND analysis, EPA ran a sophisticated photochemical air quality model, the Regional Modeling System for Aerosols and Deposition (REMSAD), to estimate baseline and post-control ambient concentrations of PM for each future year (2020 and 2030). The estimated changes in ambient concentrations were then combined with population projections to estimate population-level potential exposures to changes in ambient concentrations. Changes in population exposure to ambient air pollution were then input to impact functions[D] to generate changes in the incidence of health effects. The resulting changes in incidence were then assigned monetary values, taking into account adjustments to values for growth in real income out to the year of analysis (values for health and welfare effects are in general positively related to real income levels). Values for individual health and welfare effects were summed to obtain an estimate of the total monetary value of the changes in emissions. Finally, we scale the CAND results to reflect the magnitude of the direct PM emissions changes we estimate will occur as a result of the cold temperature standards.

Benefits estimates calculated for the CAND analysis, and scaled for the cold temperature standards, were generated using the Environmental Benefits Mapping and Analysis Program (BenMAP). BenMAP is a computer program developed by EPA that integrates a number of the modeling elements used in previous RIA's (e.g., interpolation functions, population projections, health impact functions, valuation functions, analysis and pooling methods) to translate modeled air concentration estimates into health effect incidence estimates and monetized benefit

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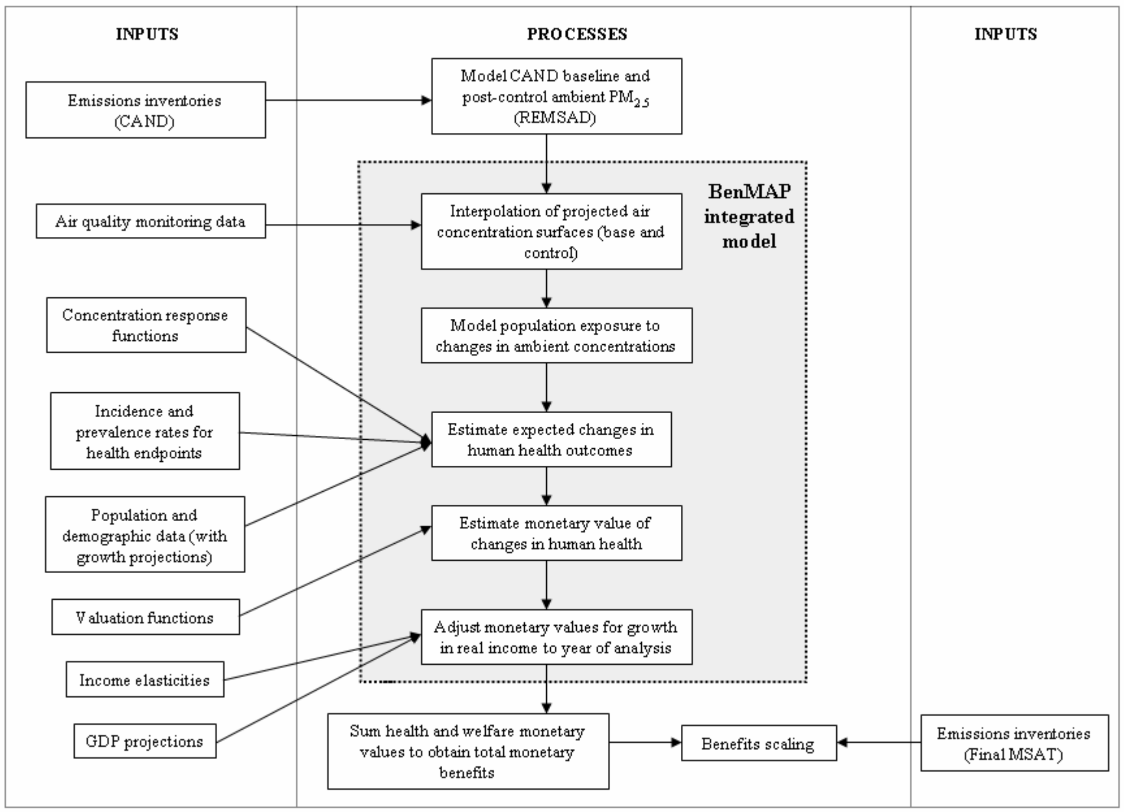
[D] The term "impact function" as used here refers to the combination of a) an effect estimate obtained from the epidemiological literature, b) the baseline incidence estimate for the health effect of interest in the modeled population, c) the size of that modeled population, and d) the change in the ambient air pollution metric of interest. These elements are combined in the impact function to generate estimates of changes in incidence of the health effect. The impact function is distinct from the C-R function, which strictly refers to the estimated equation from the epidemiological study relating incidence of the health effect and ambient pollution. We refer to the specific value of the relative risk or estimated coefficients in the epidemiological study as the "effect estimate." In referencing the functions used to generate changes in incidence of health effects for this RIA, we use the term "impact function" rather than C-R function because "impact function" includes all key input parameters used in the incidence calculation.

estimates. Interested parties may wish to consult the webpage http://www.epa.gov/ttn/ecas/benmodels.html for more information.

Figure 12.1-1. Key Steps in Air Quality Modeling Based Benefits Analysis



All of the benefit estimates for the final control options in this analysis are based on an analytical structure and sequence similar to that used in the benefits analyses for the CAND final rule, the CAIR rule, and, when feasible, the final PM NAAQS analysis.[E] By adopting the major design elements, models, and assumptions developed in recent RIAs, we rely on methods that have already received extensive review by the independent Science Advisory Board (SAB), by the public, and by other federal agencies. In addition, we will be working through the next section 812 prospective study to enhance our methods.[F]

This chapter is organized as follows. In Section 12.2, we provide an overview of the air quality impacts modeled for the final standards that are used as inputs to the benefits analysis. In

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[E] See: Clean Air Nonroad Diesel final rule (69 FR 38958, June 29, 2004); Clean Air Interstate final rule (70 FR 25162, May 12, 2005); PM NAAQS (71 FR 61144, Oct. 17, 2006).

[F] Interested parties may want to consult the webpage: http://www.epa.gov/science1 regarding components of the 812 prospective analytical blueprint.

Section 12.3, we document key differences between this benefits analysis and the benefits analysis completed for the final CAIR and CAND rules. This section also presents and discusses the key inputs and methods used in the benefits analysis. In Section 12.4, we report the results of the analysis for human health and welfare effects. Section 12.5 qualitatively describes benefits categories that are omitted from this analysis, due either to inadequate methods or resources. Section 12.6 discusses how we incorporate uncertainty into our analysis. Section 12.7 discusses the health-based cost-effectiveness analysis for the final standards. Finally, in Section 12.8, we present a comparison of the costs and benefits associated with the final standards.

12.2 Air Quality Impacts

This section summarizes the methods for and results of estimating air quality for the 2020 and 2030 base case and final control scenario for the purposes of the benefits analysis. EPA has focused on the health, welfare, and ecological effects that have been linked to ambient changes in $PM_{2.5}$ related to direct PM emission reductions estimated to occur due to the cold temperature vehicle standards. We do this by scaling the modeled relationship between emissions and ambient PM concentrations observed for the CAND analysis.[8]

12.2.1 PM Air Quality Impact Estimation

To estimate $PM_{2.5}$ benefits resulting from the cold temperature vehicle standards, we rely on a benefits transfer technique. The benefits transfer approach uses as its foundation the relationship between emission reductions and ambient $PM_{2.5}$ concentrations modeled for the Clean Air Nonroad Diesel (CAND) proposal.[G] For a given future year, we first calculate the ratio between CAND direct $PM_{2.5}$ emission reductions and direct $PM_{2.5}$ emission reductions associated with the final standards (final emission reductions/CAND emission reductions, displayed in Table 12.2-1). We multiply this ratio by the percent that direct $PM_{2.5}$ contributes towards population-weighted reductions in total $PM_{2.5}$ due to the CAND standards (displayed in Table 12.2-2). This calculation results in a "benefits apportionment factor" for the relationship between direct PM emissions and primary $PM_{2.5}$ (displayed in Table 12.2-3), which is then applied to the BenMAP-based incidence and monetized benefits from the CAND proposal. In this way, we apportion the results of the proposed CAND analysis to its underlying direct PM emission reductions and scale the apportioned benefits to reflect differences in emission reductions between the two rules.[H] This benefits transfer method is consistent with the approach used in other recent mobile and stationary source rules.[I] We refer the reader to the final CAND RIA for more details on this benefits transfer approach.[9]

[G] See 68 FR 28327, May 23, 2003.

[H] Note that while the final MSAT standards also control VOCs, which contribute to PM formation, the benefits transfer scaling approach only scales benefits based on NOx, SO2, and direct PM emission reductions. PM benefits will likely be underestimated as a result, though we are unable to estimate the magnitude of the underestimation.

[I] See: Clean Air Nonroad Diesel final rule (69 FR 38958, June 29, 2004); Nonroad Large Spark-Ignition Engines and Recreational Engines standards (67 FR 68241, November 8, 2002); Final Industrial Boilers and Process Heaters NESHAP (69 FR 55217, September 13, 2004); Final Reciprocating Internal Combustion Engines NESHAP (69 FR 33473, June 15, 2004); Final Clean Air Visibility Rule (EPA-452/R-05-004, June 15, 2005); Ozone Implementation Rule (70 FR 71611, November 29, 2005).

Table 12.2-1. Comparison of 48-state Emission Reductions in 2020 and 2030 Between the CAND and Final Cold Temperature Standards

Emissions Species	Reduction from Baseline (tons)		Ratio of Reductions (MSAT/ CAND)
	CAND Modeling Inputs[a]	Cold Temperature Emissions Changes[b]	
2020			
Direct $PM_{2.5}$	98,121	11,646	0.119
2030			
Direct $PM_{2.5}$	138,208	19,421	0.141

[a] Includes all affected nonroad sources: land-based, recreational marine, commercial marine, and locomotives. See the CAND RIA for more information regarding the CAND emission inventories.

[b] Includes changes to the light duty onroad vehicles inventory.

Table 12.2-2. Apportionment of Modeled CAND Preliminary Control Option Population-weighted Change in Ambient $PM_{2.5}$ to Nitrate, Sulfate, and Primary Particles

	2020		2030	
	Population-weighted Change (μg/m3)	Percent of Total Change	Population-weighted Change (μg/m3)	Percent of Total Change
Total $PM_{2.5}$	0.316	--	0.438	--
Sulfate	0.071	22.5%	0.090	20.5%
Nitrate	0.041	13.1%	0.073	16.8%
Primary PM	0.203	64.4%	0.274	62.7%

Source: CAND RIA, Chapter 9.

Table 12.2-3. Calculation of $PM_{2.5}$ Benefits Apportionment Factor for Final Cold Temperature-Related Direct PM Emission Reductions

	2020			2030		
	Ratio of Emission Reductions[a] (1)	% of Total Ambient Change[b] (2)	Benefits Apportionment Factor (1*2)	Ratio of Emission Reductions[a] (3)	% of Total Ambient Change[b] (4)	Benefits Apportionment Factor (3*4)
Direct PM Emissions	0.119	0.644	0.088	0.141	0.627	0.076

[a] Calculated by dividing cold temperature vehicle emission reductions by CAND emission reductions. See Table 12.2-1.
[b] See Table 12.2-2.

12.3 PM-Related Health Benefits Estimation - Methods and Inputs

The analytical approach used in this benefits analysis is largely the same approach used in the Final CAIR and Final CAND benefits analyses and the reader is referred to each RIA for details on the benefits methods and inputs. This analysis, however, also reflects advances in data and methods in epidemiology, economics, and health impact estimation. Updates to the assumptions and methods used in estimating $PM_{2.5}$-related benefits since the analysis for the CAIR and CAND rules include the following:

- We have updated our projections of mortality incidence rates to be consistent with the U.S. Census population projections that form the basis of our future population estimates. This approach combines Centers for Disease Control (CDC) county-level mortality rate data for the years 1996-1998 with US Census Bureau mortality projections out to 2050. To estimate age- and county-specific mortality rates in years 2020 and 2030, we calculated adjustment factors, based on a series of Census Bureau projected national mortality rates, to adjust the CDC Wonder age- and county-specific mortality rates in 1996-1998 to corresponding rates for each future year. This approach is different than the fixed 1996-1998 CDC mortality rate data used in the CAND and CAIR analyses, and results in a reduction in mortality impacts in future years as overall mortality rates are projected to decline for most age groups. A memorandum drafted by Abt Associates (Abt Associates, 2005) contains complete details regarding the derivation of mortality rate adjustment factors, and estimation of future-year mortality rates used in the analysis.[10] The scaled mortality benefits for the final standards have been updated accordingly.

- Use of a revised mortality lag assumption. In the Final CAND, we used a five-year segmented lag. Since that analysis, upon which the PM benefits transfer scaling approach is based, the SAB Health Effects Subcommittee (HES) recommended that until additional research has been completed, EPA should assume a segmented lag

> structure characterized by 30 percent of mortality reductions occurring in the first year, 50 percent occurring evenly over years 2 to 5 after the reduction in $PM_{2.5}$, and 20 percent occurring evenly over the years 6 to 20 after the reduction in $PM_{2.5}$. The distribution of deaths over the latency period is intended to reflect the contribution of short-term exposures in the first year, cardiopulmonary deaths in the 2- to 5-year period, and long-term lung disease and lung cancer in the 6- to 20-year period. For future analyses, the specific distribution of deaths over time will need to be determined through research on causes of death and progression of diseases associated with air pollution. It is important to keep in mind that changes in the lag assumptions do not change the total number of estimated deaths but rather the timing of those deaths. This approach is different than the 5-year segmented lag used in the CAND analysis, and the scaled benefits analysis of the final standards has been updated accordingly.

For the purposes of this RIA, the health impacts analysis is limited to those health effects that are directly linked to ambient levels of air pollution and specifically to those linked to PM. The specific studies from which effect estimates for the primary analysis are drawn are included in Table 12.3-1. The specific unit values used for economic valuation of health endpoints are included in Table 12.3-2.

Table 12.3-1. Endpoints and Studies Used to Calculate Total Monetized Health Benefits[a]

Endpoint	Pollutant	Study	Study Population
Premature Mortality			
Premature mortality — ACS cohort study, all-cause	$PM_{2.5}$	Pope et al. (2002)[11]	>29 years
Premature mortality — all-cause	$PM_{2.5}$	Woodruff et al. (1997)[12]	Infant (<1 year)
Chronic Illness			
Chronic bronchitis	$PM_{2.5}$	Abbey et al. (1995)[13]	>26 years
Nonfatal heart attacks	$PM_{2.5}$	Peters et al. (2001)[14]	Adults
Hospital Admissions			
Respiratory	$PM_{2.5}$	Pooled estimate: Moolgavkar (2003)[15]—ICD 490-496 (COPD) Ito (2003)[16]—ICD 490-496 (COPD)	>64 years
	$PM_{2.5}$	Moolgavkar (2000)[17]—ICD 490-496 (COPD)	20–64 years
	$PM_{2.5}$	Ito (2003)—ICD 480-486 (pneumonia)	>64 years
	$PM_{2.5}$	Sheppard (2003)[18]—ICD 493 (asthma)	<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	$PM_{2.5}$	Norris et al. (1999)[19]	0–18 years
Other Health Endpoints			
Acute bronchitis	$PM_{2.5}$	Dockery et al. (1996)[20]	8–12 years
Upper respiratory symptoms	$PM_{2.5}$	Pope et al. (1991)[21]	Asthmatics, 9–11 years
Lower respiratory symptoms	$PM_{2.5}$	Schwartz and Neas (2000)[22]	7–14 years
Asthma exacerbations	$PM_{2.5}$	Pooled estimate: Ostro et al. (2001)[23] (cough, wheeze and shortness of breath) Vedal et al. (1998)[24] (cough)	6–18 years[b]
Work loss days	$PM_{2.5}$	Ostro (1987)[25]	18–65 years
MRADs	$PM_{2.5}$	Ostro and Rothschild (1989)[26]	18–65 years

[a] The endpoints and studies used for the primary estimate of benefits associated with the final rule have been subject to external technical guidance and review, including the Health Effects Subgroup (HES) of the EPA's Science Advisory Board (SAB) and the Office of Management and Budget (OMB).

[b] 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 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.

Table 12.3-2. 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)	$5,500,000	$6,600,000	$6,800,000	Point estimate is the mean of a normal distribution with a 95 percent confidence interval between $1 and $10 million. Confidence interval is based on two meta-analyses of the wage-risk VSL literature: $1 million represents the lower end of the interquartile range from the Mrozek and Taylor (2002)[27] meta-analysis and $10 million represents the upper end of the interquartile range from the Viscusi and Aldy (2003)[28] meta-analysis. The VSL represents the value of a small change in mortality risk aggregated over the affected population.
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][29]) 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)				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).[30] Direct medical costs are based on simple average of estimates from Russell et al. (1998)[31] and Wittels et al. (1990).[32] 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)
3% discount rate				
Age 0–24	$66,902	$66,902	$66,902	
Age 25–44	$74,676	$74,676	$74,676	
Age 45–54	$78,834	$78,834	$78,834	
Age 55–65	$140,649	$140,649	$140,649	
Age 66 and over	$66,902	$66,902	$66,902	
7% discount rate				
Age 0–24	$65,293	$65,293	$65,293	
Age 25–44	$73,149	$73,149	$73,149	
Age 45–54	$76,871	$76,871	$76,871	
Age 55–65	$132,214	$132,214	$132,214	
Age 66 and over	$65,293	$65,293	$65,293	

(continued)

Table 12.3-2. 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)[33] (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)[34] and (2) $260.67, from Stanford et al. (1999).[35]

(continued)

Table 12.3-2. 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)[36] 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).[37] 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).[38]

(continued)

Table 12.3-2. 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.
Minor Restricted Activity Days (MRADs)	$51	$54	$55	Median WTP estimate to avoid one MRAD from Tolley et al. (1986).[39]

[a] Although the unit values presented in this table are in year 2000 dollars, all monetized annual benefit estimates associated with the final standards have been inflated to reflect values in year 2003 dollars. We use the Consumer Price Indexes to adjust both WTP- and COI-based benefits estimates to 2003 dollars from 2000 dollars.[40] For WTP-based estimates, we use an inflation factor of 1.07 based on the CPI-U for "all items." For COI-based estimates, we use an inflation factor of 1.14 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 Chapter 9 of the CAND regulatory impact analysis (EPA, 2004). 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.

EPA typically estimates the welfare impacts of effects such as changes in recreational visibility (related to reductions in ambient PM) and agricultural productivity (related to reductions in ambient ozone) in its RIAs of air quality policy. For the analysis of the final standards, however, we are unable to quantitatively characterize these impacts because of limited data availability; we are not quantifying ozone benefits related to the final standards and the PM scaling approach does not provide the spatial detail necessary to attribute specific air quality improvements to specific areas of visual interest (Class I areas). Instead, we discuss these welfare effects qualitatively in Section 12.5 of this chapter. We also qualitatively describe the impacts of other environmental and ecological effects for which we do not have an economic value.

12.4 Benefits Analysis Results for the Final Cold Temperature Vehicle Standards

Applying the impact and valuation functions described previously in this chapter to the estimated changes in $PM_{2.5}$ associated with the final cold temperature vehicle standards results in estimates of the changes in physical damages (e.g., premature mortalities, cases, admissions) and the associated monetary values for those changes. Estimates of physical health impacts are presented in Table 12.4-1. Monetized values for those health endpoints are presented in Table 12.4-2, along with total aggregate monetized benefits. All of the monetary benefits are in constant-year 2003 dollars.

Table 12.4-1. Estimated Reduction in Incidence of Adverse Health Effects Related to the Final Cold Temperature Standards[a]

Health Effect	2020 Incidence Reduction	2030
PM-Related Endpoints		
Premature Mortality[b,c] Adult, age 30+ and Infant, age <1 year	480	880
Chronic bronchitis (adult, age 26 and over)	330	570
Nonfatal myocardial infarction (adults, age 18 and older)	810	1,600
Hospital admissions—respiratory (all ages)[d]	260	530
Hospital admissions—cardiovascular (adults, age >18)[e]	210	390
Emergency room visits for asthma (age 18 years and younger)	350	610
Acute bronchitis (children, age 8–12)	780	1,400
Lower respiratory symptoms (children, age 7–14)	9,300	16,000
Upper respiratory symptoms (asthmatic children, age 9–18)	7,000	12,000
Asthma exacerbation (asthmatic children, age 6–18)	12,000	20,000
Work loss days (adults, age 18–65)	62,000	100,000
Minor restricted-activity days (adults, age 18–65)	370,000	600,000

[a] Incidences are rounded to two significant digits. PM estimates are nationwide.

[b] PM premature mortality impacts for adults are based on application of the effect estimate derived from the ACS cohort study (Pope et al., 2002).[41] Infant premature mortality based upon studies by Woodruff, et al 1997.[42]

[c] PM-related mortality benefits estimated using an assumed PM threshold at background levels (3 $\mu g/m^3$). There is uncertainty about which threshold to use and this may impact the magnitude of the total benefits estimate. For a more detailed discussion of this issue, please refer to Section 12.6.2.2 of the RIA.

[d] Respiratory hospital admissions for PM include admissions for COPD, pneumonia, and asthma.

[e] Cardiovascular hospital admissions for PM include total cardiovascular and subcategories for ischemic heart disease, dysrhythmias, and heart failure.

Table 12.4-2. Estimated Monetary Value in Reductions in Incidence of Health and Welfare Effects (in millions of 2003$)[a,b]

PM-Related Health Effect	2020 Estimated Value of Reductions	2030 Estimated Value of Reductions
Premature mortality[c,d,e]		
Adult, age 30+ and Infant, < 1 year		
3% discount rate	$3,100	$5,800
7% discount rate	$2,800	$5,200
Chronic bronchitis (adults, 26 and over)	$150	$260
Non-fatal acute myocardial infarctions		
3% discount rate	$79	$150
7% discount rate	$76	$140
Hospital admissions for respiratory causes	$4.7	$10
Hospital admissions for cardiovascular causes	$5.0	$9.1
Emergency room visits for asthma	$0.11	$0.20
Acute bronchitis (children, age 8–12)	$0.32	$0.56
Lower respiratory symptoms (children, 7–14)	$0.16	$0.29
Upper respiratory symptoms (asthma, 9–11)	$0.20	$0.35
Asthma exacerbations	$0.56	$1.0
Work loss days	$9.1	$14
Minor restricted-activity days (MRADs)	$21	$35
Monetized Total [f]		
Base Estimate:		
3% discount rate	$3,300+ B	$6,300+ B
7% discount rate	$3,000+ B	$5,700+ B

[a] Monetary benefits are rounded to two significant digits for ease of presentation and computation. PM benefits are nationwide.

[b] Monetary benefits adjusted to account for growth in real GDP per capita between 1990 and the analysis year (2020 or 2030)

[c] PM-related mortality benefits estimated using an assumed PM threshold at background levels (3 µg/m^3). There is uncertainty about which threshold to use and this may impact the magnitude of the total benefits estimate. For a more detailed discussion of this issue, please refer to Section 12.6.2.2 of the RIA.

[d] Valuation assumes discounting over the SAB recommended 20-year segmented lag structure described earlier. Results reflect the use of 3 percent and 7 percent discount rates consistent with EPA and OMB guidelines for preparing economic analyses (EPA, 2000; OMB, 2003).[43,44]

[e] Adult premature mortality estimates based upon the ACS cohort study (Pope et al., 2002).[45] Infant premature mortality based upon Woodruff et al 1997.[46]

[f] B represents the monetary value of health and welfare benefits and disbenefits not monetized. A detailed listing is provided in Table 12.1-2.

In addition to omitted benefits categories such as air toxics, ozone, and various welfare effects, not all known direct PM-related health and welfare effects could be quantified or monetized. Furthermore, we did not quantify reductions in secondary $PM_{2.5}$ and the associated health and welfare effects. The monetized value of all of these unquantified effects is represented by adding an unknown “B” to the aggregate total. The estimate of total monetized health benefits of the final MSAT control package is thus equal to the subset of monetized PM-related health benefits plus B, the sum of the nonmonetized health and welfare benefits.

Total monetized benefits are dominated by benefits of mortality risk reductions. The primary estimate projects that the final cold temperature vehicle standards will result in 480 avoided premature deaths annually in 2020 and 880 avoided premature deaths annually in 2030. The increase in annual benefits from 2020 to 2030 reflects additional emission reductions from the final cold temperature vehicle standards, as well as increases in total population and the average age (and thus baseline mortality risk) of the population.

Our estimate of total monetized benefits in 2020 for the final cold temperature vehicle standards is $3.3 billion using a three percent discount rate and $3.0 billion using a seven percent discount rate. In 2030, the monetized benefits are estimated at $6.3 billion using a three percent discount rate and $5.7 billion using a seven percent discount rate. The monetized benefit associated with reductions in the risk of premature mortality, which accounts for $3.1 billion in 2020 and $5.8 billion in 2030 (assuming a three percent discount rate), is over 90 percent of total monetized health benefits. The next largest benefit is for reductions in chronic illness (CB 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 premature mortalities, yet work loss days account for only a very small fraction of total monetized benefits. This reflects the fact that many of the less severe health effects, while more common, are valued at a lower level than the more severe health effects. Also, some effects, such as hospital admissions, are valued using a proxy measure of willingness-to-pay (e.g., cost-of-illness).[J] As such, the true value of these effects may be higher than that reported in Table 12.4-2.

12.5 Unquantified Health and Welfare Effects

In considering the monetized benefits estimates, the reader should remain aware of the many limitations of conducting the analyses mentioned throughout this RIA. One significant limitation of both the health and welfare benefits analyses is the inability to quantify many of the effects listed in Table 12.1-2. For many health and welfare effects, such as changes in health effects due to reductions in air toxics exposure, changes in ecosystem functions and PM-related materials damage, reliable impact functions and/or valuation functions are not currently available. In general, if it were possible to monetize these benefit categories, the benefits estimates presented in this analysis would increase, although the magnitude of such an increase is highly uncertain.

Other welfare effects that EPA has monetized in past RIAs, such as recreational

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[J] See Table 12.3-2 for a description of how each particular endpoint is valued.

visibility, are omitted from the current analysis. Due to time and resource constraints, we did not run the full-scale PM air quality modeling needed to estimate this benefit category. Instead, we relied on the PM scaling benefits transfer approach that provides analytical efficiency but sacrifices the full range of outputs typically generated when models such as the Community Multiscale Air Quality (CMAQ) model or the Regional Modeling System for Aerosols and Deposition (REMSAD) are run.

Unquantified benefits are qualitatively discussed in the following health and welfare effects sections. In addition to unquantified benefits, there may also be environmental costs (disbenefits) that we are unable to quantify, which we qualitatively discuss as well. The net effect of excluding benefit and disbenefit categories from the estimate of total benefits depends on the relative magnitude of the effects. Although we are not currently able to estimate the magnitude of these unquantified and unmonetized benefits, specific categories merit further discussion. EPA believes, however, the unquantified benefits associated with health and non-health benefit categories are likely significant and that their omission lends a downward bias to the monetized benefits presented in this analysis.

12.5.1 Human Health Impact Assessment

In addition to the $PM_{2.5}$ health effects discussed above, there is emerging evidence that human exposure to PM may be associated a number of health effects not quantified in this analysis (see Table 12.1-2). An improvement in ambient $PM_{2.5}$ concentrations may reduce the number of incidences within each of these unquantified effect categories that the U.S. population would experience. Although these health effects are believed to be PM-induced, effect estimates are not available for quantifying the benefits associated with reducing these effects. Furthermore, the health effects associated with reductions in air toxics are not quantified in this analysis. The health endpoints associated with individual air toxic reductions achieved by the final standards are discussed in Chapter 1 of the RIA.

Other standards included in this final rulemaking, such as the PFC standards, will also reduce the national emissions inventory of precursors to ozone, such as VOCs. Exposure to ozone has been linked to a variety of respiratory effects including hospital admissions, emergency room visits, minor restricted activity days, worker productivity and illnesses resulting in school absences. Emerging evidence has also shown that human exposure to ozone may be associated with a number of other health effects not quantified in this analysis (see Table 12.1-2). Ozone can also adversely affect the agricultural and forestry sectors by decreasing yields of crops and forests. Although ozone benefits are typically quantified in regulatory impact analyses, we do not evaluate them for this analysis because of the magnitude of, and uncertainty associated with, the ambient ozone modeling data. As discussed earlier in this chapter (and in Chapter 3), the ozone modeling conducted for the PFC standards results in a net reduction, when population-weighted, in the ozone design value metric measured within the modeled domain (37 Eastern states and the District of Columbia). The net improvement, however, is very small. For the most part, quantifiable ozone benefits will not contribute significantly to the monetized benefits; thus, their omission will not materially affect the conclusions of the benefits analysis.

12.5.2 Welfare Impact Assessment

For many welfare effects, such as changes in ecosystem functions and PM-related materials damage, reliable impact functions and/or valuation functions are not currently available. In general, if it were possible to monetize these benefit categories, the benefits estimates presented in this analysis would increase, although the magnitude of such an increase is highly uncertain.

12.5.2.1 Visibility Benefits

Changes in the level of ambient $PM_{2.5}$ caused by the final standards will change the level of visibility in much of the United States. Visibility directly affects people's enjoyment of a variety of daily activities. Individuals value visibility both in the places they live and work, in the places they travel to for recreational purposes, and at sites of unique public value, such as the Great Smoky Mountains National Park. Though not quantified in this analysis, the value of improvements in visibility monetized for regulatory analyses such as the final CAIR are significant. We refer the reader to that analysis for a complete description of the methods used to value visibility.[47]

12.5.2.2 Agricultural and Forestry Benefits

The Ozone Criteria Document notes that "ozone affects vegetation throughout the United States, impairing crops, native vegetation, and ecosystems more than any other air pollutant" (EPA, 1996, page 5-11).[48] Though we do not quantify the potential improvements in ambient ozone concentrations associated with the final standards, it is possible that yields will improve in areas of agricultural or forestry production impacted by the standards. The net ozone improvement, however, is very small. We expect that the omission of agricultural impacts will not materially affect the conclusions of the benefits analysis.

With that said, however, well-developed techniques exist to provide monetary estimates of these benefits to agricultural producers and to consumers. These techniques use models of planting decisions, yield response functions, and agricultural products' supply and demand. The resulting welfare measures are based on predicted changes in market prices and production costs. Models also exist to measure benefits to silvicultural producers and consumers. However, these models have not been adapted for use in analyzing ozone-related forest impacts. Because of resource limitations, we are unable to provide agricultural or forestry benefits estimates for the final standards.

12.5.2.2.1 Agricultural Benefits

Laboratory and field experiments have 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."[54] In addition, economic studies have shown a relationship between observed ozone levels and crop yields.[49]

12.5.2.2.2 Forestry Benefits

Ozone also has been shown conclusively to cause discernible injury to forest trees (EPA, 1996; Fox and Mickler, 1996).[54,50] In our previous analysis of the Heavy-Duty Engine/Diesel Fuel rule, we were able to quantify the effects of changes in ozone concentrations on tree growth for a limited set of species. Because the net change in measured ozone associated with the final standards was so small, we were not able to quantify such impacts for this analysis.

12.5.2.3 Benefits from Reductions in Materials Damage

The final standards that we modeled are expected to produce economic benefits in the form of reduced materials damage. There are two important categories of these benefits. Household soiling refers to the accumulation of dirt, dust, and ash on exposed surfaces. PM also has corrosive effects on commercial/industrial buildings and structures of cultural and historical significance. The effects on historic buildings and outdoor works of art are of particular concern because of the uniqueness and irreplaceability of many of these objects.

Previous EPA benefits analyses have been able to provide quantitative estimates of household soiling damage. Consistent with SAB advice, we determined that the existing data (based on consumer expenditures from the early 1970s) are too out of date to provide a reliable estimate of current household soiling damages (EPA-SAB-COUNCIL-ADV-98-003, 1998).[51]

EPA is unable to estimate any benefits to commercial and industrial entities from reduced materials damage. Nor is EPA able to estimate the benefits of reductions in PM-related damage to historic buildings and outdoor works of art. Existing studies of damage to this latter category in Sweden (Grosclaude and Soguel, 1994)[52] indicate that these benefits could be an order of magnitude larger than household soiling benefits.

12.5.3 UVb Exposure

In contrast to the unquantified benefits of the final standards discussed above, it is also possible that this rule will result in disbenefits in some areas of the United States. The effects of ozone and PM on radiative transfer in the atmosphere can lead to effects of uncertain magnitude and direction on the penetration of ultraviolet light and climate. Ground level ozone makes up a small percentage of total atmospheric ozone (including the stratospheric layer) that attenuates penetration of ultraviolet - b (UVb) radiation to the ground. EPA's past evaluation of the information indicates that potential disbenefits would be small, variable, and with too many uncertainties to attempt quantification of relatively small changes in average ozone levels over the course of a year.[53] EPA's most recent provisional assessment of the currently available information indicates that potential but unquantifiable benefits may also arise from ozone-related attenuation of UVb radiation.[54] EPA believes that we are unable to quantify any net climate-related disbenefit or benefit associated with the combined ozone and PM reductions in this rule.

12.6 Methods for Describing Uncertainty

In any complex analysis using estimated parameters and inputs from numerous models, there are likely to be many sources of uncertainty. This analysis is no exception. As outlined both in this and preceding chapters, many inputs were used to derive the benefits estimate, including emission inventories, air quality models (with their associated parameters and inputs), epidemiological health effect estimates, estimates of values (both from WTP and COI studies), population estimates, income estimates, and estimates of the future state of the world (i.e., regulations, technology, and human behavior). Each of these inputs may be uncertain and, depending on its role in the benefits analysis, may have a disproportionately large impact on estimates of total benefits. For example, emissions estimates are used in the first stage of the analysis. As such, any uncertainty in emissions estimates will be propagated through the entire analysis. Some of the key uncertainties in the quantified benefits analysis are presented in Table 12.6-1.

Table 12.6-1. Primary Sources of Uncertainty in the Quantified Benefits Analysis

1. Uncertainties Associated with Impact Functions ● The value of the PM effect estimate in each impact function. ● Application of a single impact function to pollutant changes and populations in all locations. ● Similarity of future-year impact functions to current impact functions. ● Correct functional form of each impact function. ● Extrapolation of effect estimates beyond the range of PM concentrations observed in the source epidemiological study. ● Application of some impact functions only to those subpopulations matching the original study population.
2. Uncertainties Associated with PM Concentrations ● Responsiveness of the models to changes in precursor emissions resulting from the control policy. ● Projections of future levels of precursor emissions, especially organic carbonaceous particle emissions. ● Model chemistry for the formation of ambient nitrate concentrations. ● Lack of speciation monitors in some areas requires extrapolation of observed speciation data. ● CMAQ model performance in the Western U.S., especially California indicates significant underprediction of $PM_{2.5}$.
3. Uncertainties Associated with PM Mortality Risk ● Differential toxicity of specific component species within the complex mixture of PM has not been determined. ● The extent to which adverse health effects are associated with low-level exposures that occur many times in the year versus peak exposures. ● The extent to which effects reported in the long-term exposure studies are associated with historically higher levels of PM rather than the levels occurring during the period of study. ● Reliability of the limited ambient $PM_{2.5}$ monitoring data in reflecting actual $PM_{2.5}$ exposures.
5. Uncertainties Associated with Possible Lagged Effects ● The portion of the PM-related long-term exposure mortality effects associated with changes in annual PM levels that would occur in a single year is uncertain as well as the portion that might occur in subsequent years.

6. Uncertainties Associated with Baseline Incidence Rates ● Some baseline incidence rates are not location specific (e.g., those taken from studies) and therefore may not accurately represent the actual location-specific rates. ● Current baseline incidence rates may not approximate well baseline incidence rates in 2020 and 2030. ● Projected population and demographics may not represent well future-year population and demographics.
7. Uncertainties Associated with Economic Valuation ● Unit dollar values associated with health and welfare endpoints are only estimates of mean WTP and therefore have uncertainty surrounding them. ● Mean WTP (in constant dollars) for each type of risk reduction may differ from current estimates because of differences in income or other factors.
8. Uncertainties Associated with Aggregation of Monetized Benefits ● Health and welfare benefits estimates are limited to the available impact functions. Thus, unquantified or unmonetized benefits are not included.

As part of EPA's approach to characterizing uncertainties in the benefits assessment, we generate a probabilistic estimate of statistical uncertainty based on standard errors reported in the underlying studies used in the benefits modeling framework, with particular emphasis on the health impact functions. Using a Monte Carlo procedure, the distribution of each health endpoint and its unit dollar value is characterized by the reported mean and standard error derived from the epidemiology and valuation literature. Details on the distributions used to value individual health endpoints are provided in Section 12.6.1, as well as in the CAIR RIA (Appendix B; EPA, 2005).[55] It should be noted that the Monte Carlo-generated distributions of benefits reflect only some of the uncertainties in the input parameters (described in Table 12.6-1). Uncertainties associated with emissions, air quality modeling, populations, and baseline health effect incidence rates are not represented in the distributions of benefits of attaining alternative standards. Issues such as correlation between input parameters and the identification of reasonable upper and lower bounds for input distributions characterizing uncertainty in additional model elements will be addressed in future versions of the uncertainty framework.

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, in characterizing the uncertainty related to the estimates of total benefits it is particularly important to attempt to characterize the uncertainties associated with this endpoint. As such, we specifically discuss the uncertainty related to PM-related premature mortality in Section 12.6.2.

12.6.1 Analysis of Statistical Uncertainty

For the final standards, we did not attempt to assign probabilities to all of the uncertain parameters in the model because of a lack of resources and reliable methods. At this time, we simply generate estimates of the distributions of dollar benefits for PM health effects and for total dollar benefits. For all quantified PM endpoints, we scaled the likelihood distributions of the benefit estimates from the CAND uncertainty analysis,[K] based on the same benefits transfer

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[K] U.S. Environmental Protection Agency. May 2004. *Final Regulatory Analysis: Control of Emissions from Nonroad Diesel Engines*. Prepared by: Office of Air and Radiation. Available at http://www.epa.gov/nonroad-diesel/2004fr.htm#documents. Accessed December 15, 2005.

approach we used to estimate the benefits of the standards presented in Section 12.2. The CAND likelihood distributions were based solely on the statistical uncertainty surrounding the estimated C-R functions and the assumed distributions around the unit values. We use the benefits transfer approach to scale those distributions to reflect the predicted direct PM emission reductions of the final cold temperature standards. Though the scaling approach adds another element of uncertainty that we cannot characterize in the distributions, we believe the scaled uncertainty is a reasonable approximation of the statistical uncertainty based on standard errors reported in the underlying epidemiological and valuation studies.

Our scaled estimates of the likelihood distributions for health-related PM benefits should be viewed as incomplete because of the wide range of sources of uncertainty that we have not incorporated. The 5th and 95th percentile points of our scaled estimate are based on statistical error, and cross-study variability provides some insight into how uncertain our estimate is with regard to those sources of uncertainty. However, it does not capture other sources of uncertainty regarding the benefits transfer scaling approach or the inputs to the CAND modeling upon which the scaling is based, including emissions, air quality, baseline population incidence, and projected exposures. It also does not account for aspects of the health science not captured in the studies, such as the likelihood that PM is causally related to premature mortality and other serious health effects. Thus, a likelihood description based on the standard error would provide a misleading picture about the overall uncertainty in the estimates.

Both the uncertainty about incidence changes[L] and uncertainty about unit dollar values can be characterized by *distributions*. Each "likelihood distribution" characterizes our beliefs about what the true value of an unknown variable (e.g., the true change in incidence of a given health effect in relation to PM exposure) is likely to be, based on the available information from relevant studies.[M] Unlike a sampling distribution (which describes the possible values that an *estimator* of an unknown variable might take on), this likelihood distribution describes our beliefs about what values the unknown variable itself might be. Such likelihood distributions can be constructed for each underlying unknown variable (such as a particular pollutant coefficient for a particular location) or for a function of several underlying unknown variables (such as the total dollar benefit of a regulation). In either case, a likelihood distribution is a characterization of our beliefs about what the unknown variable (or the function of unknown variables) is likely to be, based on all the available relevant information. A likelihood description based on such distributions is typically expressed as the interval from the 5th percentile point of the likelihood distribution to the 95th percentile point. If all uncertainty had been included, this range would be the "credible range" within which we believe the true value is likely to lie with 90 percent probability.

[L] Because this is a national analysis in which, for each endpoint, a single C-R function is applied everywhere, there are two sources of uncertainty about incidence: statistical uncertainty (due to sampling error) about the true value of the pollutant coefficient in the location where the C-R function was estimated and uncertainty about how well any given pollutant coefficient approximates β^*.

[M] Although such a "likelihood distribution" is not formally a Bayesian posterior distribution, it is very similar in concept and function (see, for example, the discussion of the Bayesian approach in Kennedy, 1990. A Guide to Econometrics. 2nd ed. MIT Press: Cambridge, MA., pp. 168-172).

12.6.1.1 Monte Carlo Approach

The uncertainty about the total dollar benefit associated with any single endpoint combines the uncertainties from these two sources (the C-R relationship and the valuation) and is estimated with a Monte Carlo method. In each iteration of the Monte Carlo procedure, a value is randomly drawn from the incidence distribution, another value is randomly drawn from the unit dollar value distribution; the total dollar benefit for that iteration is the product of the two.[N] When this is repeated for many (e.g., thousands of) iterations, the distribution of total dollar benefits associated with the endpoint is generated.

Using this Monte Carlo procedure, a distribution of dollar benefits can be generated for each endpoint. As the number of Monte Carlo draws gets larger and larger, the Monte Carlo-generated distribution becomes a better and better approximation of a joint likelihood distribution (for the considered parameters) making up the total monetary benefits for the endpoint.

After endpoint-specific distributions are generated, the same Monte Carlo procedure can then be used to combine the dollar benefits from different (nonoverlapping) endpoints to generate a distribution of total dollar benefits.

The estimate of total benefits may be thought of as the end result of a sequential process in which, at each step, the estimate of benefits from an additional source is added. Each time an estimate of dollar benefits from a new source (e.g., a new health endpoint) is added to the previous estimate of total dollar benefits, the estimated total dollar benefits increases. However, our bounding or likelihood description of where the true total value lies also increases as we add more sources.

As an example, consider the benefits from reductions in PM-related hospital admissions for cardiovascular disease. Because the actual dollar value is unknown, it may be described using a variable, with a distribution describing the possible values it might have. If this variable is denoted as X1, then the mean of the distribution, E(X1) and the variance of X1, denoted Var(X1), and the 5th and 95th percentile points of the distribution (related to Var(X1)), are ways to describe the likelihood for the true but unknown value for the benefits reduction.

Now suppose the benefits from reductions in PM-related hospital admissions for respiratory diseases are added. Like the benefits from reductions in PM-related hospital admissions for cardiovascular disease, the likelihood distribution for where we expect the true value to be may be considered a variable, with a distribution. Denoting this variable as X2, the benefits from reductions in the incidence of both types of hospital admissions is X1 + X2. This variable has a distribution with mean E(X1 + X2) = E(X1) + E(X2), and a variance of Var(X1 +

[N] This method assumes that the incidence change and the unit dollar value for an endpoint are stochastically independent.

$X2) = Var(X1) + Var(X2) + 2Cov(X1,X2)$; if X1 and X2 are stochastically independent, then it has a variance of $Var(X1 + X2) = Var(X1) + Var(X2)$, and the covariance term is zero.

The benefits from reductions in all nonoverlapping PM-related health and welfare endpoints are $(Xm+1, ..., Xn)$ is $X = X1 + ... + Xn$. The mean of the distribution of total benefits, X, is

$$E(X) = E(X1) + E(X2) + ... + E(Xn)$$

and the variance of the distribution of total benefits—assuming that the components are stochastically independent of each other (i.e., no covariance between variables), is

$$Var(X) = Var(X1) + Var(X2) + ... + Var(Xn)$$

If all the means are positive, then each additional source of benefits increases the point estimate (mean) of total benefits. However, with the addition of each new source of benefits, the variance of the estimate of total benefits also increases. That is,

$$E(X1) < E(X1 + X2) < E(X1 + X2 + X3) < ... < E(X1 + ... + Xn) = E(X)$$

$$Var(X1) < Var(X1 + X2) < Var(X1 + X2 + X3) < ... < Var(X1 + ... + Xn) = Var(X)$$

That is, the addition of each new source of benefits results in a larger mean estimate of total benefits (as more and more sources of benefits are included in the total) about which there is less certainty. This phenomenon occurs whenever estimates of benefits are added.

Calculated with a Monte Carlo procedure, the distribution of X is composed of random draws from the components of X. In the first draw, a value is drawn from each of the distributions, X1, X2, through Xn; these values are summed; and the procedure is repeated again, with the number of repetitions set at a high enough value (e.g., 5,000) to reasonably trace out the distribution of X. The 5th percentile point of the distribution of X will be composed of points pulled from all points along the distributions of the individual components and not simply from the 5th percentile. Although the sum of the 5th percentiles of the components would be represented in the distribution of X generated by the Monte Carlo, it is likely that this value would occur at a significantly lower percentile. For a similar reason, the 95th percentile of X will be less than the sum of the 95th percentiles of the components, and instead the 95th percentile of X will be composed of component values that are significantly lower than the 95th percentiles.

The physical effects estimated in this analysis are assumed to occur independently. It is possible that, for any given pollution level, there is some correlation between the occurrence of physical effects, due to say avoidance behavior or common causal pathways and treatments (e.g., stroke, some kidney disease, and heart attack are related to treatable blood pressure). Estimating accurately any such correlation, however, is beyond the scope of this analysis, and instead it is simply assumed that the physical effects occur independently.

12.6.1.2 Monte Carlo Results

Based on the Monte Carlo techniques and benefits transfer methods described above, we scaled the CAND likelihood distributions for the dollar value of total PM health-related benefits for the final standards. For this analysis, the likelihood descriptions for the true value of each of the health endpoint incidence estimates, including premature mortality, were based on classical statistical uncertainty measures. The measures include the mean and standard deviation of the C-R relationships in the epidemiological literature, and assumptions of particular likelihood distribution shapes for the valuation of each health endpoint value based on reported values in the economic literature. The distributions for the value used to represent incidence of a health effect in the total benefits valuation represent both the simple statistical uncertainty surrounding individual effect estimates and, for those health endpoints with multiple effects from different epidemiology studies, interstudy variability. Distributions for unit dollar values are summarized in Chapter 12, Table 12.3-2.

Results of the scaled Monte Carlo simulations are presented in Table 12.6-2. The table provides the scaled means of the distributions and the estimated 5th and 95th percentiles of the distributions. The contribution of mortality to the mean benefits and to both the 5th and 95th percentiles of total benefits is substantial, with mortality accounting for over 90 percent of the mean estimate, and even the 5th percentile of mortality benefits dominating close to the 95th percentile of all other benefit categories. Thus, the choice of value and the shape for likelihood distribution for VSL should be examined closely and is key information to provide to decision makers for any decision involving this variable. The 95th percentile of total benefits is approximately twice the mean, while the 5th percentile is approximately one-fourth of the mean. The overall range from 5th to 95th represents about one order of magnitude.

Table 12.6-2. Distribution of Value of Annual PM-Related Human Health Benefits in 2030 for the Final Mobile Source Air Toxics Rule: Cold Temperature Controls [a]

Endpoint	Monetary Benefits[b, c] (Millions 2003$, Adjusted for Income Growth)		
	5th Percentile	Mean	95th Percentile
Premature mortality[c], Long-term exposure			
Adults, 30+ yrs and Infants, <1yr			
3% Discount Rate	$1,400	$5,800	$12,000
7% Discount Rate	$1,300	$5,200	$10,000
Chronic bronchitis (adults, 26 and over)	$12	$260	$880
Nonfatal myocardial infarctions			
3% Discount Rate	$32	$150	$330
7% Discount Rate	$30	$140	$330
Hospital admissions from respiratory causes	$3.1	$10	$16
Hospital admissions from cardiovascular causes	$5.3	$9.1	$14
Emergency room visits for asthma	$0.12	$0.20	$0.30
Acute bronchitis (children, aged 8–12)	$0	$0.56	$1.4
Lower respiratory symptoms (children, aged 7–14)	$0.11	$0.29	$0.54
Upper respiratory symptoms (asthmatic children, aged 9–11)	$0.09	$0.35	$0.78
Asthma exacerbations	$0.01	$1.0	$2.8
Work loss days (adults, aged 18–65)	$12	$14	$16
Minor restricted-activity days (adults, aged 18–65)	$20	$35	$50
Monetized Total[d]			
3% Discount Rate	$1,500 + B	$6,300 + B	$13,000 + B
7% Discount Rate	$1,300 + B	$5,700 + B	$12,000 + B

[a] Monetary benefits are rounded to two significant digits.

[b] Monetary benefits are adjusted to account for growth in real GDP per capita between 1990 and 2030.

[c] Results show 3 percent and 7 percent discount rates consistent with EPA and OMB guidelines for preparing economic analyses (EPA, 2000; OMB, 2003).

[d] B represents the monetary value of the nonmonetized health and welfare benefits. A detailed listing of unquantified PM-, ozone-, and air toxics-related health effects is provided in Chapter 12, Table 12.1-2.

12.6.2 Additional Approaches to Characterizing Uncertainty Related to PM-Mortality

As part of an overall program to improve the Agency's characterization of uncertainties in health benefits analyses, we attempt to address uncertainties associated with the $PM_{2.5}$ mortality health impact function relationship and valuation. Use of the ACS cohort (Pope et al., 2002) mortality function to support this analysis does not address uncertainty associated with: (a) potential of the study to incompletely capture short-term exposure-related mortality effects, (b) potential mis-match between study and analysis populations which introduces various forms of bias into the results, (c) failure to identify all key confounders and effects modifiers, which could result in incorrect effects estimates relating mortality to $PM_{2.5}$ exposure, and (d) model uncertainty. EPA is researching methods to characterize all elements of uncertainty in the dose-response function for mortality.

As is discussed in detail in the final PM NAAQS RIA, EPA uses three methods to quantify uncertainties in the mortality function, including: the statistical uncertainty derived from the standard errors reported in the ACS cohort study, the presentation of additional estimates of mortality based upon the peer-reviewed literature, and the use of results of an expert elicitation conducted to explore a more thorough characterization of uncertainties in the mortality estimate. Because this analysis utilizes the PM scaling benefits transfer approach to estimate mortality incidence for the final cold temperature vehicle standard, we cannot quantify the PM mortality uncertainty to the same extent as was done for the CAIR or PM NAAQS analyses. However, in a similar fashion to the analysis conducted for the Clean Air Visibility Rule (CAVR),[56] we can scale the results of the CAND mortality uncertainty analysis to the PM precursor emission changes modeled for the final cold temperature standard.

12.6.2.1 Uncertainty Associated with the Concentration-Response Function

In the benefit analysis of the CAND 2030 emission control standards, the statistical uncertainty represented by the standard error of the American Cancer Society cohort study (Pope et al, 2002) was one and one-half times the mean benefit estimate at the 95th percentile and less than one-half of the mean at the 5th percentile. The CAND analysis also derived mortality from the reanalysis of the Harvard Six-Cities study (Krewski et al., 2000).[57] At the time of the CAND analysis, EPA's Science Advisory Board provided guidance stating, "The Six-Cities estimates may be used in a sensitivity analysis to demonstrate that with different but also plausible selection criteria for C-R functions, benefits may be considerably larger than suggested by the ACS study." (EPA-SAB-COUNCIL-ADV-04-002).[58] In the CAND analysis, the Harvard Six-Cities mean benefits estimate was over twice the size of the mean estimate of mortality benefits derived from the ACS study.

Recently, a new peer-reviewed extension of the Six-Cities study has been published (Laden et al., 2006).[59] This follow-up to the Harvard Six-Cities study both confirmed the effect size from the first analysis and provided additional evidence that reductions in $PM_{2.5}$ are likely associations with reductions in the risk of premature death. This additional evidence stems from the observed reductions in $PM_{2.5}$ in each city during the extended follow-up period. Laden et al. (2006) found that mortality rates consistently went down at a rate proportionate to the observed reductions in $PM_{2.5}$. In the recently finalized PM NAAQS RIA, results from this study were presented as an additional estimate of premature mortality benefits along with the benefits derived from the ACS study. The mean benefits estimate derived from the Six-Cities study was more than twice the size of the mean estimate of mortality benefits derived from the ACS study. Because this study was not available during the CAND analysis, from which the benefits of today's final standards are scaled, we are unable to provide an estimate of mortality benefits based on the Six-Cities study for this final analysis. However, based on the relationship between the Six-Cities study and the ACS cohort study observed in the final PM NAAQS RIA, we can surmise that the mean estimate of PM-related mortality associated with the final cold temperature standards could be approximately twice as large. For a full discussion of the epidemiological basis of EPA's premature mortality estimates, we refer the reader to Chapter 5.1 of the final PM NAAQS RIA.

EPA recently completed a full-scale expert elicitation that incorporated peer-review comments on the pilot application used in CAND, and that provides a more robust characterization of the uncertainty in the premature mortality function. This expert elicitation was designed to evaluate uncertainty in the underlying causal relationship, the form of the mortality impact function (e.g., threshold versus linear models) and the fit of a specific model to the data (e.g., confidence bounds for specific percentiles of the mortality effect estimates). Additional issues, such as the ability of long-term cohort studies to capture premature mortality resulting from short-term peak PM exposures, were also addressed in the expert elicitation. The recently published RIA supporting the Particulate Matter National Ambient Air Quality Standards (PM NAAQS) used the results of this expert elicitation to quantitatively characterize uncertainty.

Due to the analytical constraints associated with the PM benefits scaling approach, we are unable to assess the premature mortality health impacts derived from the formally elicited expert judgments. Compared to the final PM NAAQS estimate of mean premature mortality derived from the ACS cohort study, however, expert-based mortality incidence ranged from approximately 50 percent of the mean ACS estimate to approximately five times the size of the mean ACS estimate. In total, PM-related premature mortality derived from eleven of the experts was greater than the ACS estimate, while one expert-based estimate fell below the ACS result.

12.6.2.2 PM$_{2.5}$-Mortality Cutpoint/Threshold Analysis

Another source of uncertainty that has received recent attention from several scientific review panels is the shape of the concentration-response function for PM-related mortality, and specifically whether there exists a threshold below which there would be no benefit to further reductions in PM$_{2.5}$. The consistent advice from EPA's SAB[O] has been to model premature

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[O] The advice from the 2004 SAB-HES (EPA-SAB-COUNCIL-ADV-04-002)[69] is characterized by the following: "For the studies of long-term exposure, the HES notes that Krewski et al. (2000) have conducted the most careful work on this issue. They report that the associations between PM$_{2.5}$ and both all-cause and cardiopulmonary mortality were near linear within the relevant ranges, with no apparent threshold. Graphical analyses of these studies (Dockery et al., 1993, Figure 3, and Krewski et al., 2000, page 162) also suggest a continuum of effects mortality associated with PM exposure as a nonthreshold effect, that is, with harmful effects to exposed populations regardless of the absolute level of ambient PM concentrations. However, EPA's most recent $PM_{2.5}$ Criteria Document concludes that "the available evidence does not either support or refute the existence of thresholds for the effects of PM on mortality across the range of concentrations in the studies."[60] Some researchers have hypothesized the presence of a threshold relationship. That is, the hypothesized relationship includes the possibility that there exists a PM concentration level below which further reductions no longer yield premature mortality reduction benefits.

To consider the impact of a threshold in the response function for the chronic mortality endpoint, the final PM NAAQS RIA[61] constructed a sensitivity analysis by assigning different cutpoints below which changes in $PM_{2.5}$ are assumed to have no impact on premature mortality. In applying the cutpoints, the PM NAAQS analysis adjusted the mortality function slopes accordingly.[P] Five cutpoints (including the base case assumption) were included in the sensitivity analysis: (a) 14 µg/m^3 (assumes no impacts below a level being considered at the time for the annual $PM_{2.5}$ NAAQS), (b) 12 µg/m^3 (c) 10 µg/m^3 (reflects comments from CASAC, 2005), [62] (d) 7.5 µg/m^3 (reflects recommendations from SAB-HES to consider estimating mortality benefits down to the lowest exposure levels considered in the ACS cohort study (Pope et al., 2002) used as the basis for modeling chronic mortality) [63] and (e) background or 3 µg/m^3 (reflects NRC recommendation to consider effects all the way to background).[64] The results of the sensitivity analysis displayed the change in avoided mortality cases and associated monetary benefits associated with the alternative cutpoints (see the final PM NAAQS RIA, Chapter 5.1 and Tables 5-28 to 5-31).

A sensitivity analysis such as this can be difficult to interpret, because when a threshold above the lowest observed level of $PM_{2.5}$ in the underlying ACS cohort study (Pope et al., 2002) is assumed, the slope of the concentration-response function above that level must be adjusted upwards to account for the assumed threshold.[Q] Depending on the amount of slope adjustment and the proportion of the population exposed above the assumed threshold, the estimated mortality impact can either be lower (if most of the exposures occur below the threshold) or higher (if most of the exposures occur above the threshold). To demonstrate this, we present an example from the proposed PM NAAQS RIA. In its examination of the benefits of attaining alternative PM NAAQS in Chicago,[R] the analysis found that, because annual mean levels are generally higher in Chicago, there was a two-part pattern to the relationship between assumed threshold and mortality impacts. As the threshold increased from background to 7.5 µg/m^3, the mortality impact fell (because there is no slope adjustment). However, at an assumed threshold of 10 µg/m^3, estimated mortality impacts actually increased, because the populations exposed

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down to lower levels. Therefore, it is reasonable for EPA to assume a no threshold model down to, at least, the low end of the concentrations reported in the studies."

[P] Note that the PM NAAQS analysis only adjusted the mortality slopes for the 10 µg/m^3, 12 µg/m^3 and 14 µg/m^3 cutpoints since the 7.5 µg/m^3 and background cutpoints were at or below the lowest measured exposure levels reported in the Pope et al. (2002) study for the combined exposure dataset.

[Q] See NAS (2002)[71] and CASAC (2005)[68] for discussions of this issue.

[R] See the proposed PM NAAQS RIA (2005),[67] Appendix A, pp. A63-A64.

above 10 µg/m^3 were assumed to have a larger response to particulate matter reductions (due to the increased slope above the assumed threshold). And finally, mortality impacts again fell to zero if a 15 µg/m^3 threshold was assumed, because these impacts were measured incremental to attainment of the current standard.

We are unable to do this type of sensitivity analysis for the final MSAT rule because of the analytical limitations of the PM benefits scaling procedure. When EPA conducted the CAND analysis (from which the primary estimates of benefits for the final cold temperature vehicle standards are based), there were no PM mortality concentration-response functions with the slope adjusted upwards to account for an assumed threshold. Instead, our primary PM benefits estimate for the final cold temperature vehicle standards reflects a background threshold assumption of 3 µg/m^3. We present in Table 12.6-3 the results of our scaled PM-related mortality benefits in the context of its relationship to other cutpoints.

Table 12.6-3. PM-Related Mortality Benefits of the Final Cold Temperature Vehicle Standards: Cutpoint Sensitivity Analysis[a]

Certainty that Benefits are At Least Specified Value	*Level of Assumed Threshold*	*Discount Rate*	**PM Mortality Benefits (Billion 2003$)**	
			2020	2030
More Certain that Benefits Are at Least as Large	14 µg/m^3 [c]	3%	N/A[b]	
		7%		
↓	12 µg/m^3	3%	N/A	
		7%		
	10 µg/m^3 [d]	3%	N/A	
		7%		
	7.5 µg/m^3 [e]	3%	N/A	
		7%		
Less Certain that Benefits Are at Least as Large	3 µg/m^3 [f]	3%	$3.3	$6.3
		7%	$3.0	$5.7

[a] Note that this table only presents the effects of a cutpoint on PM-related mortality incidence and valuation estimates.
[b] Not Available. We are unable to provide cutpoint analysis results for the final MSAT rule because of the analytical limitations of the PM benefits scaling procedure.
[c] EPA intends to analyze a cutpoint between 12 µg/m^{3}and 15 µg/m^3 for the final RIA.
[d] CASAC (2005)[68]
[e] SAB-HES (2004)[69]
[f] NAS (2002)[71]

12.7 Health-Based Cost Effectiveness Analysis

Health-based cost-effectiveness analysis (CEA) and cost-utility analysis (CUA) have been used to analyze numerous health interventions but have not been widely adopted as tools to analyze environmental policies. The Office of Management and Budget (OMB) issued Circular

A-4 guidance on regulatory analyses, requiring Federal agencies to “prepare a CEA for all major rulemakings for which the primary benefits are improved public health and safety to the extent that a valid effectiveness measure can be developed to represent expected health and safety outcomes.” Environmental quality improvements may have multiple health and ecological benefits, making application of CEA more difficult and less straightforward. For the CAIR analysis, the first to incorporate an analysis of this kind, CEA provided a useful framework for evaluation: nonhealth benefits were substantial, but the majority of quantified benefits came from health effects. EPA included in the CAIR RIA a preliminary and experimental application of one type of CEA—a modified quality-adjusted life-years (QALYs) approach. For CAIR, EPA concluded that the direct usefulness of cost-effectiveness analysis is mitigated by the lack of rule alternatives to compare relative effectiveness, but that comparisons could still be made to other benchmarks bearing in mind methodological differences.

QALYs were developed to evaluate the effectiveness of individual medical treatments, and EPA is still evaluating the appropriate methods for CEA of environmental regulations. Agency concerns with the standard QALY methodology include the treatment of people with fewer years to live (the elderly); fairness to people with preexisting conditions that may lead to reduced life expectancy and reduced quality of life; and how the analysis should best account for nonhealth benefits, such as improved visibility.

The Institute of Medicine (a member institution of the National Academies of Science) established the Committee to Evaluate Measures of Health Benefits for Environmental, Health, and Safety Regulation to assess the scientific validity, ethical implications, and practical utility of a wide range of effectiveness measures used or proposed in CEA. This committee prepared a report titled “Valuing Health for Regulatory Cost-Effectiveness Analysis,” which concluded that CEA is a useful tool for assessing regulatory interventions to promote human health and safety, although not sufficient for informed regulatory decisions (Miller, Robinson, and Lawrence, 2006).[65] They emphasized the need for additional data and methodological improvements for CEA analyses, and urged greater consistency in the reporting of assumptions, data elements, and analytic methods. They also provided a number of recommendations for the conduct of regulatory CEA analyses. EPA is evaluating these recommendations and will determine a response for upcoming analyses.

In Appendix G of the RIA for the CAIR,[63] EPA conducted an extensive cost-effectiveness analysis using morbidity inclusive life years (MILY). That analysis concluded that reductions in $PM_{2.5}$ associated with CAIR were expected to be cost-saving (because the value of expenditures on illnesses and non-health benefits exceeded costs), and that costs of the CAIR could have been significantly higher and still result in cost-effective improvements in public health. Because the current analysis relies on a benefits transfer approach to estimate PM-related benefits, scaling PM benefits from the CAND rule, we do not have the necessary inputs to develop a valid cost-effectiveness measure for the final cold temperature standards. Furthermore, the CAND analysis did not include a health-based CEA, the results of which might have been scaled in a similar fashion to the benefits.

For the CAVR rule, EPA was able to draw inferences from the CAIR CEA by scaling the relative magnitude of the costs and health impacts between the two rules.[66] While the CAVR was not expected to be cost-saving like CAIR, EPA expected that CAVR was likely to have a relatively low cost per MILY. For the final cold temperature standards, however, it is difficult to draw similar inferences with CAIR because the geographic distribution of emission changes, the distribution of those changes over time, and the age distribution of the mortality and chronic disease reductions are all expected to differ between the two rules. For these reasons, we do not scale the CAIR health-based cost-effectiveness analysis for the final cold temperature standards.

12.8 Comparison of Costs and Benefits

The final rule provides three separate provisions that reduce air toxics emissions: cold temperature vehicle controls, an emissions control program for PFCs, and a control program limiting benzene in gasoline. A full appreciation of the overall economic consequences of these provisions requires consideration of the benefits and costs expected to result from each standard, not just those that could be expressed here in dollar terms. As noted above, due to limitations in data availability and analytical methods, our benefits analysis only monetizes the $PM_{2.5}$-related benefits from direct PM emission reductions associated with the cold temperature standards. There are a number of health and environmental effects associated with the final standards that we were unable to quantify or monetize (see Table 12.1-2).

Table 12.8-1 contains the estimates of monetized benefits of the final cold temperature vehicle standards and estimated social welfare costs for each of the final control programs.[S] The annual social welfare costs of all provisions of this rule are described more fully in Chapter 13. It should be noted that the estimated social welfare costs for the vehicle program contained in this table are for 2019. The 2019 vehicle program costs are included for comparison purposes only and are therefore not included in the total 2020 social costs. There are no compliance costs associated with the vehicle program after 2019; as explained in Chapter 13, the vehicle compliance costs are primarily R&D and facilities costs that are expected to be recovered by manufacturers over the first ten years of the program.

The results in Table 12.8-1 suggest that the 2020 monetized benefits of the cold temperature vehicle standards are greater than the expected social welfare costs of that program in 2019. Specifically, the annual benefits of the program will be approximately $3,300 + B million or $3,000 + B million annually in 2020 (using a three percent and seven percent discount rate in the benefits analysis, respectively), compared to estimated social welfare costs of approximately $10.6 million in the last year of the program (2019). These benefits are expected to increase to $6,300 + B million or $5,700 + B million annually in 2030 (using a three percent and seven percent discount rate in the benefits analysis, respectively), even as the social welfare costs of that program fall to zero. Table 12.8-1 also presents the costs of the other rule provisions: an emissions control program for PFCs and a control program limiting benzene in

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[S] Social costs represent the welfare costs of the rule to society. These social costs do not consider transfer payments (such as taxes) that are simply redistributions of wealth.

gasoline. Though we are unable to present the benefits associated with these two programs, we note for informational purposes that the benefits associated with the final cold temperature vehicle standards alone exceed the costs of all three rule provisions combined.

Table 12.8-1. Summary of Annual Benefits of the Final Cold Temperature Vehicle Standards and Costs of All Provisions of the Final Standards[a] (Millions of 2003 dollars)

Description	2020 (Millions of 2003 dollars)	2030 (Millions of 2003 dollars)
Estimated Social Welfare Costs[b]		
Cold Temperature Vehicle Standards	\$10.6[c]	\$0
PFC Container Standards	\$37.5	\$45.7
Fuel Standards[d]	\$402.6	\$445.8
Total	\$440.1	\$491.5
Fuel Savings	-\$80.7	-\$91.5
Net Social Welfare Costs	\$359.4	\$400.0
Total $PM_{2.5}$-Related Health Benefits of the Cold Temperature Vehicle Standards[e]		
3 percent discount rate	\$3,300 + B[f]	\$6,300 + B[f]
7 percent discount rate	\$3,000 + B[f]	\$5,700 + B[f]

[a] All estimates are rounded to two significant digits and represent annualized benefits and costs anticipated for the years 2020 and 2030, except where noted. Totals may not sum due to rounding.

[b] Note that costs are the annual costs of reducing all pollutants associated with each provision of the final MSAT control package in 2020 and 2030 (unless otherwise noted). To estimate fixed costs associated with the vehicle standards, we use a 7 percent average before-tax rate of return over 5 years to amortize the capital fixed costs. For the fuel standards, we use a 7 percent before-tax rate of return over 15 years to amortize the capital costs. Note that by 2020, PFC container standard costs are only variable and do not use a rate of return assumption. See Chapters 8 and 9 for discussion of the vehicle and fuel standard costs, respectively. In Chapter 13, however, we do use both a 3 percent and 7 percent social discount rate to calculate the net present value of total social costs consistent with EPA and OMB guidelines for preparing economic analyses (US EPA, 2000 and OMB, 2003).

[c] These costs are for 2019; the vehicle program compliance costs terminate after 2019 and are included for illustrative purposes. They are not included in the total social welfare cost sum for 2020.

[d] Our modeling for the total costs of the proposed gasoline benzene program included participation by California refineries (achieving benzene reductions below the 0.62 proposed benzene standard - thus generating credits), since it was completed before we decided that California gasoline would not be covered by the program. For the final rule, we exclude California refineries from the analysis. By excluding California refineries, other higher cost refineries will have to comply in their place, slightly increasing the costs for the program.

[e] Annual benefits reflect only direct PM reductions associated with the cold temperature vehicle standards. Annual benefits analysis results reflect the use of a 3 percent and 7 percent discount rate in the valuation of premature mortality and nonfatal myocardial infarctions, consistent with EPA and OMB guidelines for preparing economic analyses (US EPA, 2000 and OMB, 2003). [67,68] Valuation of premature mortality based on long-term PM exposure assumes discounting over the SAB recommended 20-year segmented lag structure described in the Regulatory Impact Analysis for the Final Clean Air Interstate Rule (March 2005). Valuation of nonfatal myocardial infarctions (MI) assumes discounting over a 5-year period, reflecting lost earnings and direct medical costs following a nonfatal MI. Note that we do not calculate a net present value of benefits associated with the cold temperature vehicle standards.

[f] Not all possible benefits or disbenefits are quantified and monetized in this analysis. B is the sum of all unquantified benefits and disbenefits. Potential benefit categories that have not been quantified and monetized are listed in Table 12.1-2.

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Chapter 13: Table of Contents

CHAPTER 13: Economic Impact Analysis

We prepared an Economic Impact Analysis (EIA) to estimate the economic impacts of this rule on the portable fuel container (PFC), gasoline fuel, and light-duty vehicle markets. In this chapter we describe the Economic Impact Model (EIM) we developed to estimate both the market-level changes in prices and outputs for affected markets and the social costs of the program and their distribution across affected stakeholders. We also present the result of our analysis.

We estimate the net social costs of the rule to be about $359.4 million in 2020. This estimate reflects the estimated costs associated with compliance with the gasoline, PFC, and vehicle controls and the expected gasoline fuel savings from better evaporative controls on PFCs. The results of the economic impact modeling performed for the gasoline fuel and PFC control programs suggest that the social costs of those two programs are expected to be about $440.1 million in 2020, with consumers of these products expected to bear about 58.4 percent of these costs. We estimate gasoline fuel savings of about $80.7 million in 2020, which will accrue to consumers. There are no social costs associated with the vehicle program in 2020 (these accrue only in the 10-year period from 2010 through 2019). These estimates, and all costs presented in this chapter, are in year 2003 dollars.

With regard to market-level impacts in 2020, the maximum price increase for gasoline fuel is expected to be about 0.3 percent (0.5 cents per gallon), for PADD 5.[A] The price of PFCs is expected to increase by about 1.9 percent ($0.20 per can) in areas that already have PFC requirements and 32.5 percent ($1.52 per can) in areas that do not.

13.1 Overview and Results

13.1.1 What is an Economic Impact Analysis?

An Economic Impact Analysis (EIA) is prepared to inform decision makers about the potential economic consequences of a regulatory action. The analysis consists of estimating the social costs of a regulatory program and the distribution of these costs across stakeholders. These estimated social costs can then be compared with estimated social benefits (as presented in Chapter 12). As defined in EPA's *Guidelines for Preparing Economic Analyses*, social costs are the value of the goods and services lost by society resulting from a) the use of resources to comply with and implement a regulation and b) reductions in output.[1] In this analysis, social costs are explored in two steps. In the *market analysis*, we estimate how prices and quantities of goods affected by the rule can be expected to change once the program goes into effect. In the *economic welfare analysis*, we look at the total social costs associated with the program and their distribution across stakeholders.

[A] PADD: Petroleum Administration for Defense District.

13.1.2 What is the Economic Impact Model?

The Economic Impact Model (EIM) is a behavioral model developed to estimate price and quantity changes and total social costs associated with the emission controls set out in this rule. The model relies on basic microeconomic theory to simulate how producers and consumers of affected products can be expected to respond to an increase in production costs associated with compliance with the emission control program. The economic theory that underlies the model is described in detail in Section 13.2, below.

The EIM is designed to estimate the economic impacts of the rule by simulating economic behavior. At current, pre-control market equilibrium conditions consumers are willing to purchase the same amount of that product that producers are willing to produce at that price. This is represented by pre-control market prices and quantities. Compliance with the standards ould increase the production costs of affected goods by the amount of the compliance costs. This represents a "shock" to equilibrium market conditions. Producers of affected products will try to pass some or all of the increased costs on to the consumers of these goods through price increases. In response to the price increases, consumers will adjust their consumption of affected goods. Producers will react to the change in quantity demanded by adjusting their prices and the quantity they produce. These interactions continue until a new market equilibrium price and quantity combination is achieved. The amount of the compliance costs that can be passed on to consumers is ultimately limited by the price sensitivity of purchasers and producers in the relevant market (price elasticity of demand and supply). The EIM explicitly models these behavioral responses and estimates new equilibrium prices and output and the resulting distribution of social costs across these stakeholders (producers and consumers).

13.1.3 What Economic Sectors are Included in the Economic Impact Model?

There are three economic sectors affected by the control programs described in this rule: PFCs, gasoline fuel, and light-duty vehicles.

In this Economic Impact Analysis we do not model the market impacts on the vehicle program; we model only the impacts on the PFC and gasoline fuel markets. This approach is appropriate for several reasons. As described in Chapter 8, above, the compliance costs for the light-duty vehicle controls are expected to be very small, less than $1 per vehicle. These costs are R&D and facilities costs that are expected to be recovered by the manufacturers over 10 years (completely recovered by 2019) and are not expected to be passed on in the form of higher prices. Such small compliance costs are well within the normal variation of input prices experienced by most vehicle manufacturers at any given time. In addition, a price change this small, even if it is passed on entirely, is unlikely to affect producer or consumer behavior given the price of a new vehicle. On a more practical level, a cost increase of this magnitude is not large enough to disturb an economic impact model like the one used in this analysis. At the same time, however, the light-duty vehicle compliance costs are a cost to society and should be included in the economic welfare analysis. We do this by using the engineering cost estimates as a proxy for the social costs of the light-duty vehicle controls and adding them to the estimated social costs of the gasoline fuel and PFC programs.

With regard to the gasoline fuel and PFC market analyses, we model the impacts on residential users of these products. This means that we focus the analysis on the use of these products for personal transportation (gasoline fuel) or residential lawn and garden care or recreational uses (PFCs) and do not separately model how the costs of complying with the standards may affect the production of goods and services that use gasoline fuel or PFCs as production inputs. The result is that we group residential and commercial users in a single market and assume the behavioral responses to increased costs for commercial users are similar to residential users. This is reasonable because the vast majority of users of these products are residential users. While there are commercial users of PFCs and gasoline fuel, their share of the end-user markets is relatively small. The U.S Department of Energy estimates that about 92 percent of gasoline used in the United States for transportation is used in light-duty vehicles.[2] According to DoE, only about six percent of gasoline fuel is used for commercial or industrial transportation, and the remaining two percent is used in recreational marine vessels. Similarly, although there is little publicly available national data on the users of PFCs, a 1999 study by CARB found that 94 percent of portable fuel containers in California were used by residential households.[3] In addition, for most commercial users the share of these products to total production costs is small (e.g., the cost of a PFC is only a very small part of the total production costs for an agricultural or construction firm). Therefore, a price increase of the magnitude anticipated for this control program is not expected to have a noticeable impact on prices or quantities of goods produced using these inputs (e.g., agricultural produce or buildings).

Consistent with the cost analysis, the economic impact analysis for the gasoline fuel market does not distinguish between reformulated and conventional gasoline fuels.[B] For more information, see Chapter 9 on how gasoline compliance costs were estimated. Also consistent with the cost analysis, this EIA also does not consider impacts of the fuel program on the benzene market (i.e., the market for recovered benzene). This is because, as explained elsewhere in this RIA, any impacts on that market are expected to be insignificant. Finally, as explained in Section 13.3.2.2, the gasoline fuel analysis is based on post-tax gasoline prices since state and federal taxes are included in the prices consumers pay at the pump.

The EIM relies on the estimated compliance costs for the PFC and gasoline fuel programs described elsewhere in this RIA. Thus, the EIM reflects cost savings associated with ABT or other flexibility programs to the extent they are included in the estimated compliance costs.

As summarized in Table 13.1-1, this EIA considers the economic impacts of the rule on four gasoline fuel markets and two PFC markets, for a total of six markets. More detailed information on the markets and model inputs is provided in Section 13.3.3, below, and in the industry profiles prepared for this rule (see also Chapter 4 of this document).[4,5]

[B] The cost analysis does not differentiate between conventional and reformulated gasoline because their benzene levels are expected to be similar as a result of the standards and because the cost modeling technique does not allow for estimating how the blending of gasoline blendstocks will occur.

Table 13.1-1. Summary of Markets in Economic Impact Model

Model Dimension	Light-Duty Vehicles	Gasoline (4)	Portable Fuel Containers (2)
Number of Markets	Not included in market analysis; engineering costs used to estimate total social costs	Four regions • PADDs 1 & 3 • PADD 2 • PADD 4 • PADD 5 (includes Alaska and Hawaii; California not included) No distinction between conventional and reformulated gasoline	Two markets • States with current controls (12 plus DC) • States without current controls (38)
Geographic scope		49-state; California not included in the program because they already control fuel benzene to low levels	50-State
Market structure		Perfectly competitive	Perfectly competitive
Baseline population		Energy Information Administration	Provided by manufacturers
Growth projections		Energy Information Administration	2%
Supply elasticity		Literature estimate: 0.2 (inelastic)	Econometric estimate (production function cost minimization method): 1.5 (elastic)
Demand elasticity		Literature estimate: -0.2 (inelastic)	EPA estimate (Hicks-Allen derived demand method): -0.01 (inelastic)
Regulatory shock		Direct compliance costs (fixed + variable) cause shift in supply function	Direct compliance costs (fixed + variable) cause shift in supply function

In the EIM, behavioral responses to price changes are incorporated through the price elasticity of supply and demand (reflected in the slope of the supply and demand curves). The price elasticities used in this analysis are described in Section 13.3, below. The gasoline fuel price elasticity parameters were obtained from the literature; we estimated those for the PFCs. For gasoline fuel, both the demand and supply elasticities are inelastic, meaning that both the quantity supplied and demanded are expected to be fairly insensitive to price changes. For PFCs, however, the demand elasticity is inelastic but the supply elasticity is elastic. This means that producers are expected to be sensitive to price changes but consumers are not. This will allow producers to pass more of the compliance costs on to consumers.

13.1.4 Summary of Results

The EIA consists of two parts: a market analysis and welfare analysis. The market analysis looks at expected changes in prices and quantities for affected products. The welfare analysis looks at economic impacts in terms of annual and present value changes in social costs. For this rule, the social costs are estimated as the sum of market surplus (the aggregate change in consumer and producer surplus based on the estimated market impacts associated with the rule) offset by operating cost savings (the gasoline fuel savings associated with better evaporative controls for PFCs).

Economic impact results of our modeling for selected years are summarized in this section. The year 2009 is presented because that is the first year in which both the PFC and the gasoline programs are in effect (the PFC program begins in 2009; the gasoline fuel program go into effect January 1, 2011 but the compliance cost analysis includes a phase-in starting in 2007 that ends May 2015). The year 2012 is presented because it is a high cost year due to the way the fuel program compliance costs were estimated.[C] The year 2015 is presented because beginning with that year compliance costs are stabilized for future years for both the gasoline and PFC programs (the vehicle program compliance costs continue for five more years). More detailed results for all years are included in the appendices to this chapter.

13.1.4.1 Market Analysis Results

In the market analysis, we estimate how prices and quantities of goods affected by the emission control program can be expected to change once the program goes into effect. As explained above, we estimated market impacts for only the gasoline fuel and PFC markets. The analysis relies on the baseline equilibrium prices and quantities for each market and the price elasticity of supply and demand. It predicts market reactions to the increase in production costs due to the new compliance costs. It should be noted that this analysis does not allow any other factors to vary. In other words, it does not consider that manufacturers may adjust their production processes or marketing strategies in response to the control program.

The market analysis results for 2009, 2012, 2015, and 2020 are presented in Table 13.1-2. With regard to the gasoline fuel program, the market impacts are expected to be small, on average. The price of gasoline fuel is expected to increase by less than 0.5 percent, depending on PADD, with smaller increases during the program phase-in. The expected reduction in quantity of fuel produced is expected to be less than 0.1 percent.

The market impacts for the PFC program are expected to be more significant. In 2009, the first year of PFC program, the model predicts a price increase of about seven percent for PFCs in states that currently have regulations for PFCs and about 57 percent for those that do not. Even with these large price increases, however, the quantity produced is not expected to decrease by very much: less than 0.6 percent. These percent price increases and quantity decreases are much smaller after the first five years. In 2015, the estimated PFC price increase is

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[C] Actual fuel program compliance costs are expected to be spread more smoothly across years.

expected to be less than two percent for states that currently regulate PFCs and about 32.5 percent for states without such regulations. The quantity produced is expected to decrease by less than 0.4 percent. The results for 2020 are substantially the same as 2015, with larger decreases in the number of PFCs produced.

Table 13.1-2. Summary of Market Impacts (2009, 2012, 2015 and 2020; 2003$)

Market	Engineering Cost Per Unit	Change in Price		Change in Quantity	
		Absolute	**Percent**	**Absolute**	**Percent**
2009					
	¢/gallon	¢/gallon		Million Gallons	
Gasoline Fuel					
PADD 1 & 3	0.016¢	0.009¢	0.006%	-0.9	0.001%
PADD 2	0.091¢	0.050¢	0.033%	-2.7	-0.007%
PADD 4	0.033¢	0.018¢	0.011%	-0.1	-0.002%
PADD 5 (w/out CA)	0.007¢	0.004¢	0.002%	-0.0	0.000%
	$/can			Thousand Cans	
Portable Fuel Containers					
States with existing Programs	$0.77	$0.76	6.9%	-8.0	-0.07%
States without existing programs	$2.70	$2.68	57.5%	-104.7	-0.57%
2012					
	¢/gallon			Million Gallons	
Gasoline Fuel					
PADD 1 & 3	0.058¢	0.032¢	0.021%	-3.3	-0.004%
PADD 2	0.308¢	0.168¢	0.111%	-9.7	-0.022%
PADD 4	0.213¢	0.116¢	0.074%	-0.8	-0.015%
PADD 5 (w/out CA)	0.140¢	0.076¢	0.046%	-0.8	-0.009%
	$/can			Thousand Cans	
Portable Fuel Containers					
States with existing Programs	$0.77	$0.76	6.9%	-8.5	-0.07%
States without existing programs	$2.70	$2.68	57.5%	-111.1	-0.57%

2015					
	¢/gallon			Million Gallons	
Gasoline Fuel					
PADD 1 & 3	0.149¢	0.081¢	0.055%	-8.9	-0.011%
PADD 2	0.307¢	0.167¢	0.111%	-10.1	-0.022%
PADD 4	0.501¢	0.273¢	0.174%	-1.8	-0.035%
PADD 5 (w/out CA)	0.997¢	0.544¢	0.327%	-6.1	-0.065%
	$/can			Thousand Cans	
Portable Fuel Containers					
States with existing Programs	$0.21	$0.20	1.9%	-2.4	-0.02%
States without existing programs	$1.53	$1.52	32.5%	-66.7	-0.32%
2020					
	¢/gallon			Million Gallons	
Gasoline Fuel					
PADD 1 & 3	0.149¢	0.081¢	0.055%	-9.5	-0.011%
PADD 2	0.307¢	0.167¢	0.111%	-10.7	-0.022%
PADD 4	0.501¢	0.273¢	0.174%	-2.0	-0.035%
PADD 5 (w/out CA)	0.997¢	0.544¢	0.327%	-6.4	-0.065%
Portable Fuel Containers	$/can			Thousand Cans	
States with existing Programs	$0.21	$0.20	1.9%	-2.7	-0.02%
States without existing programs	$1.53	$1.52	32.5%	-73.6	-0.32%

13.1.4.2 Economic Welfare Results

In the economic welfare analysis we look at the costs to society of the rule in terms of losses to key stakeholder groups that are the producers and consumers in the gasoline and PFC markets. These surplus losses are combined with estimated vehicle compliance costs, gasoline fuel savings, and government revenue losses to estimate the net economic welfare impacts of the program. Detailed economic welfare results for the rule are presented in Appendix C and are summarized below.

The estimated annual net social costs (total social costs less gasoline fuel savings) for all years are presented in Table 13.1-3 and Figure 13.1-1. These social costs follow the trend of the fuel program compliance costs. Initially, the estimated social costs of the program are relatively small as the gasoline program begins to phase in. The net social costs increase to 2012, fall somewhat for 2013 and 2014 due to changes in the fuel program compliance costs, and then increase again in 2015, after which time the per-gallon costs are expected to be stable. Some of the decrease in social costs in 2014 is also due a decrease in costs associated with the PFC program, since fixed costs are fully amortized by 2014. The slight decrease in 2020 is due to the end of the vehicle compliance costs, which are incurred in the 10-year period from 2010 through 2019.

Table 13.1-3. Estimated Engineering Compliance and Social Costs Through 2035 ($million; 2003$)

Year	PFC	Vehicles	Gasoline	Fuel Savings	Total Engineering	Total Social Costs
2007	0.0	0.0	29.5	0.0	$29.5	$29.5
2008	0.0	0.0	51.3	0.0	$51.3	$51.3
2009	58.1	0.0	52.3	11.3	$99.0	$98.9
2010	58.7	11.1	114.1	22.6	$161.9	$161.7
2011	59.3	11.8	115.9	35.6	$152.6	$152.4
2012	59.9	12.5	203.0	48.5	$228.7	$228.5
2013	60.6	13.3	176.3	61.5	$190.9	$190.8
2014	33.3	13.4	178.5	74.5	$150.8	$150.7
2015	34.0	12.9	379.5	75.5	$350.8	$350.7
2016	34.7	12.2	384.1	76.5	$354.5	$354.4
2017	35.4	11.4	388.7	77.6	$358.0	$357.9
2018	36.1	10.7	393.7	78.6	$361.9	$361.8
2019	36.8	10.6	398.4	79.7	$366.1	$366.0
2020	37.5	0.0	402.7	80.7	$359.5	$359.4
2021	38.3	0.0	407.0	81.8	$363.5	$363.4
2022	39.1	0.0	410.9	82.9	$367.1	$367.0
2023	39.8	0.0	414.8	83.9	$370.7	$370.6
2024	40.6	0.0	419.1	85.0	$374.7	$374.6
2025	41.5	0.0	423.4	86.1	$378.7	$378.6
2026	42.3	0.0	428.0	87.2	$383.1	$383.0
2027	43.1	0.0	432.7	88.3	$387.5	$387.4
2028	44.0	0.0	436.9	89.3	$391.6	$391.4
2029	44.9	0.0	441.6	90.4	$396.0	$395.9
2030	45.8	0.0	445.9	91.5	$400.1	$400.0
2031	46.7	0.0	450.5	92.5	$404.6	$404.5
2032	47.6	0.0	455.2	93.6	$409.2	$409.1
2033	48.6	0.0	459.9	94.6	$413.9	$413.7
2034	49.5	0.0	464.7	95.7	$418.6	$418.4
2035	50.5	0.0	469.5	96.7	$423.4	$423.2
3% NPV (2006-35)					$5,356.8	$5,354.6
7% NPV (2006-35)					$2,901.0	$2,899.7

Figure 13.1-1 Estimated Engineering Costs ($million, 2003$)

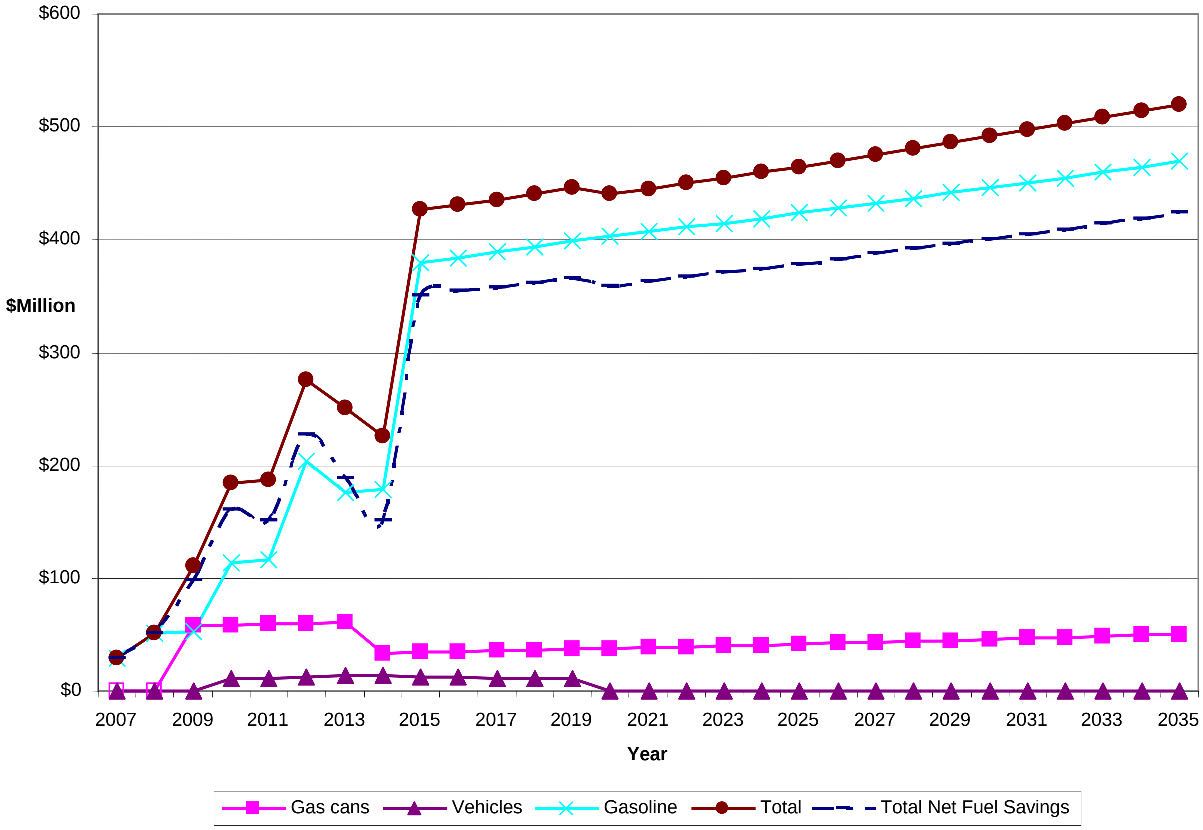

Table 13.1-4 shows how the social costs are expected to be shared across stakeholders, for selected years. Information for all years can be found in Appendix C. According to these results, consumers are expected to bear approximately 99 percent of the cost of the PFC program. This reflects the inelastic price elasticity on the demand side of the market and the elastic price elasticity on the supply side. The burden of the gasoline fuel program is expected to be shared more evenly, with about 54.5 percent expected to be borne by consumers and about 45.5 percent expected to be borne by producers. In all years, the estimated loss to consumer welfare will be offset somewhat by the gasoline fuel savings associated with PFCs. Beginning at about $11 million per year, these savings increase to about $76 million by 2015 as compliant PFCs are phased in. These savings continue for the life of the PFCs; total annual savings increase as the number of cans increases (see Table 13.3-9).

Table 13.1-4. Summary of Estimated Social Costs, 2009, 2012, 2015 and 2020 ($million; 2003$)

Market	Change in Consumer Surplus	Change in Producer Surplus	Total
2009			
Gasoline US	-$28.5	-$23.8	-$52.3
	(54.6%)	*(45.4%)*	
PADD 1 & 3	-$6.7	-$5.6	-$12.2
PADD 2	-$20.6	-$17.2	-$37.8
PADD 4	-$0.9	-$0.7	-$1.6
PADD 5 (w/out CA)	-$0.3	-$0.3	-$0.6
Portable Fuel Containers US	-$57.5	-$0.4	-$57.9
	(99.3%)	*(0.7%)*	
States with existing programs	-$8.9	-$0.1	-$8.9
States without existing programs	-$48.7	-$0.3	-$49.0
Subtotal	**-$86.1**	**-$24.1**	**-$110.2**
	(78.1%)	***(22%)***	
Fuel Savings			$11.3
Vehicle Program			$0
Total			**-$98.9**
2012			
Gasoline US	-$110.7	-$92.3	-$203.0
	(54.5%)	*(45.5%)*	
PADD 1 & 3	-$24.8	-$20.7	-$45.5
PADD 2	-$73.2	-$61.0	-$134.2
PADD 4	-$5.9	-$4.9	-$10.9
PADD 5 (w/out CA)	-$6.8	-$5.7	-$12.4
Portable Fuel Containers US	-$61.1	-$0.4	-$61.5
	(99.3%)	*(0.7%)*	
States with existing programs	-$9.4	-$0.1	-$9.5
States without existing programs	-$51.7	-$0.3	-$52.0
Subtotal	**-$171.8**	**-$92.7**	**-$264.5**
	(65.0%)	***(35.0%)***	
Fuel Savings			$48.5
Vehicle Program			-$12.5
Total			**-$228.5**
2015			
Gasoline US	-$207.0	-$172.5	-$379.4
	(54.5%)	*(45.5%)*	
PADD 1 & 3	-$66.3	-$55.3	-$121.6
PADD 2	-$75.9	-$63.2	-$139.1
PADD 4	-$14.5	-$12.1	-$26.6
PADD 5 (w/out CA)	-$50.3	-$41.9	-$92.2
Portable Fuel Containers US	-$33.7	-$0.2	-$34.0
	(99.3%)	*(0.7%)*	
States with existing programs	-$2.7	$0.0	-$2.7
States without existing programs	-$31.0	-$0.2	-$31.3
Subtotal	**-$240.7**	**-$172.7**	**-$413.4**
	(58.2%)	***(41.8%)***	
Fuel Savings			$75.5
Vehicle Program			-$12.9

Market	Change in Consumer Surplus	Change in Producer Surplus	Total
Total			**-$350.7**
2020			
Gasoline US	-$219.6 *(54.5%)*	-$183.0 *(45.5%)*	-$402.6
PADD 1 & 3	-$70.4	-$58.6	-$129.0
PADD 2	-$80.5	-$67.1	-$147.6
PADD 4	-$15.4	-$12.8	-$28.2
PADD 5 (w/out CA)	-$53.4	-$44.5	-$97.8
Portable Fuel Containers US	-$37.2 *(99.3%)*	-$0.3 *(0.7%)*	-$37.5
States with existing programs	-$3.0	$0.0	-$3.0
States without existing programs	-$34.3	-$0.2	-$34.5
Subtotal	**-$256.8** ***(58.4%)***	**-$183.3** ***(41.6%)***	**-$440.1**
Fuel Savings			$80.7
Vehicle Program			-$0
Total			**-$359.4**

The present value of net social costs (discounted back to 2006) of the standards through 2035, contained in Table 13.1-3, is estimated to be about $5.4 billion (2003$). This present value is calculated using a social discount rate of three percent and the stream of economic welfare costs through 2035. We also performed an analysis using a seven percent social discount rate.[D] Using that discount rate, the present value of the net social costs through 2035 is estimated to be about $2.9 billion (2003$).

[D] EPA presents the present value of cost and benefits estimates using both a three percent and a seven percent social discount rate. According to OMB Circular A-4, “the 3 percent discount rate represents the ‘social rate of time preference’… [which] means the rate at which ‘society’ discounts future consumption flows to their present value”; “the seven percent rate is an estimate of the average before-tax rate of return to private capital in the U.S. economy … [that] approximates the opportunity cost of capital.”

Table 13.1-5. Net Present of Estimated Social Costs 2007 through 2035, Discounted to 2006 ($million; 2003$)

Market	Change in Consumer Surplus	Change in Producer Surplus	Total
Gasoline, U.S.	-$3,115.4 *(54.6%)*	-$2,596.2 *(45.4%)*	-$5,711.6
PADD 1 & 3	-$959.7	-$799.8	-$1,759.5
PADD 2	-$1,260.4	-$1,050.4	-$2,310.8
PADD 4	-$210.8	-$175.6	-$386.4
PADD 5 (w/out CA)	-$684.5	-$570.4	-$1,254.8
Portable Fuel Containers US	-$754.9 *(99.3%)*	-$5.0 *(0.7%)*	-$759.9
States with existing programs	-$78.7	-$0.5	-$79.3
States without existing programs	-$676.2	-$4.5	-$680.7
Subtotal	-$3870.3 *59.8%*	-$2,601.2 *40.2%*	-$6,471.6
Fuel Savings	$1,208.0		$1,208.0
Vehicle Program		-$91.1	-$91.1
Total	-$2,662.3	-$2,692.3	-$5,354.6

Table 13.3-5 shows the distribution of total surplus losses for the cumulative net social costs of the rule. This analysis includes the estimated social costs through 2035, discounted to 2006 at a 3 percent discount rate. These results suggest that consumers will bear about 60 percent of the total social costs associated with the PFC and gasoline fuel programs for that period. The consumer share of the NPV social costs is about $3,870 million, or about 60 percent of the total. Of that loss of consumer surplus, about $3,115 million (80 percent) is from the gasoline fuel program. When the total costs of the program are taken into account, including the fuel savings and the vehicle program costs, the loss of consumer surplus decreases to about $2,662.3 million (about 50 percent of the social costs of the program).

13.2 Economic Methodology

Economic impact analysis uses a combination of theory and econometric modeling to evaluate potential behavior changes associated with a new regulatory program. As noted above, the goal is to estimate the impact of the regulatory program on producers and consumers. This is done by creating a mathematical model based on economic theory and populating the model using publicly available price and quantity data. A key factor in this type of analysis is estimating the responsiveness of the quantity of PFCs and gasoline fuel demanded by consumers or supplied by producers to a change in the price of that product. This relationship is called the elasticity of demand or supply.

The EIM's methodology is rooted in applied microeconomic theory and was developed following the *OAQPS Economic Analysis Resource Document*.[6] This section discusses the economic theory underlying the modeling for this EIA and several key issues that affect the way the model was developed.

13.2.1 What Is A Behavioral Economic Model?

Models incorporating different levels of economic decision making can be categorized as *with*-behavior responses or *without*-behavior responses. The EIM is a behavioral model.

Engineering cost analysis is an example of a *without*-behavior response model. These models estimate the cost of a regulation based on the projected number of affected units and engineering estimates of the annualized costs. The result is an estimate of the total compliance costs for a program. However, these models do not attempt to estimate how a regulatory program will change the prices or output of an affected industry. Therefore, the results may over-estimate the total costs of a program because they do not take decreases in quantity produced into account.

The *with*-behavior response approach builds on the engineering cost analysis and incorporates economic theory related to producer and consumer behavior to estimate changes in market conditions. As Bingham and Fox note, this framework provides "a richer story" of the expected distribution of economic welfare changes across producers and consumers.[7] In behavioral models, manufacturers of goods affected by a regulation are economic agents that can make adjustments, such as changing production rates or altering input mixes that will generally affect the market environment in which they operate. As producers change their production levels in response to a new regulation, consumers of the affected goods are typically faced with changes in prices that cause them to alter the quantity that they are willing to purchase. These changes in price and output from the market-level impacts are used to estimate the distribution of social costs between consumers and producers.

If markets are competitive and per-unit regulatory costs are small, the behavioral approach will yield approximately the same total cost impact as the engineering cost approach. However, the advantage of the *with*-behavior response approach is that it illustrates how the costs flow through the economic system and it identifies which stakeholders, producers, and consumers are likely to be most affected.

13.2.2 What Is the Economic Theory Underlying the EIM?

The EIM is a partial-equilibrium, single market numerical simulation model that estimates price and quantity changes in the intermediate run under competitive market conditions. Each of these model features is described in this section.

13.2.2.1 Partial Market Equilibrium Model

In the broadest sense, all markets are directly or indirectly linked in the economy, and a new regulatory program will theoretically affect all commodities and markets to some extent. However, not all regulatory programs have noticeable impacts on all markets. For example, a regulation that imposes significant per unit compliance costs on an important manufacturing input, such as steel, will have a larger impact on the national economy than a regulation that imposes very small per unit compliance costs on an input used by only a small number of producers.

The appropriate level of market interactions to be included in an economic impact analysis is determined by the number of industries directly affected by the requirements and the ability of affected firms to pass along the regulatory costs in the form of higher prices. There are at least three alternative approaches for modeling interactions between economic sectors that reflect three different levels of analysis.

In a *partial equilibrium* model, individual markets are modeled in isolation. The only factor affecting the market is the cost of the regulation on facilities in the industry being modeled; there are no interaction effects with other markets. Conditions in other markets are assumed either to be unaffected by a policy or unimportant for cost estimation.

In a *multimarket model,* a subset of related markets is modeled together, with sector linkages, and hence selected interaction effects, explicitly specified. This approach represents an intermediate step between a simple, single-market partial equilibrium approach and a full general equilibrium approach. This technique has most recently been referred to in the literature as "partial equilibrium analysis of multiple markets".[8]

In a *general equilibrium model,* all sectors of the economy are modeled together, incorporating interaction effects between all sectors included in the model. General equilibrium models operationalize neoclassical microeconomic theory by modeling not only the direct effects of control costs but also potential input substitution effects, changes in production levels associated with changes in market prices across all sectors, and the associated changes in welfare economy-wide. A disadvantage of general equilibrium modeling is that substantial time and resources are required to develop a new model or tailor an existing model for analyzing regulatory alternatives.

This EIM uses a partial equilibrium, single-market approach to model the economic impacts of the rule. The model examines impacts that affect the two markets that are affected (PFCs and gasoline) and does not look at potential impacts on other sectors of the economy.[E] This approach is reasonable because, as described above, most of the users of these products are households. For those commercial sectors that use these products, the impacts would be expected to be negligible and not affect output in those sectors. With regard to the gasoline fuel market, the estimated compliance costs on a per gallon basis are well within the normal price variations of gasoline. With regard to PFCs, the share of these products to total production costs is very small and therefore an increase in their price is not expected to change output. For these reasons, the additional costs of using a general equilibrium or multimarket approach far outweigh the additional precision in the results.

The two separate sub-models in the EIM, for gasoline and PFCs, are not linked (there is no feedback mechanism between them). This approach is appropriate because these sectors represent different aspects of fuel consumption (fuel storage and fuel production), and production and consumption of one is not affected by the other. In other words, an increase in the price of PFCs is not expected to have an impact on the production and supply of gasoline,

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[E] Market impacts were not modeled for the vehicle market; see Section 13.1.3, above.

and vice versa. Production and consumption of each of these products are the result of other factors that have little cross-over impacts (the need for fuel storage; the need for personal transportation).

13.2.2.2 Perfect Competition Model

For all markets that are modeled, the analyst must characterize the degree of competition within each market. The discussion generally focuses on perfect competition (price-taking behavior) versus imperfect competition (the lack of price-taking behavior). It should be noted that the perfect competition assumption is not primarily about the number of firms in a market. It is about how the market operates: whether or not individual firms have sufficient market power to influence the market price. Indicators that allow us to assume perfect competition include absence of barriers to entry, absence of strategic behavior among firms in the market, and product differentiation.

This EIM relies on an assumption of perfect competition. This means that consumers and firms are price takers and do not have the ability to influence market prices.

In a perfectly competitive market at equilibrium the market price equals the value society (consumers) places on the marginal product, as well as the marginal cost to society (producers). Producers are price takers, in that they respond to the value that consumers put on the product. It should be noted that the perfect competition assumption relies not only on the number of firms in a market but also on other market characteristics such as absence of barriers to entry and strategic behavior among firms in the market, and the lack of product differentiation.

In contrast, imperfect competition implies firms have some ability to influence the market price of output they produce. One of the classic reasons firms may be able to do this is their ability to produce commodities with unique attributes that differentiate them from competitors' products. This allows them to limit supply, which in turn increases the market price, given the traditional downward-sloping demand curve. Decreasing the quantity produced increases the monopolist's profits but decreases total social surplus because a less than optimal amount of the product is being consumed. In the monopolistic equilibrium, the value society (consumers) places on the marginal product, the market price, *exceeds* the marginal cost to society (producers) of producing the last unit. Thus, social welfare would be increased by inducing the monopolist to increase production. Social cost estimates associated with a regulation are larger with monopolistic market structures and other forms of imperfect competition because the regulation exacerbates the existing social inefficiency of too little output from a social perspective. The Office of Management and Budget (OMB) explicitly mentions the need to consider these market power-related welfare costs in evaluating regulations under Executive Order 12866.[9]

Perfect competition is a widely accepted economic practice for this type of analysis and only in rare cases are other approaches used.[10] For the markets affected by this rule, the perfect competition assumption is appropriate.

With regard to the fuel market, the Federal Trade Commission (FTC) has developed an approach to ensure competitiveness in this sector. The FTC reviews oil company mergers and frequently requires divestiture of refineries, terminals, and gas stations to maintain a minimum level of competition. This is discussed in more detail in the industry profile prepared for this rule.[11] Therefore, it is reasonable to assume a competitive market structure in this analysis.

With regard to the PFC market, the small number of firms in the market is offset by several features of this market. Because PFCs are compact and lightweight, they are easy to transport far from their place of manufacture. This means that production is not limited to local producers. Although they vary by size and material, consumers are likely to view all PFCs designed for storing a particular fuel (gasoline, diesel fuel, kerosene) as good substitutes for the storage of that specific fuel. Because the products are similar enough to be considered homogeneous (e.g., perfectly substitutable), consumers can shift their purchases from one manufacturer to another. There are only minimal technical barriers to entry that would prevent new firms from freely entering the market, since manufacturing is based on well-known plastic processing methods. In addition, there is significant excess capacity, enabling competitors to respond quickly to changes in price. Excess production capacity in the general container manufacturing market also means that manufacturers could potentially switch their product lines to compete in this segment of the market, often without a significant investment. In addition, there is no evidence of high levels of strategic behavior in the price and quantity decisions of the firms. Finally, it should be noted that contestable market theory asserts that oligopolies and even monopolies will behave very much like firms in a competitive market if manufacturers have extra production capacity and this capacity could allow them to enter the market costlessly (i.e., there are no sunk costs associated with this kind of market entry or exit).[F,12,13] As a result of all of these conditions, producers and consumers in the PFC market are expected to take the market price as given when making their production and consumption choices and the market can be modeled as a competitive market even though the number of producers is small. More information about the structure of the PFC industry organization can be found in Section 3 of the industry characterization prepared for this rule.[14]

13.2.3.3 Intermediate-Run Model

In developing partial equilibrium models, the choices available to producers must be considered. For example, are producers able to increase their factors of production (e.g., increase production capacity) or alter their production mix (e.g., substitution between materials, labor, and capital)? These modeling issues are largely dependent on the time horizon for which the analysis is performed. Three benchmark time horizons are discussed below: the very short run, the long run, and the intermediate run. This discussion relies in large part on the material contained in the *OAQPS Economic Analysis Resource Guide*.[15]

[F] A monopoly or firms in oligopoly may not behave as neoclassical economic theories of the firm predict because such firms may be concerned about new entrants to the market. If super-normal profits are earned, potential competitors may enter the market. To respond to this threat, existing firm(s) in the market may keep prices and output at a level where only normal profits are made, setting price and output levels at or close to the competitive price and output.

The EIM models market impacts in the intermediate run. The use of the intermediate run means that some factors of production are fixed and some are variable. This modeling period allows analysis of the economic effects of the rule's compliance costs on current producers. As described below, a short-run analysis imposes all compliance costs on producers, while a long-run analysis imposes all costs on consumers. The use of the intermediate time frame is consistent with economic practices for this type of analysis.

In the very short run, all factors of production are assumed to be fixed, leaving the directly affected entity with no means to respond to increased costs associated with the regulation (e.g., they cannot adjust labor or capital inputs). Within a very short time horizon, regulated producers are constrained in their ability to adjust inputs or outputs due to contractual, institutional, or other factors and can be represented by a vertical supply curve, as shown in Figure 13.2-1. In essence, this is equivalent to the nonbehavioral model described earlier. Neither the price nor quantity changes and the manufacturer's compliance costs become fixed or sunk costs. Under this time horizon, the impacts of the regulation fall entirely on the regulated entity. Producers incur the entire regulatory burden as a one-to-one reduction in their profit. This is referred to as the "full-cost absorption" scenario and is equivalent to the engineering cost estimates. Although there is no hard and fast rule for determining what length of time constitutes the very short run, it is inappropriate to use that time horizon for this analysis because the very short run assumes economic entities have no flexibility to adjust factors of production.

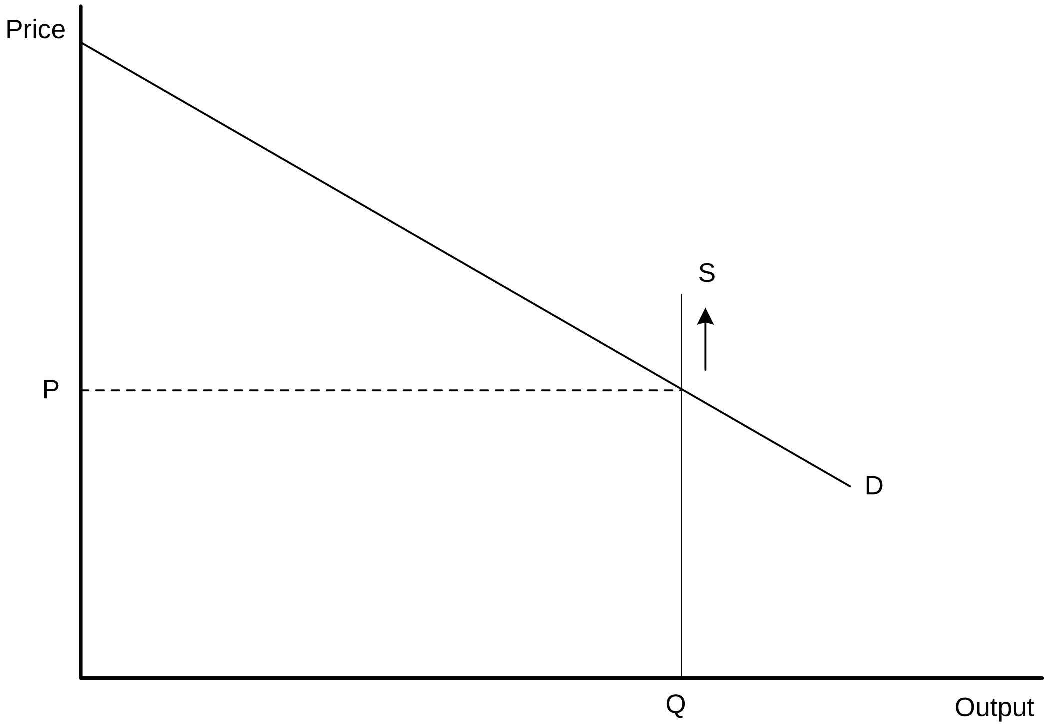


Figure 13.2-1. Short Run: All Costs Borne by Producers

In the long run, all factors of production are variable, and producers can be expected to adjust production plans in response to cost changes imposed by a regulation (e.g., using a different labor/capital mix). Figure 13.2-2 illustrates a typical, if somewhat simplified, long-run industry supply function. The function is horizontal, indicating that the marginal and average costs of production are constant with respect to output.[G] This horizontal slope reflects the fact that, under long-run constant returns to scale, technology and input prices ultimately determine the market price, not the level of output in the market.

Market demand is represented by the standard downward-sloping curve. The market is assumed here to be perfectly competitive; equilibrium is determined by the intersection of the supply and demand curves. In this case, the upward shift in the market supply curve represents the regulation's effect on production costs. The shift causes the market price to increase by the full amount of the per-unit control cost (i.e., from P to P′). With the quantity demanded sensitive to price, the increase in market price leads to a reduction in output in the new with-regulation equilibrium (i.e., Q to Q′). As a result, consumers incur the entire regulatory burden as represented by the loss in consumer surplus (i.e., the area P ac P′). In the nomenclature of EIAs, this long-run scenario is typically referred to as "full-cost pass-through" and is illustrated in Figure 13.2-2.

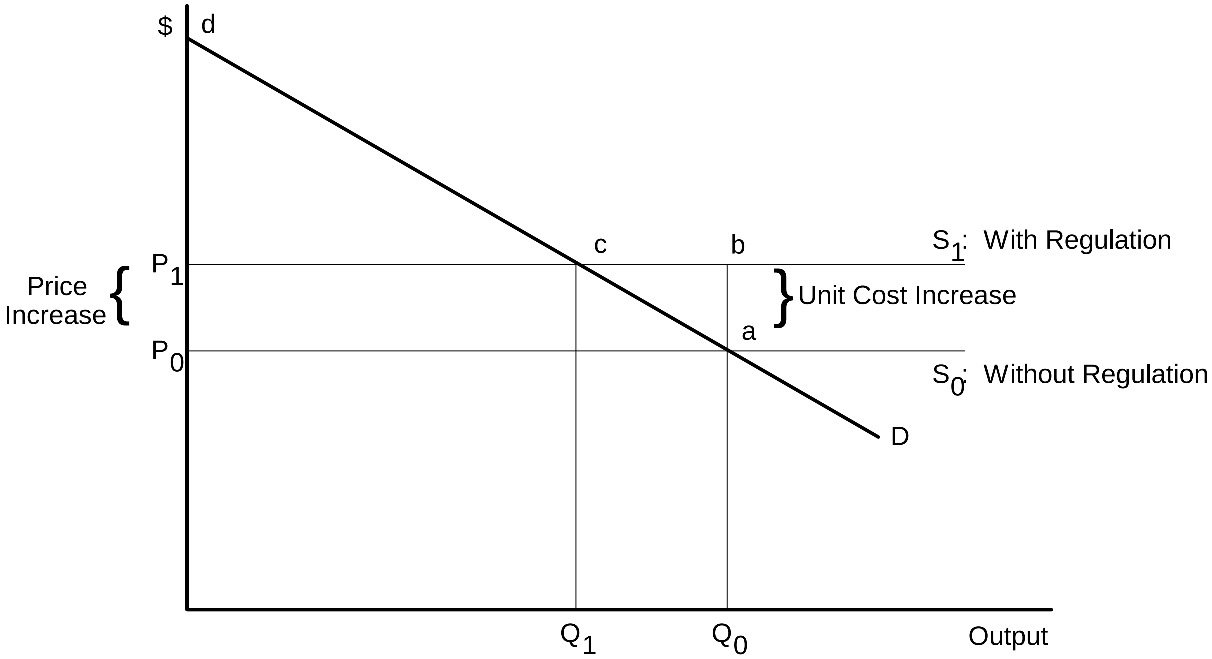


Figure 13.2-2. Long Run: Full Cost Pass Through

[G] The constancy of marginal costs reflects an underlying assumption of constant returns to scale of production, which may or may not apply in all cases.

Taken together, impacts modeled under the long-run/full-cost-pass-through scenario reveal an important point: under fairly general economic conditions, a regulation's impact on producers is transitory. Ultimately, the costs are passed on to consumers in the form of higher prices. However, this does not mean that the impacts of a regulation will have no impact on producers of goods and services affected by a regulation. For example, the long run may cover the time taken to retire all of a facility's existing capital, which could take decades. Therefore, transitory impacts could be protracted and could dominate long-run impacts in terms of present value. In addition, to evaluate impacts on current producers, the long-run approach is not appropriate. Consequently a time horizon that falls between the very short-run/full-cost-absorption case and the long-run/full-cost-pass-through case is most appropriate for this EIA.

The intermediate run time frame allows examination of impacts of a regulatory program during the transition between the short run and the long run. In the intermediate run, some factors are fixed; some are variable.[H] In other words, producers can adjust some, but not all, factors of production, meaning they will bear some portion of the costs of the regulatory program. The existence of fixed production factors generally leads to diminishing returns to those fixed factors. This typically manifests itself in the form of a marginal cost (supply) function that rises with the output rate, as shown in Figure 13.2-3.

[H] As a semantical matter, the situation where some factors are variable and some are fixed is often referred to as the "short run" in economics, but the term "intermediate run" is used here to avoid any confusion with the term "very short run."

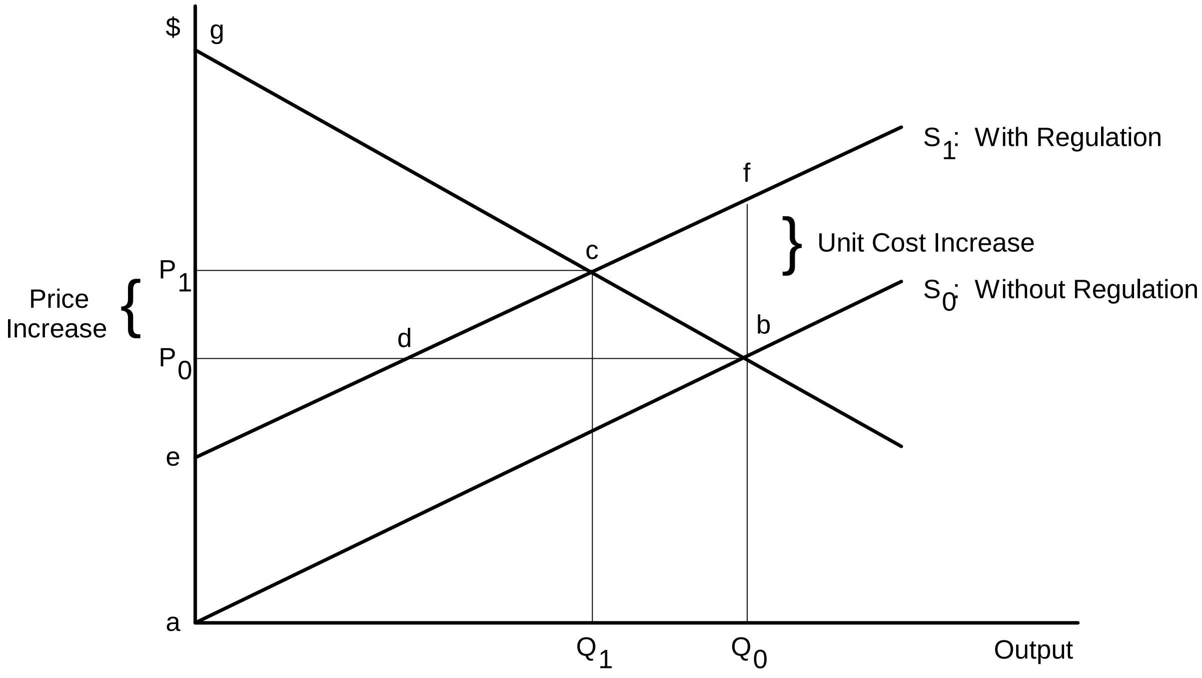


Figure 13.2-3. Intermediate Run: Partial Cost Pass Through

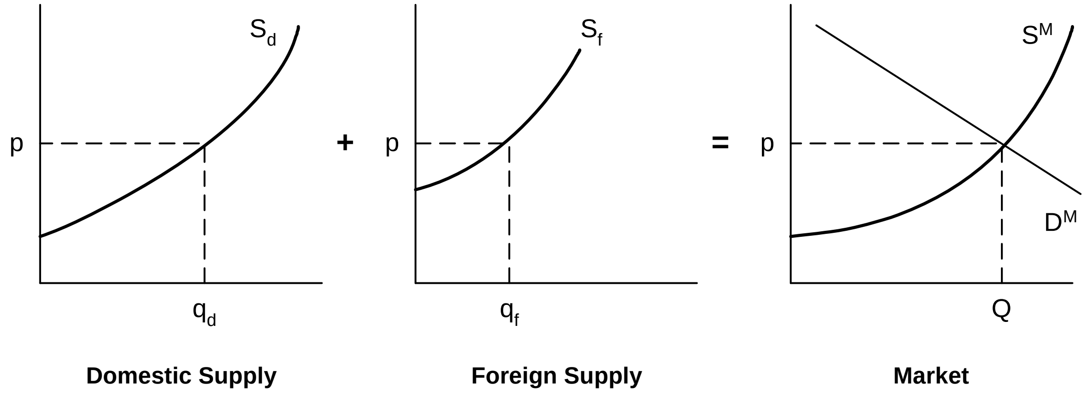
Again, the regulation causes an upward shift in the supply function. The lack of resource mobility may cause producers to suffer profit (producer surplus) losses in the face of regulation; however, producers are able to pass through some of the associated costs to consumers, to the extent the market will allow. As shown, in this case, the market-clearing process generates an increase in price (from P to P′) that is less than the per-unit increase in costs, so that the regulatory burden is shared by producers (net reduction in profits) and consumers (rise in price). In other words, there is a loss of both producer and consumer surplus.

Consistent with other economic impact analyses performed by EPA, this EIM uses an intermediate run approach. This approach allows us to examine the market and social welfare impacts of the program as producers adjust their output and consumers adjust their consumption of affected products in response to the increased production costs. During this period, the distribution of the welfare losses between producer and consumer depends in large part on the relative supply and demand elasticity parameters used in the model. For example, if demand for PFCs is relatively inelastic (i.e., demand does not decrease much as price increases), then most of the direct compliance cost on refiners will be passed along to PFC consumers in the form of higher prices.

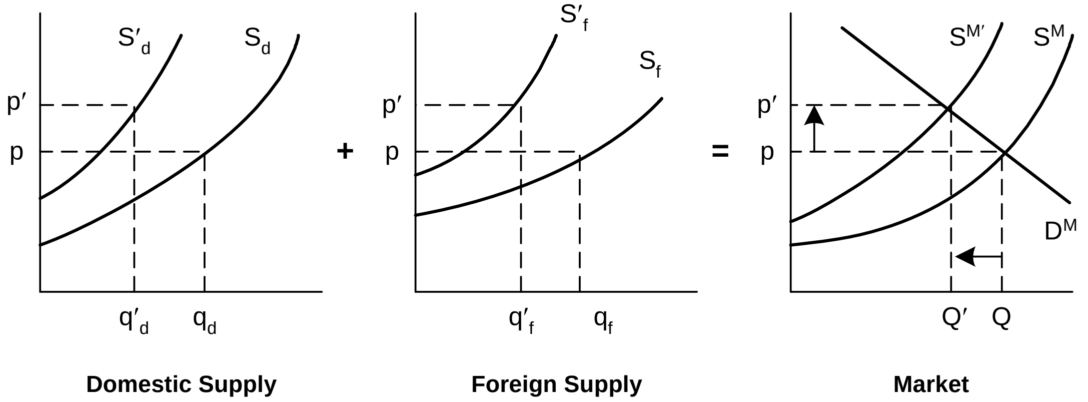
13.2.3 How is the EIM Used to Estimate Economic Impacts?

13.2.3.1 Estimation of Market Impacts

A graphical representation of a general economic competitive model of price formation, as shown in Figure 13.2-4, posits that market prices and quantities are determined by the intersection of the market supply and market demand curves. Under the baseline scenario, a market price and quantity (p,Q) combination is determined by the intersection of the downward-sloping market demand curve (D^M) and the upward-sloping market supply curve (S^M). The market supply curve reflects the sum of the domestic (S_d) and import (S_i) supply curves.



a) Baseline Equilibrium



b) With-Regulation Equilibrium

Figure 13.2-4. Market Equilibrium Without and With Regulation

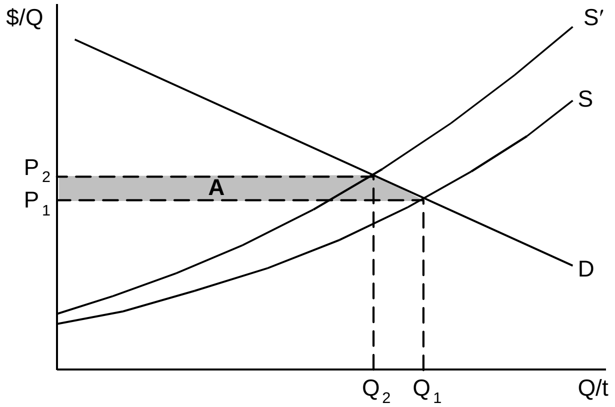
With the regulation, the costs of production increase for suppliers. The imposition of these regulatory control costs is represented as an upward shift in the supply curve for domestic and import supply by the estimated compliance costs. As a result of the upward shift in the supply curve, the market supply curve will also shift upward as shown in Figure 13.2-4(b) to reflect the increased costs of production.

At baseline without the rule, the industry produces total output, Q, at price, p, with domestic producers supplying the amount q_d and imports accounting for Q minus q_d, or q_f. With the regulation, the market price increases from p to p′, and market output (as determined from the market demand curve) declines from Q to Q′. This reduction in market output is the net result of reductions in domestic and import supply

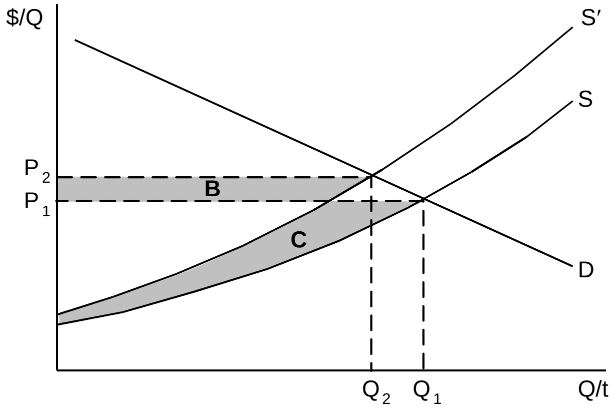
As indicated in Figure 13.2-3, when the standards are applied the supply curve will shift upward by the amount of the estimated compliance costs. The demand curve, however, does not shift. This is because a shift in the demand curve is determined by changes in factors such as income, tastes, prices of substitute and complementary goods, expectations, and population. The standards do not affect these factors and so it is appropriate to assume all these factors remain constant.

13.2.3.2 Estimation of Social Costs

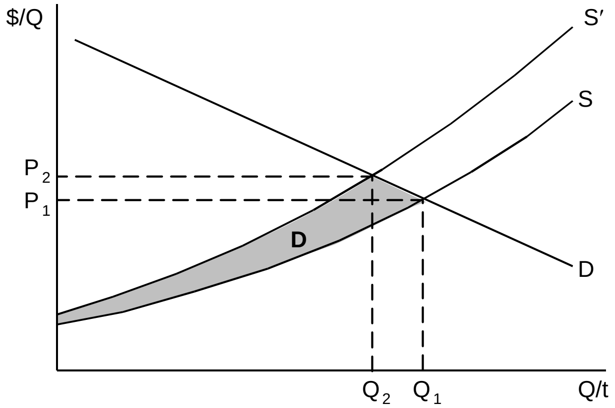
The economic welfare implications of the market price and output changes with the regulation can be examined by calculating consumer and producer net "surplus" changes associated with these adjustments. This is a measure of the negative impact of an environmental policy change and is commonly referred to as the "social cost" of a regulation. It is important to emphasize that this measure does not include the benefits that occur outside of the market, that is, the value of the reduced levels of air pollution with the regulation. Including this benefit will reduce the net cost of the regulation and even make it positive.



(a) Change in Consumer Surplus with Regulation



(b) Change in Producer Surplus with Regulation



(c) Net Change in Economic Welfare with Regulation

Figure 13.2-5. Market Surplus Changes with Regulations
Consumer and Producer Surplus

The demand and supply curves that are used to project market price and quantity impacts can be used to estimate the change in consumer, producer, and total surplus or social cost of the regulation (see Figure 13.2-5a).

The difference between the maximum price consumers are willing to pay for a good and the price they actually pay is referred to as "consumer surplus." Consumer surplus is measured as the area under the demand curve and above the price of the product. Similarly, the difference between the minimum price producers are willing to accept for a good and the price they actually receive is referred to as "producer surplus." Producer surplus is measured as the area above the supply curve below the price of the product. These areas can be thought of as consumers' net benefits of consumption and producers' net benefits of production, respectively.

In Figure 13.2-5, baseline equilibrium occurs at the intersection of the demand curve, D, and supply curve, S. Price is P_l with quantity Q_l. The increased cost of production with the regulation will cause the market supply curve to shift upward to S′. The new equilibrium price of the product is P_2. With a higher price for the product there is less consumer welfare, all else being unchanged. In Figure 13.2-5a, area A represents the dollar value of the annual net loss in consumers' welfare associated with the increased price. The rectangular portion represents the loss in consumer surplus on the quantity still consumed due to the price increase, Q_2, while the triangular area represents the foregone surplus resulting from the reduced quantity consumed, $Q_l – Q_2$.

In addition to the changes in consumers' welfare, there are also changes in producers' welfare with the regulatory action. With the increase in market price, producers receive higher revenues on the quantity still purchased, Q_2. In Figure 13.2-5b, area B represents the increase in revenues due to this increase in price. The difference in the area under the supply curve up to the original market price, area C, measures the loss in producer surplus, which includes the loss associated with the quantity no longer produced. The net change in producers' welfare is represented by area B – C.

The change in economic welfare attributable to the compliance costs of the regulations is the sum of consumer and producer surplus changes, that is, –(A) + (B–C). Figure 13.2-5c shows the net (negative) change in economic welfare associated with the regulation as area D.

As explained in Section 13.1.3, the vehicle market is not included in the EIM. Instead, compliance costs are used as a proxy for the social welfare costs associated with that part of the regulatory program. Vehicle compliance costs are likely to be absorbed by the manufacturers, thus increasing their surplus loss.

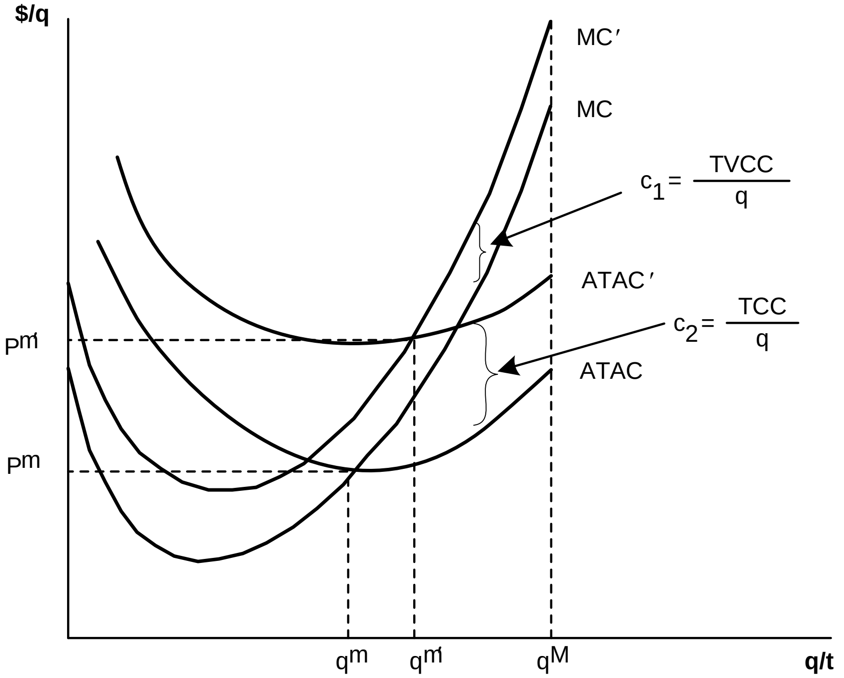
13.2.4. How Are Special Market Characteristics Addressed?

In addition to the general model features described in Section 13.2.2, there are several specific characteristics of the PFC and gasoline fuel markets that need to be addressed in the EIM. These are the treatment of gasoline fuel savings, fixed and variable costs, flexibility provisions, and substitution.

13.2.4.1 Fixed and Variable Costs

Related to short-run versus long-run modeling issues is the question of how fixed and variable costs are defined or treated by a specific industry or in the market analysis. The engineering estimates of fixed R&D and capital costs and variable material and operating and maintenance (O&M) costs provide an initial measure of total annual compliance costs without accounting for behavioral responses. The starting point for assessing the market impacts of a regulatory action is to incorporate the regulatory compliance costs into the production decision of the firm.

In general, shifting the supply curve by the total cost per unit implies that both capital and operating costs vary with output levels. At least in the case of capital, this raises some questions. In the long run, all inputs (and their costs) can be expected to vary with output. But a short(er)-run analysis typically holds some capital factors fixed. For instance, to the extent that a market supply function is tied to existing facilities, there is an element of fixed capital (or one-time R&D). As indicated above, the current market supply function might reflect these fixed factors with an upward slope. As shown in Figure 13.2-6, the marginal cost (MC) curve will only be affected, or shift upwards, by the per-unit variable compliance costs (c_1=TVCC/q), while the average total cost (ATAC) curve will shift up by the per-unit total compliance costs (c_2=TCC/q). Thus, the variable costs will directly affect the production decision (optimal output rate), and the fixed costs will affect the closure decision by establishing a new higher reservation price for the firm (i.e., $P^{m'}$). In other words, the fixed costs are important in determining whether the firm will stay in this line of business (i.e., produce anything at all), and the variable costs determine the level (quantity) of production.



(a) Upward-sloping supply function

Figure 13.2-6. Modeling Fixed Costs

Depending on the industry type, fixed costs associated with complying with a new regulation are generally treated differently in an analysis of market impacts. In a competitive market, the industry supply curve is generally based on the market's marginal cost curve; fixed costs do not influence production decisions at the margin. Therefore, the market analysis is based on variable costs only. This is the case with the vehicle controls in this analysis. The compliance costs for that program are fixed costs (R&D, test facilities) and do not affect marginal costs. As a result, this economic impact analysis does not include market impacts for the vehicle market. They are included in the social welfare analysis, however, since these compliance costs are a cost to society. By adding the vehicle program compliance costs to the social welfare costs we attribute all of the costs to the producers and assume that these costs do not change the quantities of affected vehicles produced or their prices.

The market analysis of the PFC market, however, is different and is based on total compliance costs (fixed + variable). The approach is appropriate even though this is a competitive market due to the nature of production practices in this market. Specifically, PFC manufacturers produce a product that changes very little over time. Portable fuel containers are a fairly standard product and these manufacturers do not engage in research and development to improve their products on a continuous basis as is the case with highway vehicles or nonroad engines or equipment. A design change of nature that would be required by the standards will require PFC manufacturers to devote new funds and resources to product redesign and facilities changes. Portable fuel container manufacturers are expected to increase their prices by the full amount of the compliance costs to recover those costs.

Fixed costs required to comply with the rule on the refiner side are also treated differently, to reflect the refinery industry cost structure. Most of the petroleum refinery fixed costs used are for production hardware. The decision to invest to increase, maintain, or decrease production capacity may be made in response to anticipated or actual changes in price. To reflect the different ways in which refiners can pass costs through to consumers, three scenarios were run for the following supply curve shifts in the gasoline fuel markets:

- shift by average total (variable + fixed cost)
- shift by max total (variable + fixed cost)
- shift by max variable cost.

While it may seem reasonable to estimate costs based on maximum variable or maximum total costs, it should be noted that both of those scenarios assume that refiners with the highest benzene compliance costs are also the highest-cost gasoline producers absent benzene control. We do not have information on the highest gasoline cost producers to be able to examine whether these refineries are also expected to have the highest benzene control costs. However, we believe this is an extreme assumption.

We estimate the market and social welfare impacts of each of these scenarios. The first, shift by average total cost (variable + fixed), is the primary scenario and is included in the primary analysis. The other two are investigated in the sensitivity analyses in Appendix G.

13.2.4.2 Gasoline Fuel Savings and Fuel Taxes

If all the costs of the regulation are not reflected in the supply shift, then the producer and consumer surplus changes reflected in Figure 13.2-5a will not capture the total social costs of the regulation. This will be the case, for example, if there are cost savings attributable to a program that are not readily apparent to consumers. In this case, the PFC controls are expected to reduce evaporative emissions from gasoline fuel storage, resulting in gasoline fuel savings for users of these containers. These fuel savings are not included in the market analysis for this EIA because these savings are not expected to affect consumer decisions with respect to the purchase of new containers. In other words, we assume people base their decision on whether to buy a new container on other needs (e.g., purchase of new equipment, replacement of a damaged container) and not on expected fuel savings that would accrue to them from using a compliant container. Gasoline fuel savings will be included in the social cost analysis, however, because they are a savings that accrues to society. They will be added into the estimated social costs as a separate line item.

The estimated gasoline fuel savings are estimated using the quantity of gasoline fuel saved through better evaporative controls and the post-tax price of gasoline (see Section 13.3.2.2). The post-tax price is used because this is the price consumers see at the fuel pump and is the price on which they base their purchasing decisions. In other words, consumers save the entire amount of the pump price. Also, in contrast to distillate diesel fuel used in nonroad equipment, gasoline fuel taxes are not typically rebated. This is because most gasoline fuel used in nonroad equipment is used by residential consumers and even those who could file for a tax rebate probably don't given the small amounts of fuel involved. As a result, the consumer would realize a savings equal to the pump price of gasoline for the gasoline fuel they save from evaporative controls (i.e., the full cost of the fuel and not just the pre-tax cost). At the same time, the tax savings realized on the fuel savings by consumers are reduced taxes revenues for local and federal governments. These revenue losses are estimated separately in the social welfare analysis, based on the gallons of gasoline fuel saved and the average national fuel tax (combined state and Federal government).

13.2.4.3 Flexibility Provisions

Consistent with the engineering cost estimates, the EIM does not include cost savings associated with compliance flexibility provisions or averaging, banking, and trading provisions. As a result, the results of this EIA can be viewed as somewhat conservative.

13.2.4.4 Substitution

This analysis assumes that there will be no substitution away from gasoline fuel. As explained in Section 13.2.3.3, the time horizon for this analysis is the intermediate run. In the intermediate run, economic actors can adjust some of their costs but others are fixed. So, for example, consumers can adjust the amount of gasoline they purchase but the type of vehicle or equipment they own (i.e., gasoline or diesel) is fixed. This analysis assumes that the relative proportions of gasoline to diesel vehicles and equipment are constant for the period of analysis. This assumption seems reasonable because the average cost increase for gasoline is estimated to be less than $0.01 per gallon. Gasoline prices vary considerably over time without provoking dramatic shifts in consumer behavior. Therefore, our assumption that consumers will not substitute away from gasoline vehicles and equipment in favor of diesels, or otherwise modify their behavior, is reasonable.

The analysis also assumes there will be no substitution away from PFCs. Consumers seeking to store a particular kind of fuel (gasoline, diesel, or kerosene) have only limited alternatives for safely storing that fuel: metal or plastic fuel containers approved for storage of that particular kind of fuel. Plastic containers account for the vast majority of PFCs sold due to their safety characteristics and ease of use. They are light-weight, are very durable, and do not rust. Plastic containers are also cheaper to manufacturer than their metal counterparts. Consequently, about 95 percent of the PFCs sold in the United States are plastic. While it may be the case that some consumers opt to use unapproved containers (e.g., milk jugs, glass jars), the extent to which they do this is not known. This rule will make approved plastic PFCs more expensive compared to unapproved containers, but we do not expect this rule to lead to more use of inappropriate containers by consumers than is already the case. Unapproved containers have serious defects. For example, it is difficult to pour fuel from containers such as plastic milk jugs, glass jars, and similar containers, especially into the small mouths of some lawn and garden equipment. In addition, these also are not long-term storage options as they may be damaged by the fuel. Consumers are generally aware that fuel must be transported and stored safely and are not likely to view these alternatives as safe relative to an approved fuel storage container. Finally, it is illegal in most if not all states to dispense fuel into unapproved containers, with this prohibition clearly marked on fuel pumps.

The elasticity of demand for PFCs estimated for this EIM reflects this no-substitution assumption. As noted in Section 13.1.3 and explained in more detail in Section 13.3.5 and in Appendix E, this estimated elasticity is inelastic at -0.01. This means that a 100 percent increase in price is expected to result in a 1 percent decrease in demand. In acknowledgement of the concern about use of inappropriate containers, we also performed a sensitivity analysis for the elasticity of demand estimate relaxing the no-substitution assumption and using a rate of substitution of 10 percent. This is a fairly high rate of substitution and means that 10 percent of people who would otherwise buy a PFC find some other way to store fuel (e.g., inappropriate containers) or opt not to purchase a PFC (for example, those with multiple containers will choose not to replace a container, giving up having multiple cans in multiple locations or the capability of filling multiple cans with a single trip to the gas station). Using a 10 percent rate of substitution we estimate a demand elasticity that is less inelastic, at -0.25. This means that a 100 percent increase in price results in a 25 percent decrease in demand. As described in Appendix G, this alternative demand elasticity has only a small impact on the results of the modeling. For 2015, the price impact is reduced by about 20 cents (decreasing from $1.52 to $1.31 in states that do not already have PFC requirements). In addition, producers are expected to bear more of the costs of the program (increasing from 0.7 percent to 15.1 percent). The emissions impacts of a 10 percent rate of substitution are small. If these purchasers exit the PFC market permanently (i.e., this is not a short-term adjustment with consumers only postponing their purchases), we would expect about 10 percent less emissions reductions from the PFC standards. Table 13.2-1 below provides an example of potential losses in VOC emission reductions from a ten percent substitution rate. It is important to note that the costs of the overall program would also be reduced by roughly the same 10 percent and so the overall cost per ton of emissions reduced would not significantly change. Also, in cases where the substitution occurs from consumers keeping their current PFCs for a longer period of time or by only leaving the market temporarily, the emissions reductions are only postponed to a future date. Therefore, the lost emissions reductions shown in the table below would represent a worst case for the 10 percent substitution scenario.

Table 13.2-1 - VOC Emissions Reductions from Portable Fuel Containers (tons)

	2015	2020	2030
Base Case	181,000	193,000	218,000
w/ 10 Percent Substitution	163,000	174,000	196,000
Difference	18,000	19,000	22,000

13.2.4.5 Market-Level Analysis

The EIM estimates the economic impacts of the rule at the market level. It is not a firm-level analysis. The demand elasticity facing any particular manufacturer may be different from the demand elasticity of the market as a whole, and therefore the share of the compliance costs a particular firm may pass on to consumers may be smaller or larger than estimated by this model. This difference can be important, particularly where the rule affects different firms' costs over different volumes of production. However, to the extent that there are differential effects, EPA believes that the flexibilities provided in this rule will be adequate to address any cost inequities that are likely to arise.

13.3 EIM Data Inputs and Model Solution

The EIM is a computer model comprised of a series of spreadsheet modules that simulate the supply and demand characteristics of the affected markets. The model equations, presented in Appendix D to this chapter, are based on the economic relationships described in Section 13.2. The EIM analysis consists of four basic steps:

- Define the initial market equilibrium conditions of the markets affected by this rule (equilibrium prices and quantities and behavioral parameters; these yield equilibrium supply and demand curves).
- Introduce a policy "shock" into the model based on estimated compliance costs that shift the supply functions.
- Use a solution algorithm to estimate a new, with-regulation equilibrium price and quantity for all markets.
- Estimate the change in producer and consumer surplus in all markets included in the model.

Supply responses and market adjustments can be conceptualized as an interactive process. Producers facing increased production costs due to compliance are willing to supply smaller quantities at the baseline price. This reduction in market supply leads to an increase in the market price that all producers and consumers face, which leads to further responses by producers and consumers and thus new market prices, and so on. The new with-regulation equilibrium reflects the new market prices where total market supply equals market demand.

The remainder of this section describes the data used to construct the EIM: initial equilibrium market conditions (equilibrium prices and quantities), compliance cost inputs, model elasticity parameters. Also included is a brief discussion of the analytical expression used to estimate with-regulation market conditions.

13.3.1 Description of Product Markets

There are six product markets included in this EIM: two PFC markets and four gasoline fuel markets. While the vehicle market will also be affected by the standards, that market was not included in the EIM (see Section 13.1.3). Each of these markets is described below. More information can be found in the industry characterizations prepared for this rule.[16,17]

13.3.1.1 Portable Fuel Container Market

Portable fuel containers allow people to refuel equipment in circumstances where refueling at a retail fuel establishment or central fueling location is not convenient. Gasoline storage containers support the use of a wide variety of gasoline-powered equipment ranging from lawnmowers, chainsaws, string trimmers, and garden tractors to all-terrain vehicles, off-road motorcycles, and gasoline-powered golf carts. They are also used for emergency gasoline supplies for highway vehicles. Diesel storage containers support equipment used on construction sites, manufacturing facilities, and agricultural establishments. Kerosene storage containers also support a range of construction, manufacturing, and agricultural equipment.

There is little additional publicly available national data on the users of PFCs. However, a recent study by CARB found that 94 percent of portable fuel containers in California were used by residential households.[18] Commercial businesses account for a remaining PFC use. Industry representatives have indicated that sales of PFCs are influenced by trends in sales of power equipment (i.e., lawn and garden) and recreational vehicles. As a result, factors that influence decisions to purchase these commodities (e.g., changes in the price of equipment, changes in personal income, population growth rates, home sales) will indirectly influence the decision to purchase PFCs. Economic theory for derived demand suggests that under some reasonable assumptions we can predict that an increase in the price of PFCs will have little impact on sales of PFCs both because PFCs represent a very small fraction of total expenditures and they are an essential input into household and business production functions.[19,20,21] In addition, there are only limited alternatives for storing gasoline.

The vast majority of PFCs sold in the United States are plastic (about 98 percent). Portable fuel container manufacturing is currently dominated by four firms (Blitz USA, Midwest Can, Scepter Manufacturing, Ltd., and Wedco Molded Products) and one firm accounts for about 70 percent of U.S. sales and 50 percent of North American sales. Other PFC manufacturers have very limited market share, are more geared for industrial use, and/or fill a niche specialty market. Manufacturing PFCs is not constrained geographically in that these containers are lightweight and fairly inexpensive to transport to distant markets.

Plastic PFCs are manufactured using well-known plastic processing methods to form plastic material into gas containers and spouts. The production process combines capital equipment, labor, and materials to produce portable fuel containers of desired size and technical standards. Therefore, only minimal technical barriers prevent new firms from freely entering the market, and there are many manufacturers of plastics and plastic containers who could join the market if it were profitable to do so.

California established an emissions control program for PFCs that began in 2001.[22] Twelve other states (Delaware, Maine, Maryland, Pennsylvania, New York, Connecticut, Massachusetts, New Jersey, Rhode Island, Vermont, Virginia, and Texas) and the District of Columbia have adopted the California program in recent years. Because of these existing control measures, the costs of complying with the standards is expected to be reduced for these states (fewer changes will be necessary for these PFCs). Consequently, the economic impact analysis differentiates between two markets: those states that have controls and those that do not.

13.3.1.2 Gasoline Fuel Market

Gasoline plays an important role in the American economy. The Federal Highway Administration reported that the United States consumed over 130 billion gallons of gasoline in 2002.[23] The overwhelming majority of gasoline is consumed for highway uses. About 92% of gasoline consumption on a BTU basis was consumed by light-duty vehicles. Most people rely on gasoline for personal transportation, unlike the commercial transportation that relies mostly on diesel fuel. The remaining share of gasoline consumption is for non-highway use (i.e., lawn and garden equipment and marine uses).

Consumers are not expected to be very sensitive to changes in the price of gasoline. Consumers can respond to price changes in gasoline in two ways. In the short term, they may simply consider reducing the number of vehicle miles traveled or their use of nonroad equipment. However, their ability to reduce gasoline consumption in this way depends on their ability to do without the service provided by the gasoline-consuming vehicle or equipment (forego lawnmowing or personal transportation). If the relative price of gas remains higher for longer periods, consumers might also consider long-term adjustments to their capital stock to mitigate the effects of higher prices. For example, they may purchase vehicles with better fuel economy, buy a home closer to work or shopping, or purchase nonroad equipment that relies on electricity. In either case, the price of gasoline may have to rise considerably to trigger such a change in consumption patterns.

Producers of gasoline are also expected to be insensitive to price changes, for two major reasons. First, refineries produce finished motor gasoline through a complex process that converts crude oil into three principal types of hydrocarbon products: gasoline, distillate (i.e., jet fuel, diesel fuel, and heating oil), and heavy oils (i.e., residual fuel oil, asphalt). A refiner's ability to alter the proportions of the three products generated by refining crude oil is somewhat limited. Refiners have more, but not unlimited, flexibility in adjusting production among different formulations of gasoline. Once a refiner has decided what formulations of gasoline it will produce in an upcoming production campaign, it becomes increasingly difficult to alter the planned output of the refinery as the production campaign approaches. Second, refining is a capital-intensive, high fixed-cost operation. Consequently, refiners attempt to operate at high capacity utilization rates. Industry statistics illustrate that refining capacity is generally tight, and capacity utilization has been increasing over the past decade. Industry-wide crude oil refining capacity utilization in the United States in the month of May was 85 percent in 1990, 89 percent in 1992, 93 percent in 1994 and 1996, 94 percent in 1998, and 96 percent in 2000. The average monthly capacity utilization rate in 2000 was 94 percent. These characteristics of the refining industry limit further the ability of refiners to change refinery production significantly in the short run.[24]

There are more than 100 refineries in the United States. Additional gasoline is obtained through imports, especially on the East Coast. However, production tends to be regional in nature. The Federal Trade Commission (FTC) has developed an approach to ensure competitiveness in gasoline fuel markets. It reviews oil company mergers and frequently requires divestiture of refineries, terminals, and gas stations to maintain a minimum level of competitiveness.

Finished gasoline product leaves the refinery and reaches consumers through one or more bulk transport services. Pipelines, tankers, or barges typically transport gasoline from refineries or ports to terminals that provide storage and dispensing facilities. A variety of downstream gasoline marketing arrangements (i.e. wholesale and retail) ultimately deliver gasoline to the consumer.

Given the existing region-specific gasoline performance standards and other transportation and economic barriers, this analysis uses the five regional markets (PADDs) defined by the Department of Energy. For the purpose of this analysis, two PADDs are combined, giving four regional district fuel markets. These are:

- PADD 1 & 3
- PADD 2
- PADD 4
- PADD 5 (includes Alaska and Hawaii; California fuel not included).

PADD 1 and 3 are combined because of the high level of regional trade between these areas. Other regional trading is generally constrained due to inefficiencies in transporting gasoline between regions and so is not included in this analysis. Also not included in the analysis is inter-region trading on a consumer basis (drivers who cross state lines to purchase fuel). PADD 5 does not include California fuel in the market analysis since California already has fuel benzene controls. Finally, consistent with the cost analysis, the EIM does not distinguish between conventional gasoline and reformulated gasoline (RFG).

13.3.2 Initial Market Conditions

The starting point for the economic impact analysis is initial market equilibrium conditions that exist prior to the implementation of new standards. At pre-control market equilibrium conditions, consumers are willing to purchase the same amount of a product that producers are willing to produce at the market price. This section describes the initial market equilibrium conditions (prices and quantities) for the PFC and gasoline markets.

13.3.2.1 Portable Fuel Container Market Quantities and Prices

The PFC market equilibrium sales and price data used in the EIM are contained in Tables 13.3-1 and 13.3-2. The data are based on information provided by industry.[25] Industry sales data from 2002 were grown for future years using a two percent growth rate. This growth rate is consistent with information obtained from industry representatives, who indicated that sales are expected to increase at the same pace as the retail market in general. The PFC prices for 2003 were obtained from industry. The prices in Table 3.3-2 are weighted averages of the observed prices of 3 sizes of PFCs (1 gallon, 2 gallon, and 5 gallon; 33 percent weight for each). PFC prices are held fixed for all years included in the analysis reflecting an assumption of constant (real) price of goods and services over time (see Appendix F for an explanation of this assumption).

Table 13.3-1. Portable Fuel Container Sales Data (2009 to 2035)

Year	States without Controls	States With Controls	Total
2009	18,218,155	11,647,673	29,865,827
2010	18,582,518	11,880,626	30,463,144
2011	18,954,168	12,118,239	31,072,407
2012	19,333,252	12,360,603	31,693,855
2013	19,719,917	12,607,815	32,327,732
2014	20,114,315	12,859,972	32,974,287
2015	20,516,601	13,117,171	33,633,772
2016	20,926,933	13,379,515	34,306,448
2017	21,345,472	13,647,105	34,992,577
2018	21,772,381	13,920,047	35,692,428
2019	22,207,829	14,198,448	36,406,277
2020	22,651,985	14,482,417	37,134,402
2021	23,105,025	14,772,065	37,877,090
2022	23,567,126	15,067,507	38,634,632
2023	24,038,468	15,368,857	39,407,325
2024	24,519,238	15,676,234	40,195,471
2025	25,009,622	15,989,759	40,999,381
2026	25,509,815	16,309,554	41,819,368
2027	26,020,011	16,635,745	42,655,756
2028	26,540,411	16,968,460	43,508,871
2029	27,071,220	17,307,829	44,379,048
2030	27,612,644	17,653,985	45,266,629
2031	28,164,897	18,007,065	46,171,962
2032	28,728,195	18,367,206	47,095,401
2033	29,302,759	18,734,551	48,037,309
2034	29,888,814	19,109,242	48,998,055
2035	30,486,590	19,491,426	49,978,017

Table 13.3-2. Portable Fuel Container Price Data (2003$)

States Without Controls	States With Controls
$4.66	$11.05

13.3.2.2 Gasoline Fuel Market Quantities and Prices

The gasoline fuel market equilibrium sales and price data used in the EIM are contained in Tables 13.3-3 and 13.3-4. It should be noted that the sales data is for all gasoline and that this analysis does not differentiate between reformulated and conventional gasoline. This is consistent with the cost analysis performed for this rule.[I] California gasoline is not included in this program as that state has its own benzene control program.

The sales data is Energy Information Administration data, based on the Energy Information Administration's Petroleum Market Annual fuel consumption data (Table 48) for 2004.[26] This data was adjusted using the growth rates from the Energy Information Administration's Annual Energy Outlook 2006 (with 2030 to 2035 growth based on 2025 to 2030 growth estimated by EIA).[27] The gasoline volumes used in this economic impact analysis are consumption volumes, which include imported gasoline as well as gasoline produced in the United States for domestic purposes. Consumption volumes are used because the market equilibrium price is determined by all the gasoline supplied and purchased in the market and not just the gasoline produced in the U.S. for that market.

Gasoline retail prices were estimated using the following approach.[28] First, the average price of motor gasoline by PADD (all grades, sales to end users, excluding taxes) was obtained from the Energy Information Administrations 2003 Petroleum Marketing Annual.[29] Next, state and federal motor gasoline taxes data were obtained from the Department of Transportation's *2003 Highway Statistics* to create an average state tax per model region.[30] State and federal taxes were added to the price data obtained from the Energy Information Administration. Since EIM model combines PADDs 1 and 3, the retail price for this market is an average price for the region. Each PADD's price is weighted by the gasoline consumption data used in the market model.

[I] See Note B, above.

Table 13.3-3. Gasoline Fuel Sales Data, by Region (2007 to 2035; MM gallons)

Year	PADD 1 & 3	PADD 2	PADD 4	PADD 5 w/out CA	Total
2007	72,263	40,154	4,702	8,197	125,315
2008	73,414	40,793	4,777	8,327	127,311
2009	74,794	41,560	4,867	8,484	129,705
2010	76,252	42,370	4,962	8,649	132,233
2011	77,479	43,052	5,042	8,788	134,362
2012	78,553	43,649	5,111	8,910	136,224
2013	79,551	44,203	5,176	9,023	137,953
2014	80,548	44,757	5,241	9,137	139,683
2015	81,545	45,311	5,306	9,250	141,412
2016	82,542	45,866	5,371	9,363	143,142
2017	83,540	46,420	5,436	9,476	144,871
2018	84,614	47,016	5,506	9,598	146,733
2019	85,611	47,571	5,571	9,711	148,463
2020	86,531	48,082	5,631	9,815	150,059
2021	87,452	48,594	5,691	9,920	151,656
2022	88,296	49,063	5,745	10,015	153,119
2023	89,140	49,531	5,800	10,111	154,582
2024	90,060	50,043	5,860	10,215	156,179
2025	90,981	50,554	5,920	10,320	157,775
2026	91,978	51,109	5,985	10,433	159,504
2027	92,975	51,663	6,050	10,546	161,234
2028	93,896	52,174	6,110	10,651	162,830
2029	94,893	52,728	6,175	10,764	164,560
2030	95,814	53,240	6,235	10,868	166,156
2031	96,810	53,794	6,299	10,981	167,885
2032	97,818	54,354	6,365	11,095	169,632
2033	98,836	54,919	6,431	11,211	171,397
2034	99,864	55,491	6,498	11,328	173,180
2035	100,903	56,068	6,566	11,445	174,982

Table 13.3-4. Gasoline Fuel Prices, by Region (2003$; includes fuel taxes)

PADD 1 & 3	PADD 2	PADD 4	PADD 5 w/out CA
$1.48	$1.51	$1.57	$1.66

Gasoline fuel prices are held fixed for all years included in the analysis reflecting an assumption of constant (real) price of goods and services over time (see Appendix F for an explanation of this assumption). We also performed a sensitivity analysis using gasoline fuel prices projected by the Energy Information Agency. The results of that sensitivity analysis can be found in Appendix G.

13.3.3 Compliance Costs

The social costs of the standards are estimated by shocking the initial market equilibrium conditions by the amount of the compliance costs. The compliance costs used in this analysis are the engineering compliance costs described in Chapters 9 and 10 of this RIA and are summarized in this section.

13.3.3.1 Portable Fuel Container Compliance Costs

The economic impacts of the PFC controls are estimated based on the estimated engineering compliance costs described in Chapter 10. The compliance costs used in the EIA are summarized in Table 13.3-5. The compliance costs begin to apply in 2009, when the program goes into effect.

Even though this is a competitive market, the PFC market is shocked by the sum of the fixed and variable compliance costs in the initial years of the program. The fixed costs are included for the first five years of the program, which represents the capital recovery period for the initial R&D and tooling costs. As explained in Section 13.2.4.1, in a competitive market the industry supply curve is based on its marginal cost curve and therefore the market shock should reflect only variable costs. However, as explained in that section, PFC manufacturing sector is structured such that these manufacturers are expected to pass along the full amount of the compliance costs, fixed and variable costs, to consumers in the form of higher prices.

In the engineering cost analysis, fixed costs are applied equally over the five-year recovery period. For the purpose of the EIA, a simplified constant fixed cost approach was used to allocate the fixed costs to a per-unit basis. Because the number of units produced is expected to increase every year, this approach means that the model anticipates that engine manufacturers would recover slightly more than the estimated fixed costs, and the supply curve shift would be slightly more than of another method of allocating fixed costs were used. While the resulting estimated social welfare costs of the program are slightly higher, this difference is not expected to change the overall results of the analysis.

As reflected in Table 13.3-5, variable and fixed costs are different for PFCs in states with or without existing controls. The estimated costs are expected to be less in states with existing programs because manufacturers will incur fewer costs to bring their PFCs into compliance with the standards.

Table 13.3-5. Portable Fuel Container Compliance Costs (Per Unit; 2003$)

Year	States without State Program			States with State Program		
	Fixed Costs	Variable Costs	Total Costs	Fixed Costs	Variable Costs	Total Costs
2009	$1.17	$1.53	$2.70	$0.56	$0.21	$0.77
2010	$1.17	$1.53	$2.70	$0.56	$0.21	$0.77
2011	$1.17	$1.53	$2.70	$0.56	$0.21	$0.77
2012	$1.17	$1.53	$2.70	$0.56	$0.21	$0.77
2013	$1.17	$1.53	$2.70	$0.56	$0.21	$0.77
2014		$1.53	$1.53		$0.21	$0.21
2015		$1.53	$1.53		$0.21	$0.21
2016		$1.53	$1.53		$0.21	$0.21
2017		$1.53	$1.53		$0.21	$0.21
2018		$1.53	$1.53		$0.21	$0.21
2019		$1.53	$1.53		$0.21	$0.21
2020		$1.53	$1.53		$0.21	$0.21
2021		$1.53	$1.53		$0.21	$0.21
2022		$1.53	$1.53		$0.21	$0.21
2023		$1.53	$1.53		$0.21	$0.21
2024		$1.53	$1.53		$0.21	$0.21
2025		$1.53	$1.53		$0.21	$0.21
2026		$1.53	$1.53		$0.21	$0.21
2027		$1.53	$1.53		$0.21	$0.21
2028		$1.53	$1.53		$0.21	$0.21
2029		$1.53	$1.53		$0.21	$0.21
2030		$1.53	$1.53		$0.21	$0.21
2031		$1.53	$1.53		$0.21	$0.21
2032		$1.53	$1.53		$0.21	$0.21
2033		$1.53	$1.53		$0.21	$0.21
2034		$1.53	$1.53		$0.21	$0.21
2035		$1.53	$1.53		$0.21	$0.21

13.3.3.2 Gasoline Fuel Compliance Costs

The EIM uses the estimated gasoline fuel compliance costs described in Chapter 9. The compliance costs for the primary scenario, average total (fixed + variable) costs, are summarized in Table 13.3-6. The gasoline compliance costs are different across regions, reflecting different refinery production practices. The compliance costs for PADD 1&3 is a weighted average of the compliance costs for each of those two PADDs. Compliance costs are treated the same for domestically produced fuel and imports for each PADD. This approach is reasonable because many areas (e.g., Europe, Japan, and Australia) already have benzene standards. In addition, although foreign refiners may face a compliance situation different from domestic producers in a particular PADD, they can select fuel streams for export that require less benzene removal, thereby keeping their costs low.

The compliance costs contained in Table 13.3-6 reflect a phase-in of the program starting in 2007 and ending in May 2015. After the phase-in, gasoline fuel compliance costs are constant for all years and each regional supply curve is shifted by the average total (variable + fixed) regional cost of the regulation. This approach is used for the fuel market because most of the petroleum refinery fixed costs are used for production hardware which is required by the standards. This new capital investment (fixed costs) will be amortized each year and will be replaced after a certain period. Therefore, the fixed costs required by this rule are expected to be constant for all years included in the analysis.

As explained in Section 13.2.4.1, above, we investigate two other gasoline fuel compliance cost scenarios. In the primary analysis, fuel compliance costs are based on the total average compliance costs for the industry. However, if refiners' investment in benzene control capacity is very close to that needed to satisfy the fuel demand for the benzene control program, then economic theory suggests that the last or highest increment of control in that market would determine the gasoline price. The compliance costs for each of the two alternative scenarios are described and the results presented in Appendix G: one in which the high-cost refinery’s total (variable + fixed) compliance costs determine price, and a second in which only the high-cost refinery’s variable compliance costs determine price. It should be noted, however, that both of these maximum cost scenarios assume that refiners with the highest benzene compliance costs are also the highest-cost gasoline producers absent benzene control. This is an extreme assumption.

Table 13.3-6. Gasoline Fuel Compliance Costs – Total Average (Fixed + Variable) Cost by Region (¢/gallon, 2003$)

Year	PADD 1 & 3	PADD 2	PADD 4	PADD 5 (w/out California)
2007	0.010¢	0.053¢	0.019¢	0.004¢
2008	0.016¢	0.091¢	0.033¢	0.007¢
2009	0.016¢	0.091¢	0.033¢	0.007¢
2010	0.031¢	0.194¢	0.099¢	0.035¢
2011	0.031¢	0.194¢	0.099¢	0.035¢
2012	0.058¢	0.308¢	0.213¢	0.140¢
2013	0.053¢	0.227¢	0.227¢	0.244¢
2014	0.053¢	0.227¢	0.227¢	0.244¢
2015+	0.149¢	0.307¢	0.501¢	0.997¢

13.3.3.3 Vehicle Compliance Costs

The market impacts of the vehicle control program are not modeled because they are fixed costs (primarily R&D and facility costs) and are therefore not included in the market analysis (see Section 13.2.4.1, above). However, these compliance costs are costs to society and should be included in the social cost analysis. We use the vehicle compliance costs as a proxy for the social welfare costs associated with those controls. These are added to the social costs for the gasoline fuel and PFC controls to obtain the total social costs of the program.

For this analysis, we used the vehicle compliance costs described in Chapter 8. These are summarized in Table 13.3-7. These costs are primarily for R&D, tooling, certification, and facilities. Because these costs are so small on a per vehicle basis, this analysis assumes that they are expected to be absorbed by the manufacturers.

Table 13.3-7. Vehicle Compliance Costs (2003$)

Year	Compliance Costs ($Million)
2010	$11.1
2011	$11.8
2012	$12.5
2013	$13.3
2014	$13.4
2015	$12.9
2016	$12.2
2017	$11.4
2018	$10.7
2019	$10.6
2020 and subsequent years	$0

13.3.4 Gasoline Fuel Savings

As noted in section 13.2.4.1, there are gasoline fuel savings attributable to the PFC program, reflecting the reduction in evaporative emissions. As explained in that section, these savings are included in the economic welfare analysis as a separate line item. Consumers of PFCs will realize an increase in their welfare equivalent to the amount of gallons of gasoline saved multiplied by the retail price of the gasoline (post-tax price). In the engineering cost analysis the gasoline fuel savings are estimated in this manner. However, in the context of the social welfare analysis, some of this increase in consumer welfare is offset by lost tax revenues to local, state, and federal governments. These welfare losses must be accounted for as well. Therefore, the net change in social welfare is the difference between the increase in consumer welfare and the lost tax revenues. This is equivalent to using the pre-tax price of gasoline to estimate the fuel savings for the social welfare analysis.

The amount of gallons of gasoline fuel saved is estimated based on the VOC inventory reductions attributable to PFC controls. California fuel is not included in this estimate because there are no emission reductions attributable to the federal program for that state. Tons of annual VOC reductions are translated to gallons of gasoline saved using a fuel density of 6 lbs per gallon (for lighter hydrocarbons which evaporate first).

Because the gallons of gasoline saved are based on national VOC reductions and were not estimated by PADD, we estimated a national average retail gasoline price. This estimate is the sum of the weighted average of pre-tax gasoline prices by PADD and the weighted average gasoline tax by PADD, using data from the *2003 Petroleum Marketing Annual*.[31] The results of this analysis are shown in Tables 13.3-8 and 13.3-9.

Table 13.3-8. Estimated National Average Gasoline Fuel Prices (2003$)

PADD	Weight	Pre-tax Price/Gallon	Average State Taxes	Federal Tax	Post-Tax Price/Gallon
PADD 1 & 3	0.58	$1.099	$0.201	$0.184	$1.484
PADD 2	0.32	$1.117	$0.208	$0.184	$1.509
PADD 4	0.04	$1.165	$0.225	$0.184	$1.574
PADD 5	0.06	$1.272	$0.200	$0.184	$1.663
Total		$1.118			$1.506

Source: *2003 Petroleum Marketing Annual* (Table 31). U.S. Department of Energy, Energy Information Administration, Annual Energy Outlook 2004 with projections to 2025. DOE/EIA-0383 (2004)

From 2009 until 2014 the estimated consumer savings associated with reduced gasoline consumption from the PFC controls increases sharply, from $15.2 million to $100.3 million. After 2014 the savings continue to accrue, but at a reduced rate as the PFC population turns over and fuel savings are due to the continuing benefits of using compliant PFCs. Similarly, the tax revenue losses are expected to increase from $3.9 million in 2009 to $25.8 million in 2014, but only $8 million more, to $33.5 million, by 2035.

Table 13.3-9. Estimated Gasoline Fuel Savings From PFC Controls and Tax Revenue Impacts (2003$)

Year	Gallons	Consumer Fuel Savings ($Million)	Tax revenue Impacts ($Million)	Net Fuel Savings ($Million)
2009	10,096,667	$15.2	-$3.9	$ 11.3
2010	20,193,333	$30.4	-$7.8	$ 22.6
2011	31,775,000	$47.9	-$12.3	$ 35.6
2012	43,356,333	$65.4	-$16.8	$ 48.5
2013	54,938,000	$82.8	-$21.3	$ 61.5
2014	66,519,333	$100.3	-$25.8	$ 74.5
2015	67,449,000	$101.7	-$26.2	$ 75.5
2016	68,378,880	$103.1	-$26.5	$ 76.5
2017	69,308,677	$104.5	-$26.9	$ 77.6
2018	70,238,474	$105.9	-$27.3	$ 78.6
2019	71,168,271	$107.3	-$27.6	$ 79.7
2020	72,098,068	$108.7	-$28.0	$ 80.7
2021	73,063,422	$110.1	-$28.4	$ 81.8
2022	74,028,775	$111.6	-$28.7	$ 82.9
2023	74,994,128	$113.1	-$29.1	$ 83.9
2024	75,959,482	$114.5	-$29.5	$ 85.0
2025	76,924,835	$116.0	-$29.9	$ 86.1
2026	77,890,188	$117.4	-$30.2	$ 87.2

Year	Gallons	Consumer Fuel Savings ($Million)	Tax revenue Impacts ($Million)	Net Fuel Savings ($Million)
2027	78,855,542	$118.9	-$30.6	$ 88.3
2028	79,820,895	$120.3	-$31.0	$ 89.3
2029	80,786,248	$121.8	-$31.4	$ 90.4
2030	81,751,602	$123.2	-$31.7	$ 91.5
2031	82,681,399	$124.6	-$32.1	$ 92.5
2032	83,611,196	$126.0	-$32.5	$ 93.6
2033	84,540,993	$127.4	-$32.8	$ 94.6
2034	85,470,790	$128.8	-$33.2	$ 95.7
2035	86,400,587	$130.2	-$33.5	$ 96.7

13.3.5 Supply and Demand Elasticity Estimates

The estimated market impacts and economic welfare costs of this emission control program are a function of the ways in which producers and consumers of the PFC and gasoline fuel affected by the standards change their behavior in response to the costs incurred in complying with the standards. These behavioral responses are incorporated in the EIM through the price elasticity of supply and demand (reflected in the slope of the supply and demand curves), which measure the price sensitivity of consumers and producers.

Table 13.3-10 provides a summary of the demand and supply elasticities used to estimate the economic impact of the rule. More detailed information is provided in Appendix E. The gasoline elasticities were obtained from the literature. Because we were unable to find published supply and demand elasticities for the PFC market, we estimated these parameters using the procedures described in Appendix E. These methods are well-documented and are consistent with generally accepted econometric practice. It should be noted that these elasticities reflect intermediate run behavioral changes. In the long run, both supply and demand are expected to be more elastic.

The price elasticity parameters for gasoline fuel used in this analysis are -0.2 for demand and 0.2 for supply. This means that both the quantity supplied and demanded are expected to be fairly insensitive to price changes and that increases in prices are not expected to cause sales to fall or production to increase by very much. The inelastic supply elasticity for the gasoline fuel market reflects the fact that most refineries operate near capacity and are therefore less responsive to fluctuations in market prices. Note that these elasticities reflect intermediate run behavioral changes. In the long run, both supply and demand are expected to be more elastic since more substitutes may become available.

The price elasticity parameters for PFCs used in this analysis are -0.01 for demand) and 1.5 for supply. The estimated demand elasticity is nearly perfectly inelastic (equal to zero). This means that a change in price is expected to have very little effect on the quantity of PFCs demanded. This makes intuitive sense since households needing to store gasoline for convenient use do not have many alternatives. However, supply is fairly elastic, meaning producers are expected to be fairly responsive to a change in price. This also makes intuitive sense since PFC producers can take steps in both the short term and long term to adjust production in response to price changes. In the short run, if prices decrease, they can easily store finished PFCs, holding them out of the market until prices increase again. If prices increase, it is relatively inexpensive for producers to increase output since the production processes are not complex or require expensive equipment. Therefore, consumers are expected to bear more of the burden of PFC regulatory control costs.

Because the elasticity estimates are a key input to the model, a sensitivity analysis for supply and demand elasticity parameters was performed as part of this analysis. The results are presented in Appendix E.

Table 13.3-10. Summary of Elasticities Used in the EIM

Market	Estimate	Source	Method	Input Data Summary
Supply Elasticities				
Gasoline Fuel	0.24	Considine (2002)[32]	Literature estimate	NA
Portable Fuel Containers	1.50	EPA econometric estimate (see Appendix C)	Cobb-Douglas production function	Bartlesman[33]; 1980–1996; SIC 3089
Demand Elasticities				
Gasoline Fuel	–0.20	Federal Trade Commission (2001)[34]	Literature estimate	NA
Portable Fuel Containers	–0.01	EPA numerical simulation (see Appendix D)	Hicks-Allen derived demand	Described in Appendix D

13.3.6 Economic Impact Model Structure

The EIM developed for this analysis is a spreadsheet model that estimates changes in price and quantity in a market that are expected to occur as a result of an increase in producer costs in the amount of the compliance costs associated with the standards. The impacts on the gasoline and PFC markets are modeled separately, and there is no feedback between the two models. The model for each of these two markets consists of one demand curve and one supply curve, reflecting the fact that the standards affect only one group of producers (PFC manufacturers, gasoline fuel refiners) and one group of consumers (residential PFC users, residential gasoline fuel users). There are no intermediate levels in the market since there are no intermediate producers and consumers affected by the standards.

This structure makes the model relatively simple to construct and solve. Specifically, the EIM's partial equilibrium models use a commonly used analytical expression used in the analysis of supply and demand in a single market.[35,36] Appendix D explains in detail how this expression is derived using the following steps:

1. *Specify* a set of supply and demand relationships for each market.
2. *Simplify* the equations by transforming them into a set of linear equations.
3. *Solve* the equilibrium system of equations.

Using this expression, we can estimate the market price change in terms of the market's supply and elasticity parameters and the regulatory program's per unit cost (Equation D.5 in Appendix D).

$$\Delta \text{price} = \frac{\text{Supply Elasticity}}{(\text{Supply Elasticity - Demand Elasticity})} \times \text{per - unit cost}$$

Given the market price change due to increased cost required by the rule and the demand elasticity for each market, we can also estimate the market quantity change.

$$\Delta \text{quantity} = \Delta \text{price} \times \text{ Demand Elasticity}$$

Appendix 13A: Impacts on Portable Fuel Container Markets

This appendix provides the time series of impacts from 2009 through 2035 for the PFC markets. Two separate markets were modeled and segmented by existence of a state regulatory program.

Table 13A-1 provides the time series of impacts for each market and includes the following:

- average engineering costs (variable and fixed) per can
- absolute change in the market price ($)
- relative change in market price (%)
- absolute change in market quantity (%)
- relative change in market quantity (%)
- consumer, producer, and total surplus losses

All prices and costs are presented in 2003$ and real PFC prices are assumed to be constant during the period of analysis.

Table 13A-1. Regional Impacts: Portable Fuel Container Markets

	Without State Program (Average price $4.66)							
Year	**Average Total Cost ($/can)**	**Change in Price ($/can)**	**Change in Price (%)**	**Change in Quantity (thousand cans)**	**Change in Quantity (%)**	**CS Loss (million $)**	**PS Loss (million $)**	**Total Social Cost (million $)**
2007	$0.00	$0.00	0.00%	0	0.00%	$0	$0	$0
2008	$0.00	$0.00	0.00%	0	0.00%	$0	$0	$0
2009	$2.70	$2.68	57.45%	-104.7	−0.57%	−$48.7	−$0.3	−$49.0
2010	$2.70	$2.68	57.45%	-106.8	−0.57%	−$49.7	−$0.3	−$50..0
2011	$2.70	$2.68	57.45%	-108.9	−0.57%	−$50.7	−$0.3	−$51.0
2012	$2.70	$2.68	57.45%	-111.1	−0.57%	−$51.7	−$0.4	−$52.0
2013	$2.70	$2.68	57.45%	-113.3	−0.57%	−$52.7	−$0.4	−$53.1
2014	$1.53	$1.52	32.49%	-65.35	−0.32%	−$30.4	−$0.2	−$30.6
2015	$1.53	$1.52	32.49%	-66.66	−0.32%	−$31.0	−$0.2	−$31.3
2016	$1.53	$1.52	32.49%	-67.99	−0.32%	−$31.7	−$0.2	−$31.9
2017	$1.53	$1.52	32.49%	-69.35	−0.32%	−$32.3	−$0.2	−$32.5
2018	$1.53	$1.52	32.49%	-70.74	−0.32%	−$32.9	−$0.2	−$33.2
2019	$1.53	$1.52	32.49%	-72.15	−0.32%	−$33.6	−$0.2	−$33.3
2020	$1.53	$1.52	32.49%	-73.60	−0.32%	−$34.3	−$0.2	−$34.5
2021	$1.53	$1.52	32.49%	-75.07	−0.32%	−$35.0	−$0.2	−$35.2
2022	$1.53	$1.52	32.49%	-76.57	−0.32%	−$35.7	−$0.2	−$35.9
2023	$1.53	$1.52	32.49%	-78.10	−0.32%	−$36.4	−$0.2	−$36.6
2024	$1.53	$1.52	32.49%	-79.66	−0.32%	−$37.1	−$0.3	−$37.4
2025	$1.53	$1.52	32.49%	-81.26	−0.32%	−$37.8	−$0.3	−$38.1
2026	$1.53	$1.52	32.49%	-82.88	−0.32%	−$38.6	−$0.3	−$38.9
2027	$1.53	$1.52	32.49%	-84.54	−0.32%	−$39.4	−$0.3	−$39.6
2028	$1.53	$1.52	32.49%	-86.23	−0.32%	−$40.2	−$0.3	−$40.4
2029	$1.53	$1.52	32.49%	-87.96	−0.32%	−$41.0	−$0.3	−$41.2
2030	$1.53	$1.52	32.49%	-89.72	−0.32%	−$41.8	−$0.3	−$42.1
2031	$1.53	$1.52	32.49%	-91.51	−0.32%	−$42.6	−$0.3	−$42.9
2032	$1.53	$1.52	32.49%	-93.34	−0.32%	−$43.5	−$0.3	−$43.8
2033	$1.53	$1.52	32.49%	-95.21	−0.32%	−$44.3	−$0.3	−$44.6
2034	$1.53	$1.52	32.49%	-97.11	−0.32%	−$45.2	−$0.3	−$45.5
2035	$1.53	$1.52	32.49%	-99.05	−0.32%	−$46.1	−$0.3	−$46.4
NPV 3%						−$676.2	−$4.5	−$680.7
NPV 7%						−$399.8	−$2.7	−$402.5

(continued)

Table 13A-1. Regional Impacts: Portable Fuel Container Markets (continued)

	With State Program (Average price $11.05)							
Year	**Average Total Cost ($/can)**	**Change in Price ($/can)**	**Change in Price (%)**	**Change in Quantity (thousand cans)**	**Change in Quantity (%)**	**CS Loss (million $)**	**PS Loss (million $)**	**Total Social Cost (million $)**
2007	$0.00	$0.00	0.00%	0.00	0.00%	$0.00	$0.00	$0.00
2008	$0.00	$0.00	0.00%	0.00	0.00%	$0.00	$0.00	$0.00
2009	$0.77	$0.76	6.89%	-8.02	-0.07%	−$8.86	−$0.06	-$8.92
2010	$0.77	$0.76	6.89%	-8.19	-0.07%	−$9.04	−$0.06	-$9.10
2011	$0.77	$0.76	6.89%	-8.35	-0.07%	−$9.22	−$0.06	-$9.28
2012	$0.77	$0.76	6.89%	-8.52	-0.07%	−$9.40	−$0.06	-$9.47
2013	$0.77	$0.76	6.89%	-8.69	-0.07%	−$9.59	−$0.06	-$9.65
2014	$0.21	$0.20	1.85%	-2.38	-0.02%	−$2.63	−$0.02	-$2.65
2015	$0.21	$0.20	1.85%	-2.43	-0.02%	−$2.68	−$0.02	-$2.70
2016	$0.21	$0.20	1.85%	-2.48	-0.02%	−$2.74	−$0.02	-$2.76
2017	$0.21	$0.20	1.85%	-2.53	-0.02%	−$2.79	−$0.02	-$2.81
2018	$0.21	$0.20	1.85%	-2.58	-0.02%	−$2.85	−$0.02	-$2.87
2019	$0.21	$0.20	1.85%	-2.63	-0.02%	−$2.91	−$0.02	-$2.93
2020	$0.21	$0.20	1.85%	-2.68	-0.02%	−$2.96	−$0.02	-$2.98
2021	$0.21	$0.20	1.85%	-2.74	-0.02%	−$3.02	−$0.02	-$3.04
2022	$0.21	$0.20	1.85%	-2.79	-0.02%	−$3.08	−$0.02	-$3.10
2023	$0.21	$0.20	1.85%	-2.85	-0.02%	−$3.15	−$0.02	-$3.17
2024	$0.21	$0.20	1.85%	-2.91	-0.02%	−$3.21	−$0.02	-$3.23
2025	$0.21	$0.20	1.85%	-2.96	-0.02%	−$3.27	−$0.02	-$3.29
2026	$0.21	$0.20	1.85%	-3.02	-0.02%	−$3.34	−$0.02	-$3.36
2027	$0.21	$0.20	1.85%	-3.08	-0.02%	−$3.41	−$0.02	-$3.43
2028	$0.21	$0.20	1.85%	-3.14	-0.02%	−$3.47	−$0.02	-$3.50
2029	$0.21	$0.20	1.85%	-3.21	-0.02%	−$3.54	−$0.02	-$3.57
2030	$0.21	$0.20	1.85%	-3.27	-0.02%	−$3.61	−$0.02	-$3.64
2031	$0.21	$0.20	1.85%	-3.34	-0.02%	−$3.69	−$0.02	-$3.71
2032	$0.21	$0.20	1.85%	-3.40	-0.02%	−$3.76	−$0.03	-$3.78
2033	$0.21	$0.20	1.85%	-3.47	-0.02%	−$3.83	−$0.03	-$3.86
2034	$0.21	$0.20	1.85%	-3.54	-0.02%	−$3.91	−$0.03	-$3.94
2035	$0.21	$0.20	1.85%	-3.61	-0.02%	−$3.99	−$0.03	-$4.02
NPV 3%						−$78.7	−$0.5	−$79.3
NPV 7%						−$50.7	−$0.3	−$51.1

Appendix 13B: Impacts on Gasoline Fuel Markets

This appendix provides the time series of impacts from 2009 through 2035 for the gasoline markets. Four gasoline markets were modeled: Four PADDs (PADDs 1 & 3, PADD 2, PADD 4, and PADD 5). Note that PADD 5 includes Alaska and Hawaii but excludes California fuel volumes because they are covered by separate California standards.

Table 13B-1 provides the time series of impacts for each market and includes the following:

- average engineering costs (variable and fixed) per gallon
- absolute change in the market price ($)
- relative change in market price (%)
- absolute change in market quantity (%)
- relative change in market quantity (%)
- consumer, producer, and total surplus losses

All prices and costs are presented in 2003$ and real gasoline prices are assumed to be constant during the period of analysis. A sensitivity analysis of the constant price assumption is provided in Appendix G.

Table 13B-1. Regional Impacts: Gasoline Markets

Year	PADD I&III (Average price $1.48) Average Total Cost (cents/ gallon)	Change in Price (cents/ gallon)	Change in Price (%)	Change in Quantity (million gallons)	Change in Quantity (%)	CS Loss (million $)	PS Loss (million $)	Total Social Cost (million $)
2007	0.010	0.005	0.004%	−0.507	−0.001%	−$3.760	−$3.140	−$6.900
2008	0.016	0.009	0.006%	−0.883	−0.001%	−$6.550	−$5.460	−$12.010
2009	0.016	0.009	0.006%	−0.900	−0.001%	−$6.680	−$5.560	−$12.240
2010	0.031	0.017	0.012%	−1.762	−0.002%	−$13.070	−$10.890	−$23.970
2011	0.031	0.017	0.012%	−1.790	−0.002%	−$13.280	−$11.070	−$24.350
2012	0.058	0.032	0.021%	−3.345	−0.004%	−$24.830	−$20.690	−$45.510
2013	0.053	0.029	0.019%	−3.100	−0.004%	−$23.010	−$19.170	−$42.180
2014	0.053	0.029	0.019%	−3.139	−0.004%	−$23.290	−$19.410	−$42.710
2015	0.149	0.081	0.055%	−8.935	−0.011%	−$66.300	−$55.250	−$121.550
2016	0.149	0.081	0.055%	−9.044	−0.011%	−$67.110	−$55.930	−$123.040
2017	0.149	0.081	0.055%	−9.153	−0.011%	−$67.920	−$56.600	−$124.520
2018	0.149	0.081	0.055%	−9.271	−0.011%	−$68.800	−$57.330	−$126.120
2019	0.149	0.081	0.055%	−9.380	−0.011%	−$69.610	−$58.000	−$127.610
2020	0.149	0.081	0.055%	−9.481	−0.011%	−$70.350	−$58.630	−$128.980
2021	0.149	0.081	0.055%	−9.582	−0.011%	−$71.100	−$59.250	−$130.350
2022	0.149	0.081	0.055%	−9.674	−0.011%	−$71.790	−$59.820	−$131.610
2023	0.149	0.081	0.055%	−9.767	−0.011%	−$72.470	−$60.400	−$132.870
2024	0.149	0.081	0.055%	−9.868	−0.011%	−$73.220	−$61.020	−$134.240
2025	0.149	0.081	0.055%	−9.969	−0.011%	−$73.970	−$61.640	−$135.610
2026	0.149	0.081	0.055%	−10.078	−0.011%	−$74.780	−$62.320	−$137.100
2027	0.149	0.081	0.055%	−10.187	−0.011%	−$75.590	−$62.990	−$138.590
2028	0.149	0.081	0.055%	−10.288	−0.011%	−$76.340	−$63.620	−$139.960
2029	0.149	0.081	0.055%	−10.397	−0.011%	−$77.150	−$64.290	−$141.450
2030	0.149	0.081	0.055%	−10.498	−0.011%	−$77.900	−$64.920	−$142.820
2031	0.149	0.081	0.055%	−10.607	−0.011%	−$78.710	−$65.590	−$144.300
2032	0.149	0.081	0.055%	−10.718	−0.011%	−$79.530	−$66.280	−$145.810
2033	0.149	0.081	0.055%	−10.829	−0.011%	−$80.360	−$66.970	−$147.320
2034	0.149	0.081	0.055%	−10.942	−0.011%	−$81.190	−$67.660	−$148.860
2035	0.149	0.081	0.055%	−11.056	−0.011%	−$82.040	−$68.370	−$150.410
NPV 3%						−$959.735	−$799.789	−$1,759.536
NPV 7%						−$499.236	−$416.034	−$915.276

Table 13B−1. Regional Impacts: Gasoline Markets (continued)

Year	PADD II (Average price $1.51) Average Total Cost (cents/ gallon)	Change in Price (cents/ gallon)	Change in Price (%)	Change in Quantity (million gallons)	Change in Quantity (%)	CS Loss (million $)	PS Loss (million $)	Total Social Cost (million $)
2007	0.053	0.029	0.019%	−1.541	−0.004%	−$11.630	−$9.690	−$21.310
2008	0.091	0.050	0.033%	−2.683	−0.007%	−$20.250	−$16.870	−$37.120
2009	0.091	0.050	0.033%	−2.734	−0.007%	−$20.630	−$17.190	−$37.820
2010	0.194	0.106	0.070%	−5.942	−0.014%	−$44.830	−$37.360	−$82.190
2011	0.194	0.106	0.070%	−6.038	−0.014%	−$45.550	−$37.960	−$83.520
2012	0.308	0.168	0.111%	−9.702	−0.022%	−$73.200	−$61.000	−$134.210
2013	0.227	0.124	0.082%	−7.253	−0.016%	−$54.730	−$45.610	−$100.330
2014	0.227	0.124	0.082%	−7.344	−0.016%	−$55.410	−$46.180	−$101.590
2015	0.307	0.167	0.111%	−10.056	−0.022%	−$75.870	−$63.220	−$139.090
2016	0.307	0.167	0.111%	−10.179	−0.022%	−$76.800	−$64.000	−$140.790
2017	0.307	0.167	0.111%	−10.302	−0.022%	−$77.720	−$64.770	−$142.490
2018	0.307	0.167	0.111%	−10.434	−0.022%	−$78.720	−$65.600	−$144.320
2019	0.307	0.167	0.111%	−10.557	−0.022%	−$79.650	−$66.380	−$146.030
2020	0.307	0.167	0.111%	−10.670	−0.022%	−$80.510	−$67.090	−$147.600
2021	0.307	0.167	0.111%	−10.784	−0.022%	−$81.360	−$67.800	−$149.170
2022	0.307	0.167	0.111%	−10.888	−0.022%	−$82.150	−$68.460	−$150.610
2023	0.307	0.167	0.111%	−10.992	−0.022%	−$82.930	−$69.110	−$152.040
2024	0.307	0.167	0.111%	−11.106	−0.022%	−$83.790	−$69.820	−$153.610
2025	0.307	0.167	0.111%	−11.219	−0.022%	−$84.650	−$70.540	−$155.180
2026	0.307	0.167	0.111%	−11.342	−0.022%	−$85.570	−$71.310	−$156.890
2027	0.307	0.167	0.111%	−11.465	−0.022%	−$86.500	−$72.080	−$158.590
2028	0.307	0.167	0.111%	−11.579	−0.022%	−$87.360	−$72.800	−$160.160
2029	0.307	0.167	0.111%	−11.702	−0.022%	−$88.290	−$73.570	−$161.860
2030	0.307	0.167	0.111%	−11.815	−0.022%	−$89.140	−$74.290	−$163.430
2031	0.307	0.167	0.111%	−11.938	−0.022%	−$90.070	−$75.060	−$165.130
2032	0.307	0.167	0.111%	−12.062	−0.022%	−$91.010	−$75.840	−$166.850
2033	0.307	0.167	0.111%	−12.188	−0.022%	−$91.950	−$76.630	−$168.580
2034	0.307	0.167	0.111%	−12.315	−0.022%	−$92.910	−$77.430	−$170.340
2035	0.307	0.167	0.111%	−12.443	−0.022%	−$93.880	−$78.230	−$172.110
NPV 3%						−$1,260.43	−$1,050.36	−$2,310.79
NPV 7%						−$699.59	−$582.99	−$1,282.59

Table 13B−1. Regional Impacts: Gasoline Markets (continued)

	PADD IV (Average price $1.57)							
Year	Average Total Cost (cents/ gallon)	Change in Price (cents/ gallon)	Change in Price (%)	Change in Quantity (million gallons)	Change in Quantity (%)	CS Loss (million $)	PS Loss (million $)	Total Social Cost (million $)
2007	0.019	0.011	0.007%	−0.063	−0.001%	−$0.490	−$0.410	−$0.910
2008	0.033	0.018	0.011%	−0.109	−0.002%	−$0.860	−$0.720	−$1.580
2009	0.033	0.018	0.011%	−0.111	−0.002%	−$0.880	−$0.730	−$1.610
2010	0.099	0.054	0.034%	−0.340	−0.007%	−$2.680	−$2.230	−$4.910
2011	0.099	0.054	0.034%	−0.346	−0.007%	−$2.720	−$2.270	−$4.990
2012	0.213	0.116	0.074%	−0.753	−0.015%	−$5.920	−$4.940	−$10.860
2013	0.227	0.124	0.079%	−0.814	−0.016%	−$6.410	−$5.340	−$11.750
2014	0.227	0.124	0.079%	−0.825	−0.016%	−$6.490	−$5.410	−$11.900
2015	0.501	0.273	0.174%	−1.842	−0.035%	−$14.500	−$12.080	−$26.580
2016	0.501	0.273	0.174%	−1.865	−0.035%	−$14.680	−$12.230	−$26.900
2017	0.501	0.273	0.174%	−1.888	−0.035%	−$14.850	−$12.380	−$27.230
2018	0.501	0.273	0.174%	−1.912	−0.035%	−$15.040	−$12.540	−$27.580
2019	0.501	0.273	0.174%	−1.934	−0.035%	−$15.220	−$12.680	−$27.900
2020	0.501	0.273	0.174%	−1.955	−0.035%	−$15.380	−$12.820	−$28.200
2021	0.501	0.273	0.174%	−1.976	−0.035%	−$15.550	−$12.960	−$28.500
2022	0.501	0.273	0.174%	−1.995	−0.035%	−$15.700	−$13.080	−$28.780
2023	0.501	0.273	0.174%	−2.014	−0.035%	−$15.850	−$13.210	−$29.050
2024	0.501	0.273	0.174%	−2.035	−0.035%	−$16.010	−$13.340	−$29.350
2025	0.501	0.273	0.174%	−2.056	−0.035%	−$16.180	−$13.480	−$29.650
2026	0.501	0.273	0.174%	−2.078	−0.035%	−$16.350	−$13.630	−$29.980
2027	0.501	0.273	0.174%	−2.101	−0.035%	−$16.530	−$13.770	−$30.300
2028	0.501	0.273	0.174%	−2.122	−0.035%	−$16.690	−$13.910	−$30.600
2029	0.501	0.273	0.174%	−2.144	−0.035%	−$16.870	−$14.060	−$30.930
2030	0.501	0.273	0.174%	−2.165	−0.035%	−$17.030	−$14.200	−$31.230
2031	0.501	0.273	0.174%	−2.187	−0.035%	−$17.210	−$14.340	−$31.550
2032	0.501	0.273	0.174%	−2.210	−0.035%	−$17.390	−$14.490	−$31.880
2033	0.501	0.273	0.174%	−2.233	−0.035%	−$17.570	−$14.640	−$32.220
2034	0.501	0.273	0.174%	−2.256	−0.035%	−$17.750	−$14.800	−$32.550
2035	0.501	0.273	0.174%	−2.280	−0.035%	−$17.940	−$14.950	−$32.890
NPV 3%						−$210.758	−$175.646	−$386.393
NPV 7%						−$109.585	−$91.329	−$200.910

Table 13B−1. Regional Impacts: Gasoline Markets (continued)

PADD V (excluding California)

(Average price $1.66)

Year	Average Total Cost (cents/ gallon)	Change in Price (cents/ gallon)	Change in Price (%)	Change in Quantity (million gallons)	Change in Quantity (%)	CS Loss (million $)	PS Loss (million $)	Total Social Cost (million $)
2007	0.004	0.002	0.001%	−0.022	0.000%	−$0.180	−$0.150	−$0.330
2008	0.007	0.004	0.002%	−0.038	0.000%	−$0.320	−$0.270	−$0.580
2009	0.007	0.004	0.002%	−0.039	0.000%	−$0.320	−$0.270	−$0.590
2010	0.035	0.019	0.011%	−0.199	−0.002%	−$1.650	−$1.380	−$3.030
2011	0.035	0.019	0.011%	−0.202	−0.002%	−$1.680	−$1.400	−$3.080
2012	0.140	0.076	0.046%	−0.816	−0.009%	−$6.780	−$5.650	−$12.430
2013	0.244	0.133	0.080%	−1.445	−0.016%	−$12.010	−$10.010	−$22.020
2014	0.244	0.133	0.080%	−1.463	−0.016%	−$12.160	−$10.130	−$22.290
2015	0.997	0.544	0.327%	−6.051	−0.065%	−$50.280	−$41.900	−$92.190
2016	0.997	0.544	0.327%	−6.125	−0.065%	−$50.900	−$42.420	−$93.320
2017	0.997	0.544	0.327%	−6.199	−0.065%	−$51.510	−$42.930	−$94.440
2018	0.997	0.544	0.327%	−6.279	−0.065%	−$52.180	−$43.480	−$95.660
2019	0.997	0.544	0.327%	−6.353	−0.065%	−$52.790	−$43.990	−$96.790
2020	0.997	0.544	0.327%	−6.421	−0.065%	−$53.360	−$44.470	−$97.830
2021	0.997	0.544	0.327%	−6.489	−0.065%	−$53.930	−$44.940	−$98.870
2022	0.997	0.544	0.327%	−6.552	−0.065%	−$54.450	−$45.370	−$99.820
2023	0.997	0.544	0.327%	−6.614	−0.065%	−$54.970	−$45.810	−$100.770
2024	0.997	0.544	0.327%	−6.683	−0.065%	−$55.540	−$46.280	−$101.820
2025	0.997	0.544	0.327%	−6.751	−0.065%	−$56.100	−$46.750	−$102.860
2026	0.997	0.544	0.327%	−6.825	−0.065%	−$56.720	−$47.270	−$103.980
2027	0.997	0.544	0.327%	−6.899	−0.065%	−$57.330	−$47.780	−$105.110
2028	0.997	0.544	0.327%	−6.967	−0.065%	−$57.900	−$48.250	−$106.150
2029	0.997	0.544	0.327%	−7.041	−0.065%	−$58.520	−$48.760	−$107.280
2030	0.997	0.544	0.327%	−7.110	−0.065%	−$59.080	−$49.240	−$108.320
2031	0.997	0.544	0.327%	−7.184	−0.065%	−$59.700	−$49.750	−$109.450
2032	0.997	0.544	0.327%	−7.258	−0.065%	−$60.320	−$50.270	−$110.590
2033	0.997	0.544	0.327%	−7.334	−0.065%	−$60.950	−$50.790	−$111.740
2034	0.997	0.544	0.327%	−7.410	−0.065%	−$61.580	−$51.320	−$112.900
2035	0.997	0.544	0.327%	−7.487	−0.065%	−$62.220	−$51.850	−$114.070
NPV 3%						−$684.454	−$570.394	−$1,254.848
NPV 7%						−$343.746	−$286.466	−$630.211

Appendix 13C: Time Series of Social Costs

This appendix provides a time series of the rule's estimated social costs from 2009 through 2035. Costs are presented in 2003 dollars.

Table 13C-1. Time Series of Social Costs

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Consumer Surplus Change, Total	**−$16.1**	**−$28.0**	**−$86.1**	**−$120.9**	**−$123.1**	**−$171.8**	**−$158.5**	**−$130.4**	**−$240.7**	**−$243.9**
Gasoline, U.S.	−$16.1	−$28.0	−$28.5	−$62.2	−$63.2	−$110.7	−$96.2	−$97.4	−$207.0	−$209.5
PADD I & III	−$3.8	−$6.6	−$6.7	−$13.1	−$13.3	−$24.8	−$23.0	−$23.3	−$66.3	−$67.1
PADD II	−$11.6	−$20.3	−$20.6	−$44.8	−$45.6	−$73.2	−$54.7	−$55.4	−$75.9	−$76.8
PADD IV	−$0.5	−$0.9	−$0.9	−$2.7	−$2.7	−$5.9	−$6.4	−$6.5	−$14.5	−$14.7
PADD V (excludes California)	−$0.2	−$0.3	−$0.3	−$1.7	−$1.7	−$6.8	−$12.0	−$12.2	−$50.3	−$50.9
Gas Cans, U.S.	$0.0	$0.0	−$57.5	−$58.7	−$59.9	−$61.1	−$62.3	−$33.1	−$33.7	−$34.4
States With State Regulatory Programs	$0.0	$0.0	−$8.9	−$9.0	−$9.2	−$9.4	−$9.6	−$2.6	−$2.7	−$2.7
States Without State Regulatory Programs	$0.0	$0.0	−$48.7	−$49.7	−$50.7	−$51.7	−$52.7	−$30.4	−$31.0	−$31.7
Producer Surplus Change, Total	**−$13.4**	**−$23.3**	**−$24.1**	**−$52.3**	**−$53.1**	**−$92.7**	**−$80.5**	**−$81.4**	**−$172.7**	**−$174.8**
Gasoline, U.S.	−$13.4	−$23.3	−$23.8	−$51.9	−$52.7	−$92.3	−$80.1	−$81.1	−$172.5	−$174.6
PADD I & III	−$3.1	−$5.5	−$5.6	−$10.9	−$11.1	−$20.7	−$19.2	−$19.4	−$55.3	−$55.9
PADD II	−$9.7	−$16.9	−$17.2	−$37.4	−$38.0	−$61.0	−$45.6	−$46.2	−$63.2	−$64.0
PADD IV	−$0.4	−$0.7	−$0.7	−$2.2	−$2.3	−$4.9	−$5.3	−$5.4	−$12.1	−$12.2
PADD V (excludes California)	−$0.2	−$0.3	−$0.3	−$1.4	−$1.4	−$5.7	−$10.0	−$10.1	−$41.9	−$42.4
PADD V (California)	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
Gas Cans, U.S.	$0.0	$0.0	−$0.4	−$0.4	−$0.4	−$0.4	−$0.4	−$0.2	−$0.2	−$0.2
States With State Regulatory Programs	$0.0	$0.0	−$0.1	−$0.1	−$0.1	−$0.1	−$0.1	$0.0	$0.0	$0.0
States Without State Regulatory Programs	$0.0	$0.0	−$0.3	−$0.3	−$0.3	−$0.3	−$0.4	−$0.2	−$0.2	−$0.2
Fuel Savings	**$0.0**	**$0.0**	**$11.3**	**$22.6**	**$35.6**	**$48.5**	**$61.5**	**$74.5**	**$75.5**	**$76.5**
Consumer Savings	$0.0	$0.0	$15.2	$30.4	$47.9	$65.4	$82.8	$100.3	$101.7	$103.1
Fuel	$0.0	$0.0	$11.3	$22.6	$35.6	$48.5	$61.5	$74.5	$75.5	$76.5
Tax	$0.0	$0.0	$3.9	$7.8	$12.3	$16.8	$21.3	$25.8	$26.2	$26.5
Government Revenue	$0.0	$0.0	−$3.9	−$7.8	−$12.3	−$16.8	−$21.3	−$25.8	−$26.2	−$26.5
Vehicle Program	**$0.0**	**$0.0**	**$0.0**	**−$11.1**	**−$11.8**	**−$12.5**	**−$13.3**	**−$13.4**	**−$12.9**	**−$12.2**
Total Surplus Change	**−$29.5**	**−$51.3**	**−$98.9**	**−$161.7**	**−$152.4**	**−$228.5**	**−$190.8**	**−$150.7**	**−$350.7**	**−$354.4**

(continued)

Table 13C−1. Time Series of Social Costs (continued)

	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026
Consumer Surplus Change, Total	**−$247.1**	**−$250.5**	**−$253.8**	**−$256.8**	**−$259.9**	**−$262.8**	**−$265.7**	**−$268.9**	**−$272.0**	**−$275.4**
Gasoline, U.S.	−$212.0	−$214.7	−$217.3	−$219.6	−$221.9	−$224.1	−$226.2	−$228.6	−$230.9	−$233.4
PADD I & III	−$67.9	−$68.8	−$69.6	−$70.4	−$71.1	−$71.8	−$72.5	−$73.2	−$74.0	−$74.8
PADD II	−$77.7	−$78.7	−$79.7	−$80.5	−$81.4	−$82.2	−$82.9	−$83.8	−$84.7	−$85.6
PADD IV	−$14.9	−$15.0	−$15.2	−$15.4	−$15.6	−$15.7	−$15.9	−$16.0	−$16.2	−$16.4
PADD V (excludes California)	−$51.5	−$52.2	−$52.8	−$53.4	−$53.9	−$54.5	−$55.0	−$55.5	−$56.1	−$56.7
Gas Cans, U.S.	−$35.1	−$35.8	−$36.5	−$37.2	−$38.0	−$38.7	−$39.5	−$40.3	−$41.1	−$41.9
States With State Regulatory Programs	−$2.8	−$2.9	−$2.9	−$3.0	−$3.0	−$3.1	−$3.2	−$3.2	−$3.3	−$3.3
States Without State Regulatory Programs	−$32.3	−$32.9	−$33.6	−$34.3	−$35.0	−$35.7	−$36.4	−$37.1	−$37.8	−$38.6
Producer Surplus Change, Total	**−$176.9**	**−$179.2**	**−$181.3**	**−$183.3**	**−$185.2**	**−$187.0**	**−$188.8**	**−$190.7**	**−$192.7**	**−$194.8**
Gasoline, U.S.	−$176.7	−$179.0	−$181.1	−$183.0	−$185.0	−$186.7	−$188.5	−$190.5	−$192.4	−$194.5
PADD I & III	−$56.6	−$57.3	−$58.0	−$58.6	−$59.3	−$59.8	−$60.4	−$61.0	−$61.6	−$62.3
PADD II	−$64.8	−$65.6	−$66.4	−$67.1	−$67.8	−$68.5	−$69.1	−$69.8	−$70.5	−$71.3
PADD IV	−$12.4	−$12.5	−$12.7	−$12.8	−$13.0	−$13.1	−$13.2	−$13.3	−$13.5	−$13.6
PADD V (excludes California)	−$42.9	−$43.5	−$44.0	−$44.5	−$44.9	−$45.4	−$45.8	−$46.3	−$46.8	−$47.3
PADD V (California)	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
Gas Cans, U.S.	−$0.2	−$0.2	−$0.2	−$0.3	−$0.3	−$0.3	−$0.3	−$0.3	−$0.3	−$0.3
States With State Regulatory Programs	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
States Without State Regulatory Programs	−$0.2	−$0.2	−$0.2	−$0.2	−$0.2	−$0.2	−$0.2	−$0.3	−$0.3	−$0.3
Fuel Savings	**$77.6**	**$78.6**	**$79.7**	**$80.7**	**$81.8**	**$82.9**	**$83.9**	**$85.0**	**$86.1**	**$87.2**
Consumer Savings	$104.5	$105.9	$107.3	$108.7	$110.1	$111.6	$113.1	$114.5	$116.0	$117.4
Fuel	$77.6	$78.6	$79.7	$80.7	$81.8	$82.9	$83.9	$85.0	$86.1	$87.2
Tax	$26.9	$27.3	$27.6	$28.0	$28.4	$28.7	$29.1	$29.5	$29.9	$30.2
Government Revenue	−$26.9	−$27.3	−$27.6	−$28.0	−$28.4	−$28.7	−$29.1	−$29.5	−$29.9	−$30.2
Vehicle Program	**−$11.4**	**−$10.7**	**−$10.6**	**$0.0**	**$0.0**	**$0.0**	**$0.0**	**$0.0**	**$0.0**	**$0.0**
Total Surplus Change	**−$357.9**	**−$361.8**	**−$366.0**	**−$359.4**	**−$363.3**	**−$367.0**	**−$370.6**	**−$374.6**	**−$378.6**	**−$383.0**

)

Table 13C−1. Time Series of Social Costs (continued)

	2027	2028	2029	2030	2031	2032	2033	2034	2035
Consumer Surplus Change, Total	**−$278.7**	**−$281.9**	**−$285.3**	**−$288.5**	**−$292.0**	**−$295.5**	**−$299.0**	**−$302.6**	**−$306.2**
Gasoline, U.S.	−$236.0	−$238.3	−$240.8	−$243.2	−$245.7	−$248.3	−$250.8	−$253.4	−$256.1
PADD I & III	−$75.6	−$76.3	−$77.2	−$77.9	−$78.7	−$79.5	−$80.4	−$81.2	−$82.0
PADD II	−$86.5	−$87.4	−$88.3	−$89.1	−$90.1	−$91.0	−$92.0	−$92.9	−$93.9
PADD IV	−$16.5	−$16.7	−$16.9	−$17.0	−$17.2	−$17.4	−$17.6	−$17.8	−$17.9
PADD V (excludes California)	−$57.3	−$57.9	−$58.5	−$59.1	−$59.7	−$60.3	−$61.0	−$61.6	−$62.2
Gas Cans, U.S.	−$42.8	−$43.6	−$44.5	−$45.4	−$46.3	−$47.2	−$48.2	−$49.1	−$50.1
States With State Regulatory Programs	−$3.4	−$3.5	−$3.5	−$3.6	−$3.7	−$3.8	−$3.8	−$3.9	−$4.0
States Without State Regulatory Programs	−$39.4	−$40.2	−$41.0	−$41.8	−$42.6	−$43.5	−$44.3	−$45.2	−$46.1
Producer Surplus Change, Total	**−$196.9**	**−$198.9**	**−$201.0**	**−$203.0**	**−$205.0**	**−$207.2**	**−$209.4**	**−$211.5**	**−$213.7**
Gasoline, U.S.	−$196.6	−$198.6	−$200.7	−$202.7	−$204.7	−$206.9	−$209.0	−$211.2	−$213.4
PADD I & III	−$63.0	−$63.6	−$64.3	−$64.9	−$65.6	−$66.3	−$67.0	−$67.7	−$68.4
PADD II	−$72.1	−$72.8	−$73.6	−$74.3	−$75.1	−$75.8	−$76.6	−$77.4	−$78.2
PADD IV	−$13.8	−$13.9	−$14.1	−$14.2	−$14.3	−$14.5	−$14.6	−$14.8	−$15.0
PADD V (excludes California)	−$47.8	−$48.3	−$48.8	−$49.2	−$49.8	−$50.3	−$50.8	−$51.3	−$51.9
PADD V (California)	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
Gas Cans, U.S.	−$0.3	−$0.3	−$0.3	−$0.3	−$0.3	−$0.3	−$0.3	−$0.3	−$0.3
States With State Regulatory Programs	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
States Without State Regulatory Programs	−$0.3	−$0.3	−$0.3	−$0.3	−$0.3	−$0.3	−$0.3	−$0.3	−$0.3
Fuel Savings	**$88.3**	**$89.3**	**$90.4**	**$91.5**	**$92.5**	**$93.6**	**$94.6**	**$95.7**	**$96.7**
Consumer Savings	$118.9	$120.3	$121.8	$123.2	$124.6	$126.0	$127.4	$128.8	$130.2
Fuel	$88.3	$89.3	$90.4	$91.5	$92.5	$93.6	$94.6	$95.7	$96.7
Tax	$30.6	$31.0	$31.4	$31.7	$32.1	$32.5	$32.8	$33.2	$33.5
Government Revenue	−$30.6	−$31.0	−$31.4	−$31.7	−$32.1	−$32.5	−$32.8	−$33.2	−$33.5
Vehicle Program	**$0.0**	**$0.0**	**$0.0**	**$0.0**	**$0.0**	**$0.0**	**$0.0**	**$0.0**	**$0.0**
Total Surplus Change	**−$387.4**	**−$391.4**	**−$395.9**	**−$400.0**	**−$404.5**	**−$409.1**	**−$413.7**	**−$418.4**	**−$423.2**

Appendix 13D: Overview of Economic Model Equations

We illustrate our approach for addressing conceptual questions of market-level impacts using a numerical simulation model. Our method involves specifying a set of nonlinear supply and demand relationships for the affected markets, simplifying the equations by transforming them into a set of linear equations, and then solving the equilibrium system of equations.[37]

13D.1 Discussion and Specification of Model Equations

First, we consider the formal definition of the elasticity of supply with respect to changes in own price:

$$\varepsilon_S \equiv \frac{dQ_S / Q_S}{dp / p} \tag{D.1}$$

Next, we can use "hat" notation to transform Eq. (D.1) to proportional changes and rearrange terms:

$$\hat{Q}_S = \varepsilon_S \hat{p} \tag{D.1a}$$

$\hat{Q}_S$ = percentage change in the quantity of market supply,

ε_S = market elasticity of supply, and

$\hat{p}$ = percentage change in market price.

As Fullerton and Metcalfe[38] note, we have taken the elasticity definition and turned it into a linear *behavioral* equation for our market. Similarly, we can specify a demand equation as follows:

$$\hat{Q}_d = \eta_d \hat{p} \tag{D.2}$$

$\hat{Q}_d$ = percentage change in the quantity of market demand,

η_d = market elasticity of demand, and

$\hat{p}$ = percentage change in market price.

To introduce the direct impact of the regulatory program, we assume the per-unit cost (c) leads to a proportional shift in the marginal cost of production. Under the assumption of perfect competition (price equals marginal cost), we can approximate this shift at the initial equilibrium point as follows:

$$\hat{MC} = \frac{c}{MC_o} = \frac{c}{p_o} \tag{D.3}$$

Finally, we specify the market equilibrium conditions in the affected markets. In response to the exogenous increase in production costs, producer and consumer behaviors are represented in Eq. (D.1a) and Eq. (D.2), and the new equilibrium satisfies the condition that the change in supply equals the change in demand:

$$\hat{Q}_s = \hat{Q}_d \tag{D.4}$$

We now have three linear equations in three unknowns ($\hat{p}$, $\hat{Q}_d$, and $\hat{Q}_s$) and we can solve for the proportional price change in terms of the elasticity parameters(ε_s and η_d) and the proportional change in marginal cost:

$$\hat{p} = \frac{\varepsilon_s}{\varepsilon_s - \eta_d} \bullet \hat{MC} \tag{D.5}$$

Given this solution, we can solve for the proportional change in market quantity using Eq. (D.2).

13D.2 Consumer and Producer Welfare Calculations

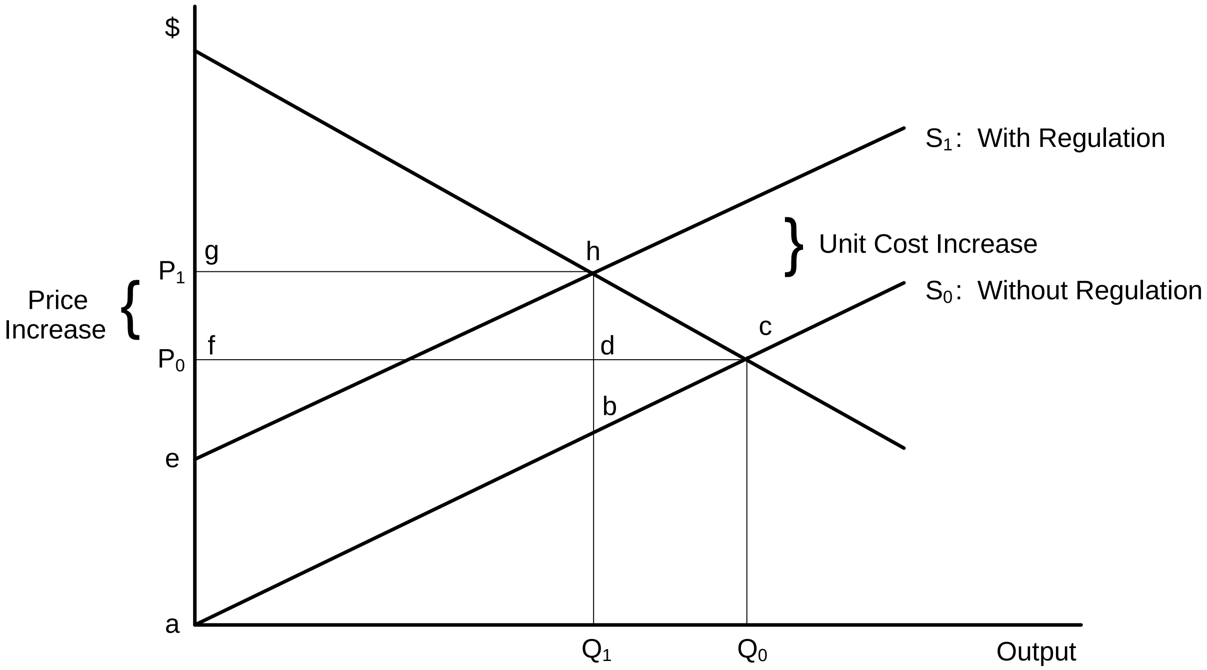
The change in consumer surplus in the affected markets can be estimated using the following linear approximation method:

$$\Delta CS = - Q_1 \bullet \Delta p + 0.5 \bullet \Delta Q \bullet \Delta p. \tag{D.6}$$

As shown, higher market prices and reduced consumption lead to welfare losses for consumers. A geometric representation of this calculation is illustrated in Figure D-1.

For affected supply, the change in producer surplus can be estimated with the following equation:

$$\Delta PS = Q_1 \bullet (\Delta p - c) - 0.5 \bullet \Delta Q \bullet (\Delta p - c). \tag{D.7}$$



Δ consumer surplus = –[fghd + dhc]

Δ producer surplus = [fghd – aehb] – bdc

Δ total surplus = –[aehb + dhc + bdc]

Figure D-1. Welfare Calculations

Increased regulatory costs and output declines have a negative effect on producer surplus, because the net price change (Δp – c) is negative. However, these losses are mitigated, to some degree, as a result of higher market prices. A geometric representation of this calculation is illustrated in Figure D-1.

Appendix 13E: Elasticity Parameters

To estimate market equilibrium price and quantity, supply and demand elasticities are needed to represent the behavior adjustments that are likely to be made by market participants.[J] Tables 13E-1 and 13E-2 provide a summary of the supply and demand elasticities used to estimate the economic impact of the rule.

Table 13E-1. Summary of Supply Elasticities Used in the EIA Model

Markets	Estimate	Source	Method	Input Data Summary
All Gasoline Markets	0.24	Considine[39]	Literature estimate	NA
Portable Fuel Container Markets	1.50	EPA econometric estimate (see Section 13E.4)	Cobb-Douglas production function	Bartlesman[40]; 1980–1996; SIC 3089

Table E-2. Summary of Demand Elasticities Used in EIA Model

Market	Estimate	Source	Method	Input Data Summary
All Gasoline Markets	–0.20	FTC[41]	Literature estimate	NA
Portable Fuel Container Markets	–0.01	EPA numerical simulation (see Section 13E.3)	Hicks-Allen derived demand	Described in Section 13E.3

13E.1 Gasoline Market Parameters

Very few studies have attempted to quantify supply responsiveness for individual refined products, such as gasoline fuel. For example, a study for the California Energy Commission stated “There do not seem to be credible estimates of gasoline supply elasticity.”[42] However, sources agree that refineries have little or no ability to change output in response to price: high fixed costs compel them to operate as close to their capacity limit as possible. The Federal Trade Commission (FTC) analysis made this point explicitly.[43]

Greene and Tishchishyna reviewed supply elasticity estimates available in the literature.[44] The supply elasticity values cited in most of these studies were for “petroleum” or “oil” production in the United States, which includes exploration, distribution and refining activities. The lowest short-term numbers cited were 0.02 to 0.05, with long-run values ranging

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[J] The models equations are described in Appendix A.

from 0.4 to 1.0. It seems likely that these extremely low numbers are influenced by the limited domestic supply of crude petroleum and the difficulty of extraction.

A recent paper by Considine provides one of the few supply elasticity estimates for refining production (excluding extraction and distribution), based on historical price and quantity data.[45] In this study, Considine estimates a refining production supply elasticity of 0.24. This estimate is for aggregate refinery production and includes distillate and nondistillate fuels. Because petroleum products are made in strict proportion and refineries have limited ability to adjust output mix in the short to medium run, it is reasonable to assume that supply is relatively inelastic and similar across refinery products. This value of 0.24 was used for the supply elasticity for this market. This estimated elasticity is inelastic, which means that the quantity of goods and services supplied is expected to be fairly insensitive to price changes.

For demand elasticity estimates, EPA's NESHAP analysis of refinery markets included the development of a price elasticity of demand elasticity for several refined petroleum products.[46] To compute this elasticity, EPA reviewed the economic literature and found estimated for the following petroleum products:

- Motor gasoline: −0.55 to − 0.82.
- Jet fuel: −0.15.
- Residual fuel oil: −0.61 to −0.74.
- Distillate fuel oil: −0.50 to −0.99.
- Liquefied petroleum gas: −0.60 to −1.00

EPA developed a weighted average elasticity for petroleum products using the midpoints of the elasticity estimates and production data for 1995. The use of the average value of –0.69 is more consistent with long-run estimates of the gasoline price elasticity of demand.

However, a better choice for the primary analysis in this EIM is a short- to midterm-run elasticity of -0.2 cited by the Federal Trade Commission.[47] This value is consistent with recent surveys of the gasoline demand literature.[48,49] In addition, recent applied work on the incidence of gas taxes suggests that the national demand elasticity should approximately equal the negative of the national supply elasticity.[50] Given that the supply elasticity we are using in the economic model is 0.24, this implies a national gasoline demand elasticity of approximately -0.2.

13E.2 Portable Fuel Container Market Parameters

There are no estimated PFC demand elasticities from current economic literature. As a result, we estimated this parameter numerically using a Hicks-Allen derived demand approach (see Section E.3 for discussion) for a class of products that use similar production technologies (SIC 3089, Plastic Products, Not Elsewhere Classified). Our Monte Carlo simulation and generated a mean value of –0.01 for the derived demand elasticity estimate for PFCs. Using this value, a 1 percent change in the price of PFCs would lead to approximately a 0.014 percent reduction in the quantity of PFCs demanded by consumers.

There are also no estimated PFC supply elasticities from the economic literature. As a result, we estimated this parameter econometrically using a production function cost minimization approach (see Section E.4 for discussion) for a class of products that use similar production technologies (SIC 3089, Plastic Products, Not Elsewhere Classified). This category includes manufacturers engaged in manufacturing plastic products not elsewhere classified and includes such products as plastic containers and plastics drums. Using this approach, we found the elasticity supply for these products is approximately 1.5, which means a 1 percent change in the price of PFCs would lead to a 1.5 percent increase in the quantity of PFCs manufacturers would be willing to sell in the market.

13E.3 Portable Fuel Container Demand Elasticity Estimation Procedure

Portable Fuel Containers are an integral component of any activity involving small gasoline engines. These activities range from lawn and garden work to recreation use. The behavioral change in PFC consumption is expected to be quite small in response to an increased price because PFCs represent a small fraction of overall lawn and garden or recreation expenditures. In addition, because PFCs are in many cases a necessity for small engine use, households have limited ability to substitute away from PFCs as their price increases.

However, it is probably not appropriate to assume that the demand elasticity for PFCs is zero. There will likely be some behavior response to the increased price of PFCs—even though it is anticipated to be small. Unfortunately, an elasticity of demand for PFCs is not available in the literature. Nor does the historical price and quantity data exist that would be required to empirically estimate a demand elasticity for cans.

An alternative approach is to model PFCs as an input in the household production function for household lawn and garden activities and develop a derived demand for PFCs through changes in the household for lawn and garden products and services market. Because over 90 percent of PFCs are used to support lawn and garden activities, we use the lawn and garden market to derive a demand elasticity for PFCs.

The demand for PFCs is directly linked to the demand for lawn and garden products and services. When the price of PFCs increases, the cost of the bundled commodity, lawn and garden products services, also increases. This is illustrated in the supply curve’s upward shift in Figure E-1. This results in a reduced equilibrium quantity in the household lawn and garden services market. Then, this reduced quantity feeds back into a reduced demand in the PFC market. For example, if households reduce their purchases by X percent in the lawn and garden service market, this translates into the same X percent decrease in PFC purchases, which in turn determines the derived demand point d_1 in Figure E-1.[K]

13E.3.1 Numerical Example: Base Case

Because PFCs represent such as small fraction of household expenditures in the lawn and garden services market, the resulting derived elasticity of demand is very small. As illustrated below, with average annual household expenditures on lawn and garden services of \$500 to \$2,500, and a \$5 increase in the price of PFCs because of the regulation, the resulting shift in the supply function is 1.0 percent to 0.2 percent.

Economic theory states that the elasticity of the derived demand for an input is a function of the following:[51,52,53]

- demand elasticity for the final good it will be used to produce,
- the elasticity of supply of other inputs,
- the cost share of the input in total production cost, and
- the elasticity of substitution between this input and other inputs in production.

Using Hicks' formula,

$$E_{dc} = [\ \alpha*(E_{df} + E_{si}) + C*E_{si}*(E_{df} - \alpha)] / [(E_{df} + E_{si}) - C*(E_{df} - \alpha)] \qquad \text{(E.1)}$$

where

E_{dc} = price elasticity of demand for the cans,

E_{df} = price elasticity of demand for final product,

E_{si} = price elasticity of supply of other inputs,

C = cost share of cans in total production cost, and

α = elasticity of substitution between cans and all other inputs.

[K] This assumes that PFCs are a fixed proportion input into the lawn and garden services market.

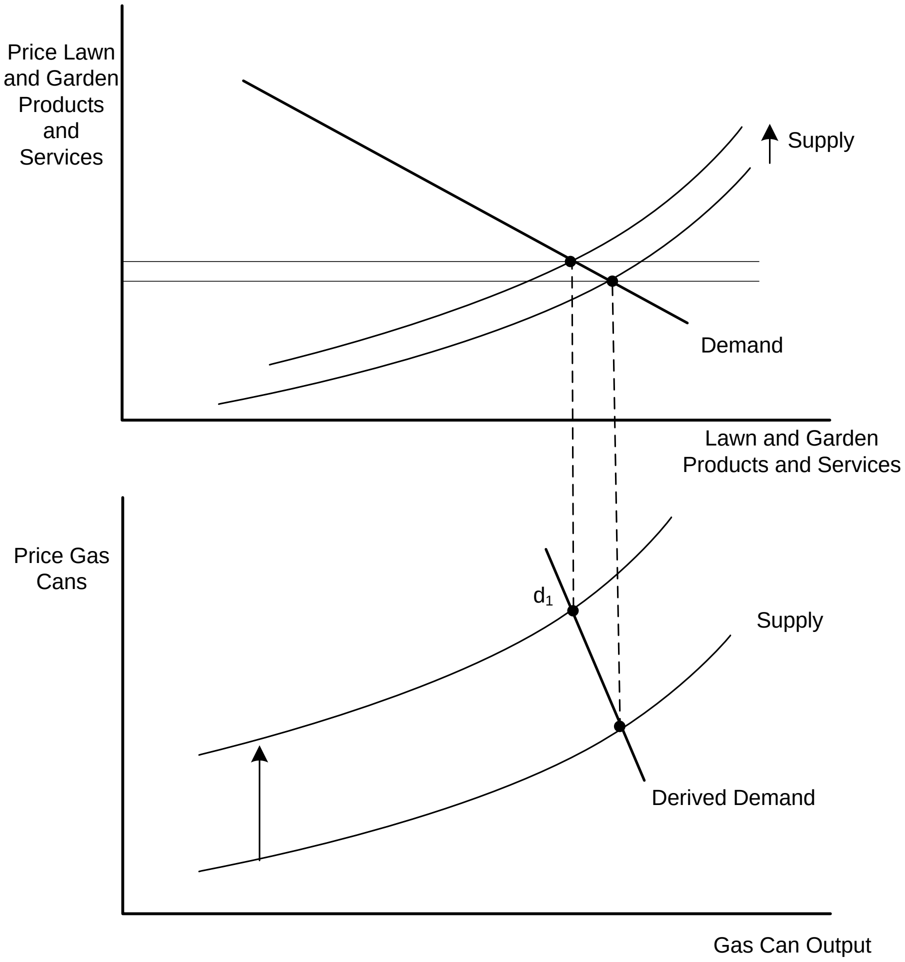


Figure 13E-1. Derived Demand for Portable Fuel Containers

Using the parameter values in Table E-3, we conducted a Monte Carlo simulation and generated the following derived demand elasticity estimate for PFCs:

Mean Value = –0.01

Standard Deviation = 0.004

Using the mean value, a 100 percent change in the price of PFCs would lead to approximately a 1.0 percent reduction in the quantity of PFCs demanded by consumers.

13E.3.2 Numerical Example: Sensitivity

In the baseline analysis for the EIA, we propose to use a zero elasticity of substitution between PFCs and all other inputs. This implies that consumers do not substitute away from PFCs as the price increases. However, we acknowledge that there is a potential for households with more than one PFC to reduce the number of multiple can purchases as the price increases (i.e., they may choose to reduce the number of cans they purchase, giving up the "luxury" of having multiple cans in multiple locations, or the capability of filling multiple cans with a single trip to the gas station). These decisions in effect substitute additional household labor for the convenience of having more than one PFC.

Table 13E-3. Assumed Parameter Values Used to Generate Derived Demand Elasticity for Portable Fuel Containers

Parameter	Type of Distribution	Values (range)	Comments
E_{df}	Normal	Mean = –1.2 StDev = 0.64	EPA econometric estimate for consumer walk behind mowers
E_{si}	Uniform	Min = 0.5 Max = 2.0	Assumed range
C	Uniform	Min = 0.20% Max = 1.0%	Example: $5 increase in cost for PFC, with household lawn and garden expenditures of $500 to $2,500
α		0	Assume fixed proportions technology

To investigate the potential impact of substitution in the PFC market, we conducted a sensitivity analysis. Unfortunately, neither a literature estimate of substitution elasticity for PFCs nor the data to estimate such elasticities exist. Thus, a substitution elasticity value of $\alpha = 0.1$ was used in the sensitivity analysis (see Table E-4). Using this value yields a demand elasticity for cans with a mean value = –0.25 and a standard deviation = 0.45. This implies that a 100 percent change in the price of PFCs would lead to approximately a 25 percent reduction in the quantity of PFCs demanded by consumers. Specific impact estimates were estimated with engineering cost data.

13E.4 Portable Fuel Container Supply Elasticity Estimation

Our approach assumes that firms minimize costs subject to production technology constraints. To characterize these constraints, we use a "production function" that describes the relationship between inputs and outputs of the production process. The functional form (Cobb-Douglas) of the production function is specified as

$$Q_t = A\,(K_t)^{\alpha_K}\,(L_t)^{\alpha_L}\,(M_t)^{\alpha_M}\,t^{\lambda} \qquad \text{(E.2)}$$

Table 13E-4. Assumed Parameter Values Used to Generate Derived Demand Elasticity for Portable Fuel Containers

Parameter	Type of Distribution	Values (range)	Comments
E_{df}	Normal	Mean = –1.2 StDev = 0.64	EPA econometric estimate for consumer walk behind mowers
E_{si}	Uniform	Min = 0.5 Max = 2.0	Assumed range
C	Uniform	Min = 0.20% Max = 1.0%	Example: $5 increase in cost for PFC, with household expenditures of $500 to $2,500 on lawn and garden services
α		0.1	Used a single value

where

Q_t = output in year t,
K_t = real capital consumed in production in year t,
L_t = quantity of labor used in year t,
M_t = material inputs in year t, and
t = a time trend variable to reflect technology changes.

This equation can be written in linear form by taking the natural logarithms of each side of the equation. The parameters of this model, α_K, α_L, α_M, can then be estimated using linear regression techniques:

$$\ln Q_t = \ln A + \alpha_K \ln K_t + \alpha_L \ln L_t + \alpha_M \ln M_t + \lambda \ln t. \qquad \text{(E.3)}$$

Under the assumptions of a competitive market and perfect competition, the elasticity of supply with respect to the price of the final product can be expressed in terms of the parameters of the production function:

$$\text{Supply Elasticity} = (\alpha_L + \alpha_M) / (1 - \alpha_L - \alpha_M). \qquad \text{(E.4)}$$

To maintain the desired properties of the Cobb-Douglas production function, it is necessary to place restrictions on the estimated coefficients. For example, if $\alpha_L + \alpha_M = 1$, then the supply elasticity will be undefined. Alternatively, if $\alpha_L + \alpha_M > 1$, this yields a negative supply elasticity. Thus, a common assumption is that $\alpha_K + \alpha_L + \alpha_M = 1$. This implies constant returns to scale, which is consistent with most empirical studies.

13E.4.1 Data Sets

The National Bureau of Economic Research-Center for Economic Studies publishes industry-level data used for the analysis (years 1958 to 1996).[54] In cases where a price index was not available, we used the most recent implicit gross domestic product (GDP) price deflator reported by the U.S. Bureau of Economic Analysis.[55] The following variables were used:[56]

- value of shipments,
- price index of value shipments,
- production worker wages,
- GDP deflator,[57]
- cost of materials,
- price index for materials, and
- value added.

To provide a measure of capital consumed, a capital variable is calculated as follows:

Capital = (Value added – Production worker wages)/GDP deflator.

The NBER data set is restricted to four-digit SIC codes for the manufacturing industries. As a result, we selected a class of products that use similar production technologies (SIC 3089, Plastic Products, Not Elsewhere Classified). This category includes manufacturers engaged in manufacturing plastic products not elsewhere classified and includes such products as plastic containers and plastics drums. We also restricted our analysis to years after 1980, the time period the Consumer Products Safety Commission identified plastic cans were introduced.[58] The data cover the period 1980 through 1996.

13E.4.2 Results of Supply Elasticity Estimation

We used an autoregressive error model to estimate Eq. (E.3). SAS procedure PROC AUTOREG was used to compute a linear regression corrected for auto correlation. We assume the error term is AR(2). This approach is identical to the one used successfully for the Nonroad CI Engines and Equipment EIA completed in 2003, with some of the independent variables updated with the most recent data.[59] In addition, we also tested the assumption of constant error variance using a Goldfeld-Quandt test and could not reject the hypothesis of homoskedasticity. Using this model, we estimate a supply elasticity of 1.5 for this industry (see Table E-5).

Table 13E-5. Supply Elasticity Estimate for SIC 3089, Plastic Products, Not Elsewhere Classified: 1980–1996

Supply elasticity =	1.5
Number of observations =	17
R-squared =	99.79

Goldfeld-Quandt F(4,4) = 2.62 (p-value = 0.187)

d_{DW} = 1.40

d_l = 0.90

d_u = 1.71

Variable	Estimate	t-value	p-value
Intercept	–0.3544		
ln K	0.4048	4.07	0.0019
ln L	0.4404	3.21	0.0083
ln M	0.1548	1.26	0.2339
ln T	0.5087	7.27	<0.0001

Appendix 13F: Initial Market Equilibrium - Price Forecasts

The EIM analysis begins with current market conditions: equilibrium supply and demand. To estimate the economic impact of a regulation, standard practice uses projected market equilibrium (time series of prices and quantities) as the baseline and evaluates market changes from this projected baseline. Consequently, it is necessary to forecast equilibrium prices and quantities for future years.

Equilibrium quantity forecasts are driven by projected activity factors and this approach implicitly incorporates changes in production capacity during the period of analysis into the baseline.

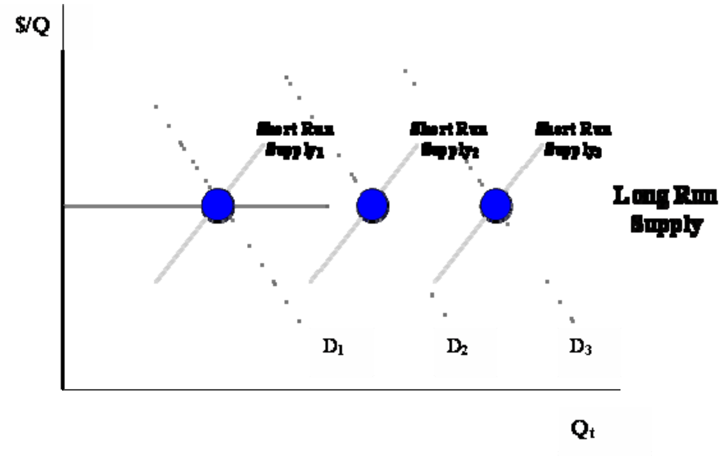


Figure 13.3-1. Prices and Quantities in Long Run Market Equilibrium

Equilibrium price forecasts typically use one of two approaches.[60] The first assumes a constant (real) price of goods and services over time. The second models a specific time series where prices may change over time due to exogenous factors.

In the absence of shocks to the economy or the supply of raw materials, economic theory suggests that the equilibrium market price for goods and services should remain constant over time. As shown in Figure 13.3-1, demand grows over time, in the long run, capacity will also grow as existing firms expand or new firms enter the market and eliminate any excess profits. This produces a flat long run supply curve. Note that in the short to medium run time frame the supply curve has a positive slope due to limitations in how quickly firms can react.

If capacity is constrained (preventing the outward shift of the baseline supply curve) or if the price of production inputs increase (shifting the baseline supply curve upward over time), then prices may trend upward reflecting that either the growth in demand is exceeding supply or the commodity is becoming more expensive to produce.

It is very difficult to develop forecasts events (such as those mentioned above) that influence long run prices. As a result, the approach used in this analysis is to use a constant 2003 observed price for PFCs and gasoline prices.

Nevertheless, there are forecasts of future gasoline prices, such as those provided by the Annual Energy Outlook. To take these forecasts into account we performed a sensitivity analysis using AEO forecasted prices for gasoline markets (see Appendix 13G).

Appendix 13G: Sensitivity Analyses

The economic impact analysis presented in this Chapter 13 is based on an economic impact mode (EIM) developed specifically for this analysis. This EIM reflects certain assumptions about behavioral responses (modeled by supply and demand elasticities), how compliance costs are treated by refiners, and how prices will behave in the future. This Appendix presents several sensitivity analyses in which various model parameters are varied to examine how different values for these parameters would affect model results. Four parameters are examined:

- Scenario 1: alternative market supply and demand elasticity parameters
- Scenario 2: alternative ways to treat fuel market compliance costs
- Scenario 3: alternative ways to project future gasoline prices
- Scenario 4: alternative social discount rates

The results of these sensitivity analyses are presented below. The results for the first two scenarios are presented for 2015. The results for the other two scenarios are presented for 2007 through 2035.

In general, varying the model parameters does not significantly change the estimated net impacts on economic welfare. The estimated net surplus loss in 2015 for the program is about \$350.7 million. The net surplus losses (consumer plus producer) across the sensitivity analysis scenarios are all about \$350 million. The exceptions are the alternative fuel market compliance cost scenarios. The results of those scenarios suggest the rule will result in a substantial consumer loss that is expected to be captured by refiners in the form of excess profits and resulting in a net gain for producers. In those cases, the net surplus losses are \$322.8 million and \$333.9 million.

With regard to how the compliance costs are expected to be shared, the alternative fuel market compliance cost scenarios result in significant wealth transfers from consumers to producers. For the elasticity scenarios, even if expected net surplus losses are similar across most scenarios, varying the model parameters has an impact on how costs would be distributed between producers and consumers. Varying the supply elasticity in Scenario 1, for example, results in the producer share of the gasoline fuel program varying from \$34.5 million (9.1 percent) to \$316.2 million (83.3 percent), compared to \$172.5 million (45.5 percent) for the primary analysis. Finally, the alternative gasoline prices in Scenario 3 do not substantially affect the distribution of costs between consumers and producers.

13G.1 Scenario 1: Model Elasticity Parameters

The supply and demand price elasticities are key parameters in the EIM. They characterize the behavioral responses of producers and consumers in the gasoline fuel and PFC markets. Demand and supply elasticities measure the responsiveness of producers and consumers to a change in price: how much the quantity demanded or supplied is expected to change. A detailed discussion regarding the estimation and selection of the elasticities used in the EIM is provided in Appendix 13E. In this section we examine the impact of changes in the selected values of the elasticity parameters, holding other parameters constant. The goal is to determine whether alternative elasticity values significant alter the conclusions of the primary analysis.

13G.1.1 Alternative Demand and Supply Elasticities

The values of the demand and supply elasticities for the gasoline fuel and PFC markets is important because the distribution of regulatory costs depends on the relative supply and demand elasticities used in the analysis. For example, consumers will bear less of the regulatory burden of a program if they are more responsive to prices than producers (demand is relatively more elastic). Similarly, producers will bear less of the regulatory burden if they are more responsive (supply is relatively more elastic).

Table 13G.1-1 reports the upper- and lower-bound values of the values of the elasticity parameters (supply and demand) used in this sensitivity analysis.

Table 13G.1-1. Sensitivity Analysis of the Supply and Demand Elasticities for the Application Markets

Market/Parameter	Elasticity Source	Lower Bound	Base Case	Upper Bound
Gasoline Market				
Supply	Clean Air Nonroad Diesel rule [61]	0.04	0.24	2.0
Demand	Federal Trade Commission [62]	-0.10	-0.20	-0.40
Portable Fuel Container Market				
Supply	EPA estimate	0.7	1.5	3.9
Demand	EPA estimate	N/A	-0.01	-0.25

For the gasoline market, the upper- and lower-bounds of the demand and supply elasticities are those reported in the literature. It should be noted that these are these ranges do not include long-run elasticity estimates. As explained in Section 13.2.3, the EIM uses an intermediate time frame, during which producers have some resource immobility which may cause them to suffer producer surplus losses. In the long run, in contrast, all factors of production are variable and producers can adjust production in response to cost changes. This allows them to shift more of the burden of the rule to consumers.

The elasticites for the PFC market are estimated econometrically. The sensitivity ranges are derived by estimating a 90 percent confidence interval around the estimated elasticities, using the coefficient and standard error values from the econometric analysis (See Appendix 13E). Because PFC expenditures are only such a small portion of total household production inputs, households are not expected to switch their preferences for PFCs due to the standards. The sensitivity analysis reflects a hypothetical assumption that 10 percent of demand is substituted away from PFCs, a fairly large assumption since it is not clear what consumers would use instead of PFCs for such a significant share of their consumption. This forms the upper bound of the sensitivity analysis. Such a household behavioral change would increase the demand elasticity for PFCs to -0.25 from -0.01. In other words, a 1.0 percent increase in the price of PFCs will result in a 0.25 percent decrease in the quantity demanded.

13G.1.2 Results

The results of the sensitivity analysis for the demand and supply elasticities are reported in Tables 13G.1-2 and 13G.1-3.

In the gasoline fuel case, price increases are the highest for the upper-bound supply elasticity and lower-bound demand elasticity. In other words, when producers are more able to respond to cost increases (more elastic supply elasticity) they can adjust their production and pass more of the costs on to producers. Similarly, when consumers are less able to respond to price increases (less elastic demand elasticity) they cannot reduce their demand and must accommodate higher prices, resulting in their bearing more of the costs of the program. It is important to note, however, that none of these estimated price increases are very large, with the smallest being about 0.02 cent per gallon and the largest about 0.9 cent per gallon, as compared to 0.08 to 0.54 cent per gallon in the primary case.

In the PFC case, changes in the elasticity parameters have no impacts on the price of PFCs. This is not surprising given that the alternative elasticities are perfectly inelastic (elasticity of zero) or very inelastic (elasticity of -0.25), meaning that consumers are not expected to alter their purchases very much, if at all, in response to a change in price.

With regard to how the compliance costs of the program are distributed among producers and consumers in the gasoline fuel market, producers bear a larger portion of the burden when supply elasticity is less elastic (producers are less responsive to price changes) or the demand elasticity is more elastic (consumers are more responsive to price changes), ranging from about 63 percent to 83 percent compared to the primary analysis of 45 percent. Similarly, consumers bear a larger portion of the burden when the supply elasticity is more elastic (producers are more responsive to price changes) or the demand elasticity is less elastic (consumers are less responsive to price changes), ranging from 71 percent to 91 percent compared to the primary analysis of about 55 percent.

In the PFC case, however, varying the demand and supply parameters does not vary the results, with consumers expected to bear most of the burden across all cases. The sole exception is the demand upper-bound, in which the consumer burden decreases from 99 percent in the primary case to 85 percent. Again, this is because the alternative elasticities are also highly inelastic.

Finally, the overall expected social costs of the program across scenarios do not change, and are always about $350 million.

Table 13G.1-2. Application Market Sensitivity Analysis for Supply Elasticities[a, b]

Scenario	Supply Lower Bound		Base Case		Supply Upper Bound	
	Absolute	**Relative [c]**	**Absolute**	**Relative [c]**	**Absolute**	**Relative [c]**
Gasoline Fuel						
Price (¢/q)						
PADD I+III	0.02¢	0.02%	0.08¢	0.05%	0.14¢	0.09%
PADD II	0.05¢	0.03%	0.17¢	0.11%	0.28¢	0.18%
PADD IV	0.08¢	0.05%	0.27¢	0.17%	0.46¢	0.29%
PADD V (w/out CA)	0.17¢	0.10%	0.54¢	0.33%	0.91¢	0.55%
Change in Consumer Surplus ($$10^6$/yr)	–$63.2	*16.7%*	–$207.0	*54.5%*	–$344.9	*90.9%*
Change in Producer Surplus ($$10^6$/yr)	–$316.2	*83.3%*	–$172.5	*45.5%*	–$34.5	*9.1%*
Gas Cans						
Price ($/q)						
States w/Programs	$0.20	1.8%	$0.20	1.9%	$0.21	1.9%
States w/out Programs	$1.50	32.2%	$1.52	32.5%	$1.52	32.6%
Change in Consumer Surplus ($$10^6$/yr)	–$33.5	*98.6%*	–$33.7	*99.3%*	–$33.9	*99.7%*
Change in Producer Surplus ($$10^6$/yr)	–$0.5	*1.4%*	–$0.2	*0.7%*	–$0.1	*0.3%*
Subtotal Social Costs	–$413.4		–$413.4		–$413.3	
Fuel Savings	$75.5		$75.5		$75.5	
Vehicle Program	–$12.9		–$12.9		–$12.9	
Total Social Costs ($$10^6$/yr)	**–$350.8**		**–$350.7**		**–$350.7**	

[a] Sensitivity analysis is presented for 2015.

[b] Figures are in 2003 dollars.

[c] For “prices” rows the “relative” column refers to the relative change in price (with regulation) from the baseline price. For “Surplus” rows, the “relative” column contains the percent distribution between consumer and producer surplus.

Table 13G.1-3. Application Market Sensitivity Analysis for Demand Elasticities[a, b]

	Demand Lower Bound		**Base Case**		**Demand Upper Bound**	
Scenario	**Absolute**	**Relative** [c]	**Absolute**	**Relative** [c]	**Absolute**	**Relative** [c]
Gasoline Fuel						
Price (¢/q)						
PADD I+III	0.11¢	0.07%	0.08¢	0.05%	0.06¢	0.04%
PADD II	0.22¢	0.14%	0.17¢	0.11%	0.12¢	0.08%
PADD IV	0.35¢	0.22%	0.27¢	0.17%	0.19¢	0.12%
PADD V (w/out CA)	0.70¢	0.42%	0.54¢	0.33%	0.37¢	0.22%
Change in Consumer Surplus ($\$10^6$/yr)	–$267.8	*70.6%*	–$207.0	*54.5%*	–$142.3	*37.5%*
Change in Producer Surplus ($\$10^6$/yr)	–$111.6	*29.4%*	–$172.5	*45.5%*	–$237.1	*62.5%*
Gas Cans						
Price ($/q)						
States w/Programs	$0.21	1.9%	$0.20	1.9%	$0.18	1.6%
States w/out Programs	$1.53	32.7%	$1.52	32.5%	$1.31	28.0%
Change in Consumer Surplus ($\$10^6$/yr)	–$34.0	*100.0%*	–$33.7	*99.3%*	–$28.2	*85.7%*
Change in Producer Surplus ($\$10^6$/yr)	$0.0	*0.0%*	–$0.2	*0.7%*	–$4.7	*14.3%*
Subtotal Social Costs	–$413.4		–$413.4		–$412.3	
Fuel Savings	$75.5		$75.5		$75.5	
Vehicle Program	–$12.9		–$12.9		–$12.9	
Total Social Costs ($\$10^6$/yr)	**–$350.8**		**–$350.7**		**–$349.7**	

[a] Sensitivity analysis is presented for 2015.

[b] Figures are in 2003 dollars.

[c] For “prices” rows the “relative” column refers to the relative change in price (with regulation) from the baseline price. For “Surplus” rows, the “relative” column contains the percent distribution between consumer and producer surplus.

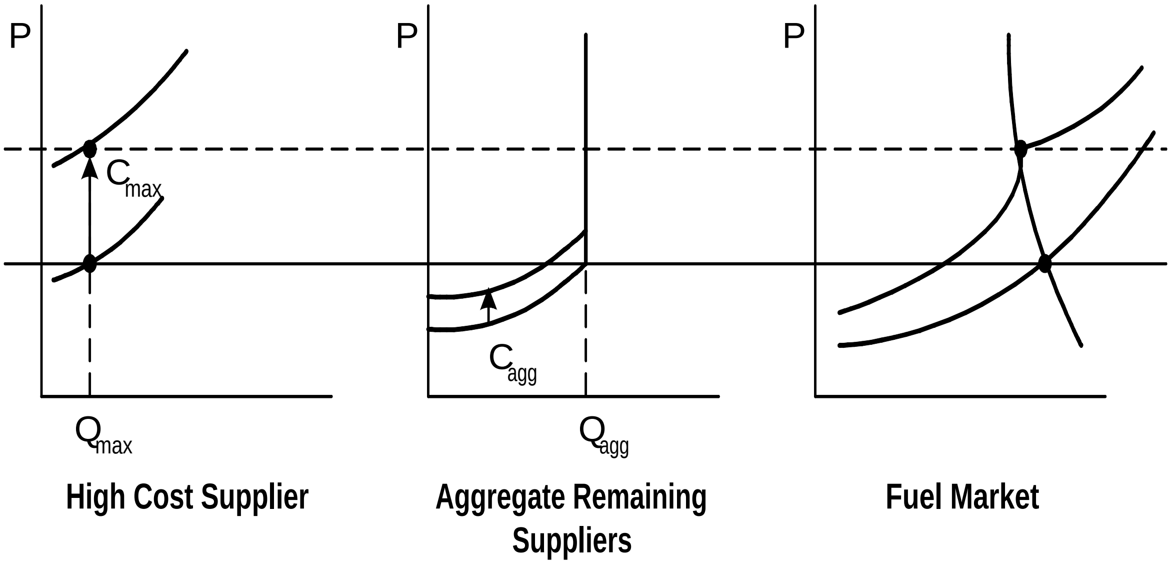
13G.2 Scenario 2: Fuel Market Compliance Costs

13G.2.1 Scenarios Modeled

Section 13.2 discusses alternative approaches to shifting the supply curve in the market model. Three alternatives for the fuel market supply shift are investigated in this sensitivity analysis:

- Total average (variable + fixed) cost shift—the results presented in Section 13.1 and the appendices are generated using this cost shift.
- Total maximum (variable + fixed) cost shift
- Variable maximum cost shift

Figure 13G2-1 High Cost Producer Drives Price Increases



While it may seem reasonable to estimate costs based on maximum variable or maximum total costs, it should be noted that both of those scenarios assume that refiners with the highest benzene compliance costs are also the highest-cost gasoline producers absent benzene control. We do not have information on the highest gasoline cost producers to be able to examine whether these refineries are also expected to have the highest benzene control costs. However, we believe this is an extreme assumption.

To model the total and variable maximum cost scenarios, the high-cost producer is represented by a separate supply curve as shown in Figure 13G-1. The remainder of the market is represented as a single aggregate supplier. The high-cost producer's supply curve is then shifted by Cmax (either total or variable), and the aggregate supply curve is shifted by Cagg. Using this structure, the high-cost producer will determine price as long as

- the decrease in market quantity does not shut down the high-cost producer, and

- the supply from aggregate producers is highly inelastic (i.e., remaining producers are operating close to capacity); thus, the aggregate producers cannot expand output in response to the price increase.

Note that the aggregate supply curve is no longer shifted by the average compliance costs but slightly less than the average because the high-cost producer has been removed. The adjusted average aggregate cost shift (Cagg) is calculated from the following:

$$C_{ave}*Q_{tot} = C_{max} * Q_{max} + C_{agg} * Q_{agg} \qquad (13G.1)$$

where C_{ave} is the average control cost for the total population; Q_{max}, C_{max}, and Q_{agg}, C_{agg} are the baseline output and cost shift for the maximum cost producer; and the baseline output and cost shift for the remaining aggregate producers, respectively.

13G.2.2 Compliance Costs

This analysis is based on the alternative compliance costs set out in Tables 13G.2-1 and 13G.2-2.

Table 13G.2-1 Gasoline Fuel Compliance Costs - Maximum Variable Cost Scenario by Region (¢/gallon, 2003$)

Year	PADD 1 & 3	PADD 2	PADD 4	PADD 5 (w/out California)
2007	0.323¢	0.243¢	0.609¢	0.334¢
2008	0.323¢	0.243¢	0.609¢	0.334¢
2009	0.323¢	0.243¢	0.609¢	0.334¢
2010	0.424¢	0.473¢	0.176¢	0.334¢
2011	0.424¢	0.473¢	0.176¢	0.334¢
2012	5.670¢	3.538¢	2.464¢	3.368¢
2013	5.670¢	3.538¢	2.464¢	3.368¢
2014	5.670¢	3.538¢	2.464¢	3.368¢
2015+	5.670¢	5.890¢	5.623¢	4.290¢

Table 13G.2-2. Gasoline Fuel Compliance Costs – Maximum Variable Cost Scenario by Region (¢/gallon, 2003$)

Year	PADD 1 & 3	PADD 2	PADD 4	PADD 5 (w/out California)
2007	0.323¢	0.243¢	0.609¢	0.334¢
2008	0.323¢	0.243¢	0.609¢	0.334¢
2009	0.323¢	0.243¢	0.609¢	0.334¢
2010	0.342¢	0.351¢	0.609¢	0.334¢
2011	0.342¢	0.351¢	0.609¢	0.334¢
2012	4.566¢	3.018¢	2.014¢	2.753¢
2013	4.566¢	3.018¢	2.014¢	2.753¢
2014	4.566¢	3.018¢	2.014¢	2.753¢
2015+	4.566¢	4.415¢	4.271¢	3.336¢

13G.2.3 Results

The results of the sensitivity analysis for the fuel compliance scenarios reported in Table 13G.2-1. According to these results, market prices are sensitive to changes in assumptions about compliance costs. The way in which the cost burden is shared across producers and consumers is also sensitive to changes in these assumptions.

With regard to prices, the Maximum Total Cost and Maximum Variable Cost scenarios both lead to larger estimated price increases. In the primary case (Total Average Cost scenario), prices are expected to increase between 0.08 to 0.54 cents per gallon, depending on the PADD. In the Maximum Total Cost scenario, prices are expected to increase from 4.3 to 5.9 cents per gallon. In the Maximum Variable Cost scenario, the estimated prices increases range from 3.3 to 4.4 cents per gallon.

With regard to how the burden is shared, both the Maximum Total Cost and Maximum Variable Cost scenarios lead to a significant outcome: producers are expected to benefit from the regulations and consumers are expected to experience a much larger surplus loss. In the Maximum Total Cost scenario, producers would benefit by about $7,308 million, while consumers surplus would decline by about $7,659 million. In the Maximum Variable Cost scenario, producers would benefit by about $5,596 million and consumers surplus would decline by about $5,958 million..

Table 13G.2-3. Sensitivity Analysis to Cost Shifts in the Gasoline Fuel Market (2015)[a,b]

	Total Average Scenario		Maximum Total Scenario		Maximum Variable Scenario	
Scenario	**Absolute**	**Relative[c]**	**Absolute**	**Relative[c]**	**Absolute**	**Relative[c]**
Gasoline Fuel						
Price (¢/q)						
PADD I+III	0.08¢	0.05%	5.3¢	3.6%	4.2¢	2.8%
PADD II	0.17¢	0.11%	5.9¢	3.9%	4.4¢	2.9%
PADD IV	0.27¢	0.17%	5.6¢	3.6%	4.3¢	2.7%
PADD V (w/out CA)	0.54¢	0.33%	4.3¢	2.6%	3.3¢	2.0%
Change in Consumer Surplus ($$10^6$/yr)	–$207.0		–$7,659.0		–$5,958.4	
Change in Producer Surplus ($$10^6$/yr)	-$172.5		$7,307.5		$5,595.8	
Gas Cans						
Price ($/q)						
States w/Programs	$0.20	1.9%	$0.20	1.9%	$0.20	1.9%
States w/out Programs	$1.52	32.5%	$1.52	32.5%	$1.52	32.5%
Change in Consumer Surplus ($$10^6$/yr)	–$33.7	*99.3%*	–$33.7	*99.3%*	–$33.7	*99.3%*
Change in Producer Surplus ($$10^6$/yr)	–$0.2	*0.7%*	–$0.2	*0.7%*	–$0.2	*0.7%*
Subtotal Social Costs	–$413.4		–$385.5		–$396.6	
Fuel Savings	$75.5		$75.5		$75.5	
Vehicle Program	–$12.9		–$12.9		–$12.9	
Total Social Costs ($$10^6$/yr)	**–$350.7**		**–$322.8**		**–$333.9**	

a Sensitivity analysis is presented for 2015.

b Figures are in 2003 dollars.

c For “prices” rows the “relative” column refers to the relative change in price (with regulation) from the baseline price. For “Surplus” rows, the “relative” column contains the percent distribution between consumer and producer surplus

Under the base case (Total Average Cost scenario), refiners are expected to pass more than half of the average compliance costs on to consumers, and the net decrease in producer surplus for refiners is about $172.5 million, or 45 percent of the gasoline program social costs. Under this scenario, prices are expected to increase less than 0.4 percent. Note that these are industry averages, and individual refiners will gain or lose because compliance costs vary across individual refineries.

In the Total Maximum Cost scenario, the highest operating cost refinery determines the new market price through the impacts on both fixed and variable costs. This refinery has the highest per-unit supply shift, which leads to a higher price increase relative to the Total Average Cost scenario. As a result, all refiners except the highest cost refiner are expected to benefit from the rule, with an increase in producer surplus of about $7,308 million. This would occur because the change in market price exceeds the additional per-unit compliance costs for most of the refineries (i.e., most refiners have costs less than the costs for the highest operating cost refinery). Consequently, in this scenario gasoline fuel consumers are expected to bear a larger share of the total cost of the program: $7,659 million compared to $207 million in the base case.

The Variable Maximum Cost scenario is similar to the Total Maximum Cost scenario in that the highest cost refinery determines the with-regulation market price. However, the Variable Maximum Cost scenario leads to an expected price increase that is smaller than the Total Maximum Cost scenario because the refiner supply shift includes only variable compliance costs. In other words, the refiners do not pass along any fixed costs; they absorb the fixed costs. Refiners also experience a net surplus gain in this scenario, about $5,596 million, because the change in market price (driven by the Maximum Variable Cost supply curve shift) exceeds the additional per-unit compliance costs for many refineries (i.e., many refiners still have total costs less than the costs for the highest operating cost refinery in this scenario). The net surplus gain for refiners is smaller than the Total Maximum Cost scenario ($5,596 million compared to $7,308 million) because refiners absorb fixed costs, and the projected market price increase is smaller. Again, gasoline fuel consumers are expected to bear a larger share of the total cost of the program, about $5,958 million.

The results of this sensitivity analysis suggest that the expected impacts on producers and consumers are affected by how refinery costs are modeled. In the EIM these costs are modeled based on the Average Total Cost scenario (variable + fixed), reflecting a competitive market situation in all regional markets. However, if the highest cost refinery drives the new market price, then prices are expected to increase more (up to 3.9 percent in PADD 2) and output is expected to contract more. In both of the maximum cost scenarios, gasoline fuel consumers are expected to bear more than the cost of the rule and refiners will bear less than in the base case.

13G.3 Scenario 3: Alternative Gasoline Price

Appendix F discusses two ways to handle future prices in the Economic Impact Analysis. The first assumes a constant (real) price of goods and services over time. The second approach allows prices change over time.

The primary analysis reflects the first alternative, and prices are held constant. As explained in Appendix F, this is a reasonable assumption because in a competitive market as demand grows over time production capacity will also grow as existing firms expand or new firms enter the market and eliminate any excess profit. If, however, capacity is constrained or if the price of inputs increases, then prices may change over time. In this sensitivity analysis we relax the constant price assumption and allow prices to change over time.

This sensitivity analysis examines the constant price assumption for the gasoline fuel market. We do not examine the impacts of relaxing the constant price assumption for the PFC market because there are no publicly available price forecasts for that market. Gasoline price forecasts are available through the Annual Energy Outlook's Reference (DoE 2006, Supplemental Table 20).[63] The AEO forecasted gasoline prices are national averages and are reported in dollar per million btu. To compute prices per gallon, we convert the AEO price data into an index (assume 2003 price as 1.00) and multiply this index by the appropriate 2003 baseline gasoline price. For example, the calculation for PADD II gasoline price in 2010 is:

$$\text{2003 price (\$/gallon)} \times \text{2010 AEO Price (\$/million btu)/2003 AEO Price(\$/million btu)}$$
$$= \$1.51 \times [16.52/13.31] = \$1.87$$

The resulting indexes were applied to the individual PADD prices presented in Table 13.3-4 (2003 price multiplied by the index). The resulting price forecasts by PADD are presented in Table 13G.3-1. Because the final year of the AEO projections is 2030, it is necessary to estimate projected prices through 2035. This was done by applying a linear growth rate based on the average annual growth Rate between 2021 and 2030.

Gasoline fuel forecast prices are presented in Figure 13G-2. This graph shows that prices are initially expected to decrease from 2007 to about 2014, and then gradually increase after 2014. The trends in fluctuations in gas prices reported in the AEO 2006 forecast have changed when compared with the AEO 2005 forecasts (forecasted gasoline prices used in the analysis). For example, annual growth in motor gasoline prices between 2003 and 2025 is higher (0.6 versus -0.0). In addition, absolute gasoline prices are substantially higher (approximately 50 cent per gallon) in the latest forecast.

Figure 13G3-1Forecast Motor Fuel Prices (Includes Federal and State Taxes, 2003$)

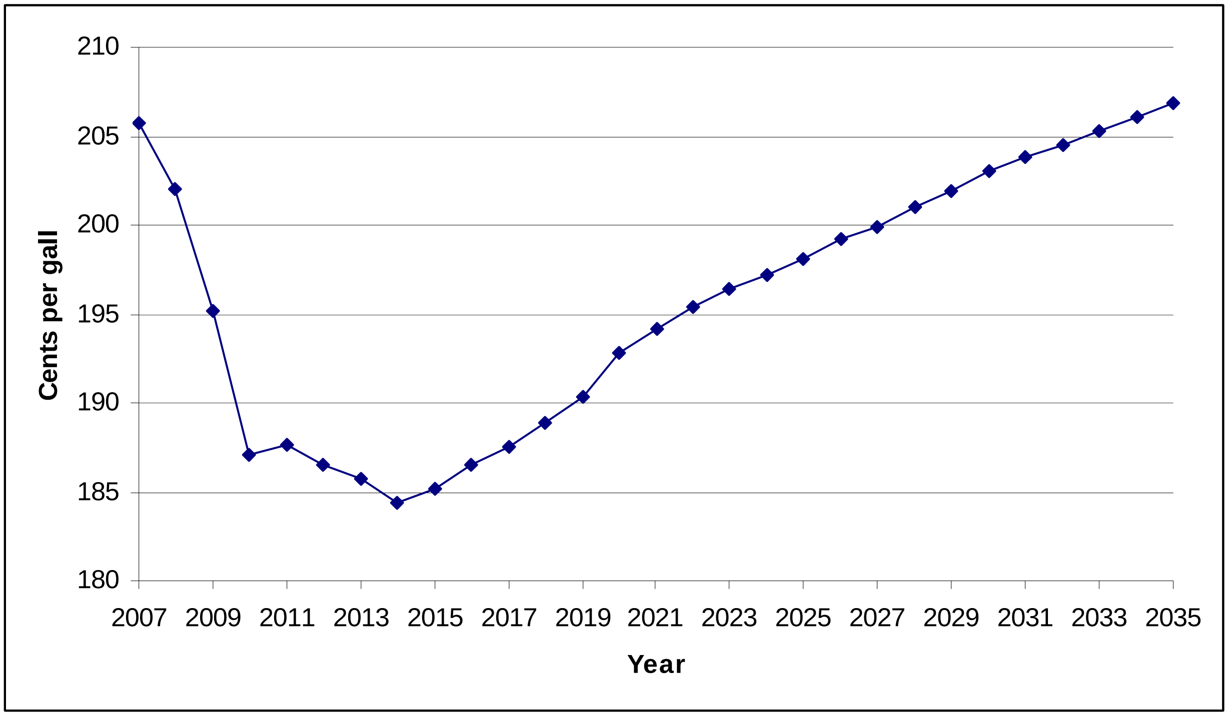


Table 13G.3-1. Forecast Gasoline Prices (2003$)

Year	PADD 1 & 3	PADD 2	PADD 4	PADD 5
Constant Price (Primary Case)	$1.48	$1.51	$1.57	$1.66
	Forecast Prices			
2007	$2.02	$2.06	$2.14	$2.27
2008	$1.98	$2.02	$2.10	$2.22
2009	$1.92	$1.95	$2.03	$2.15
2010	$1.84	$1.87	$1.95	$2.06
2011	$1.84	$1.88	$1.95	$2.07
2012	$1.83	$1.87	$1.94	$2.05
2013	$1.82	$1.86	$1.93	$2.04
2014	$1.81	$1.85	$1.92	$2.03
2015	$1.82	$1.85	$1.93	$2.04
2016	$1.83	$1.87	$1.94	$2.05
2017	$1.84	$1.88	$1.95	$2.06
2018	$1.85	$1.89	$1.97	$2.08
2019	$1.87	$1.91	$1.98	$2.10
2020	$1.89	$1.93	$2.01	$2.12
2021	$1.91	$1.94	$2.02	$2.14
2022	$1.92	$1.96	$2.04	$2.15
2023	$1.93	$1.97	$2.05	$2.16
2024	$1.94	$1.98	$2.05	$2.17
2025	$1.95	$1.98	$2.06	$2.18
2026	$1.96	$2.00	$2.07	$2.19
2027	$1.96	$2.00	$2.08	$2.20
2028	$1.97	$2.01	$2.09	$2.21
2029	$1.98	$2.02	$2.10	$2.22
2030	$1.99	$2.03	$2.11	$2.24
2031	$2.00	$2.04	$2.12	$2.24
2032	$2.01	$2.05	$2.13	$2.25
2033	$2.02	$2.06	$2.14	$2.26
2034	$2.02	$2.06	$2.15	$2.27
2035	$2.03	$2.07	$2.15	$2.28

The results of this sensitivity analysis are presented in Table 13G.3-2. Results are reported for 2015, 2020, and 2030, for each PADD. These results suggest there is no measurable difference between holding the price of gasoline constant or allowing it to vary in terms of the impact of the standard on gasoline prices or in the distribution of social welfare costs among producers and consumers of gasoline fuel. Relative gasoline price changes are slightly smaller because the baseline price of gasoline in the variable price scenario is substantially higher. This is not surprising, since the estimated compliance costs are the same for both the constant price and variable price scenarios and are small, and the difference in fuel prices between the two scenarios is small, less than five cents per gallon for all PADDs.

Table 13G3.2. Sensitivity Analysis Constant and Variable Prices[a]

	2015				2020				2030			
	Constant Price		Variable Price		Constant Price		Variable Price		Constant Price		Variable Price	
Scenario	Absolute	Relative[b]	Absolute	Relative[b]	Absolute	Relative[c]	Relative	Relative[b]	Absolute	Relative[b]	Absolute	Relative[b]
Gasoline Fuel												
Price (¢/q)												
PADD I+III	0.08¢	0.05%	0.08¢	0.04%	0.08¢	0.05%	0.08¢	0.04%	0.08¢	0.05%	0.08¢	0.04%
PADD II	0.17¢	0.11%	0.17¢	0.09%	0.17¢	0.11%	0.17¢	0.09%	0.17¢	0.11%	0.17¢	0.08%
PADD IV	0.27¢	0.17%	0.27¢	0.14%	0.27¢	0.17%	0.27¢	0.14%	0.27¢	0.17%	0.27¢	0.13%
PADD V (w/out CA)	0.54¢	0.33%	0.54¢	0.27%	0.54¢	0.33%	0.54¢	0.26%	0.54¢	0.33%	0.54¢	0.24%
Change in Consumer Surplus ($\$10^6$/yr)												
PADD I+III	–$66.3	17.5%	–$66.3	17.5%	–$70.4	17.5%	–$70.4	17.5%	–$77.9	17.5%	–$77.9	17.5%
PADD II	–$75.9	20.0%	–$75.9	20.0%	–$80.5	20.0%	–$80.5	20.0%	–$89.1	20.0%	–$89.1	20.0%
PADD IV	–$14.5	3.8%	–$14.5	3.8%	–$15.4	3.8%	–$15.4	3.8%	–$17.0	3.8%	–$17.0	3.8%
PADD V (w/out CA)	–$50.3	13.3%	–$50.3	13.3%	–$53.4	13.3%	–$53.4	13.3%	–$59.1	13.3%	–$59.1	13.3%
Change in Producer Surplus ($\$10^6$/yr)												
PADD I+III	–$55.3	14.6%	–$55.3	14.6%	–$58.6	14.6%	–$58.6	14.6%	–$64.9	14.6%	–$64.9	14.6%
PADD II	–$63.2	16.7%	–$63.2	16.7%	–$67.1	16.7%	–$67.1	16.7%	–$74.3	16.7%	–$74.3	16.7%
PADD IV	–$12.1	3.2%	–$12.1	3.2%	–$12.8	3.2%	–$12.8	3.2%	–$14.2	3.2%	–$14.2	3.2%
PADD V (w/out CA)	–$41.9	11.0%	–$41.9	11.0%	–$44.5	11.0%	–$44.5	11.0%	–$49.2	11.0%	–$49.2	11.0%
Total Gasoline Fuel Social Costs	–$379.4	100.0%	–$379.4	100.0%	–$402.6	100.0%	–$402.6	100.0%	–$445.8	100.0%	–$445.8	100.0%

a Figures are in 2003 dollars.

[b] For “prices” rows the “relative” column refers to the relative change in price (with regulation) from the baseline price. For “Surplus” rows, the “relative” column contains the percent distribution between consumer and producer surplus

13G.4 Scenario 4: Alternative Social Discount Rates

Future benefits and costs are commonly discounted to account for the time value of money. Pursuant to Circular A-4, we provide present value estimates using real discount rates of 3 percent and 7 percent, in Table 13G.4-1. According to OMB Circular A-4, “the 3 percent discount rate represents the ‘social rate of time preference’… [which] means the rate at which ‘society’ discounts future consumption flows to their present value”; “the seven percent rate is an estimate of the average before-tax rate of return to private capital in the U.S. economy … [that] approximates the opportunity cost of capital.”[64] The net present value of the social costs through 2035 using the 3 percent discount rate is $5,354 million. Using a seven percent social discount rate, the present value of total social costs is $2,900 million.

Table 13G.4-1. Net Present Value of Cumulative Estimated Social Costs Through 2035 (discounted to 2006; $million; 2003$)

Market	Change in Consumer Surplus	Change in Producer Surplus	Total	Change in Consumer Surplus	Change in Producer Surplus	Total
	Net Present Value 3%			Net Present Value 7%		
Gasoline, U.S.						
PADD 1 & 3	−$959.7	−$799.8	−$1,759.5	−$499.2	−$416.0	−$915.3
PADD 2	−$1,260.4	−$1,050.4	−$2,310.8	−$699.6	−$583.0	−$1,282.6
PADD 4	−$210.8	−$175.6	−$386.4	−$109.6	−$91.3	−$200.9
PADD 5 (w/out CA)	−$684.5	−$570.4	−$1,254.8	−$343.7	−$286.5	−$630.2
Portable Fuel Containers US						
States with existing programs	−$78.7	−$0.5	−$79.3	−$50.7	−$0.3	−$51.1
States without existing programs	−$676.2	−$4.5	−$680.7	−$399.8	−$2.7	−$402.5
Subtotal	−$3870.3 *59.8%*	−$2,601.2 *40.2%*	−$6,471.6	−$2,102.7 *60.4%*	-$1,379.8 *39.6%*	−$3,482.5
Fuel Savings			$1,208.0			$647.3
Vehicle Program			−$91.1			−$64.6
Total			−$5,354.6			−$2,899.8

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Chapter 14: Table of Contents

CHAPTER 14: Small-Business Flexibility Analysis

This chapter discusses our Final Regulatory Flexibility Analysis, which evaluates the potential impacts of new standards on small entities. The Regulatory Flexibility Act, as amended by the Small Business Regulatory Enforcement Fairness Act of 1996 (SBREFA), generally requires an agency to prepare a regulatory flexibility analysis of any rule subject to notice-and-comment rulemaking requirements under the Administrative Procedure Act or any other statute, unless the agency certifies that the rule will not have a significant economic impact on a substantial number of small entities. Prior to issuing a proposal for this rulemaking, we analyzed the potential impacts of these regulations on small entities. As a part of this analysis, we convened a Small Business Advocacy Review Panel (SBAR Panel, or 'the Panel'). During the Panel process, we gathered information and recommendations from Small Entity Representatives (SERs) on how to reduce the impact of the rule on small entities, and those comments are detailed in the Final Panel Report which is located in the public record for this rulemaking (Docket EPA-HQ-OAR-2005-0036).

14.1 Overview of the Regulatory Flexibility Act

In accordance with section 609(b) of the Regulatory Flexibility Act, we convened an SBAR Panel before conducting the Regulatory Flexibility Analysis. A summary of the Panel's recommendations can be found in our proposal. Further, the Final Panel Report contains a detailed discussion of the Panel's advice and recommendations (as well as the SER recommendations). The regulatory alternatives that are being adopted in this final rule are described below.

Section 609(b) of the Regulatory Flexibility Act further directs the Panel to report on the comments of small entity representatives and make findings on issues related to identified elements of the Regulatory Flexibility Analysis under section 603 of the Regulatory Flexibility Act. Key elements of a Regulatory Flexibility Analysis are:

- a description and, where feasible, an estimate of the number of small entities to which the proposed rule applies;
- projected reporting, record keeping, and other compliance requirements of the proposed rule, including an estimate of the classes of small entities that would be subject to the rule and the type of professional skills necessary to prepare reports or other records;
- an identification, to the extent practicable, of all other relevant federal rules that may duplicate, overlap, or conflict with the proposed rule;
- any significant alternatives to the proposed rule that accomplish the stated objectives of applicable statutes and that minimize any significant economic impact of the proposed rule on small entities.

The Regulatory Flexibility Act was amended by SBREFA to ensure that concerns regarding small entities are adequately considered during the development of new regulations that affect those entities. Although we are not required by the Clean Air Act to provide special treatment to small businesses, the Regulatory Flexibility Act requires us to carefully consider the economic impacts that our rules may have on small entities. The recommendations made by the Panel may serve to help lessen these economic impacts on small entities when consistent with Clean Air Act requirements.

14.2 Need for the Rulemaking and Rulemaking Objectives

A detailed discussion on the need for and objectives of this rule are located in the preamble to the final rule. As previously stated, controlling emissions from light-duty highway vehicles, gasoline, and portable fuel containers has important public health and welfare benefits.

Section 202(l)(2) of the Clean Air Act (CAA) authorizes EPA to promulgate standards to control emissions of mobile source air toxics (MSATs) from new motor vehicles and fuels. Specifically, this section states that EPA must:

> ...promulgate (and from time to time revise) regulations under subsection (a)(1) or section 211(c)(1) containing reasonable requirements to control hazardous air pollutants from motor vehicles and motor vehicle fuels. The regulations shall contain standards for such fuels or vehicles, or both, which the Administrator determines reflect the greatest degree of emission reduction achievable through the application of technology which will be available, taking into consideration the standards established under subsection (a), the availability and costs of the technology, and noise, energy, and safety factors, and lead time....The regulations shall, at a minimum, apply to emissions of benzene and formaldehyde.

Thus, EPA must determine the maximum amount of emission reduction possible through application of technology, and further assess the reasonableness of these reductions after considering cost, lead time, and the other enumerated factors. Controls on NMHC (a surrogate for organic mobile source air toxics) for light-duty vehicles, and benzene emissions from gasoline, implement this provision. In addition, many prior rules (including the Tier 2 standards and the highway and nonroad diesel engine standards) control toxics emitted by motor vehicles.

In addition, section 183(e) directs EPA to study, list, and regulate consumer and commercial products that are significant sources of VOC emissions. The final rule for portable fuel containers implements this provision. Regulations under section 183(e) must require the "best available control," considering technological and economic feasibility and health, environmental, and energy impacts.

14.3 Definition and Description of Affected Entities

Small entities include small businesses, small organizations, and small governmental jurisdictions. For the purposes of assessing the impacts of the proposed rule on small entities, a small entity is defined as: (1) a small business that meets the definition for business based on the Small Business Administration’s (SBA) size standards (see Table 14.3-1); (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 14.3-1 provides an overview of the primary SBA small business categories potentially affected by this regulation.

The following sections discuss the small entities directly regulated by this final rule—namely light-duty manufacturers, gasoline fuel refiners, and portable fuel container manufacturers. We conducted preliminary industry profiles to identify the universe of small entities in each sector.

Table 14.3-1. Small Business Definitions

Industry	Defined as small entity by SBA if less than or equal to:	NAICS[a] Codes
Light-duty vehicles:		
- vehicle manufacturers (including small volume manufacturers)	1,000 employees	336111
- independent commercial importers	$6 million annual sales	811111, 811112, 811198
- alternative fuel vehicle converters	100 employees 1,000 employees $6 million annual sales	424720 335312 811198
Gasoline fuel refiners	1,500 employees [b]	324110
Portable Fuel Container Manufacturers:		
- plastic container manufacturers	500 employees	326199
- metal fuel container manufacturers	1,000 employees	332431

a North American Industrial Classification System

b We have included in past fuels rulemakings a provision that, in order to qualify for the small refiner flexibilities, a refiner must also have a company-wide crude refining capacity of no greater than 155,000 barrels per calendar day. We have included this criterion to qualify for the small refiner provisions for this program as well.

14.3.1 Description of Highway Light-Duty Vehicle Manufacturers

To assess how many small entities would be directly affected by the rule, EPA first created a database comprised of firms specified in its Certification and Fuel Economy Information System (CFEIS) and EPA's independent commercial importers (ICIs) and converters lists. Sales and employment data for the parent companies of these firms was then found using the Dunn and Bradstreet (and Hoover's) and ReferenceUSA databases. Due to the range of manufacturers and ICIs, there are several NAICS codes in which these businesses report their sales, but the majority of the manufacturers and ICIs are listed under the following major groups, respectively: 33611x - *Automobile and Light Duty Motor Vehicle Manufacturing* and 8111xx - *Automotive Repair and Maintenance*. For alternative fuel converters, there did not appear to be a prominent NAICS code, and the codes range from 335312 - *Motor and Generator Manufacturing* (and/or 336312 - *Gasoline Engine and Engine Parts Manufacturing*) to 811198 - *All Other Automotive Repair and Maintenance*.

Based on the preliminary industry characterization, we identified a total of about 50 businesses that would be covered by the new light-duty vehicle standards. However, due to a lack of sales or employment data, a few of these entities could not be confirmed for consideration in EPA's analysis. Out of these 50 businesses, 21 entities (or 42 percent) fit the SBA criterion of a small business. EPA estimates that these entities comprise about 0.02 percent of the total light-duty vehicle sales in the U.S. for the year 2004.[A]

In addition to major vehicle manufacturers, three distinct categories of businesses characterize the above 50 total entities (and the subset of 21 small businesses): small volume manufacturers (SVMs), ICIs, and alternative fuel vehicle converters. The below discussion gives more detail on these categories.

14.3.1.1 Vehicle Manufacturers

In most cases, new standards for light-duty vehicles would minimally increase the costs of vehicle manufacturers to produce these vehicles. In addition to major vehicle manufacturers, SVMs are companies that sell less than 15,000 vehicles per year, as defined in past EPA regulations, and this status allows vehicle models to be certified under a slightly simpler certification process.

Using information from a preliminary assessment of the industry, EPA identified a total of 30 businesses that manufacture vehicles (including about 14 SVMs). The top 10 vehicle manufacturers comprise 97 percent of the U.S. total market (there were about 16.9 million total U.S. sales for the year 2004), while the other 20 manufacturers (including SVMs), ICIs, and converters make up the remaining 3 percent. Of the 30 manufacturers (14 SVMs included), 5 SVMs fit the SBA definition of a small entity. These five small businesses comprise about 0.01 percent of the total vehicle sales for the year 2004. Also, these businesses produce vehicles for small niche markets, and nearly all of these entities manufacture limited production, high performance cars. In addition, there are four other SVMs that EPA believes meet the SBA small-entity criterion, but since they are foreign businesses, they cannot be considered in the SBREFA work.

14.3.1.2 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 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).[B] ICIs would likely have minimal increased cost from the new standards.

[A] Sales information used for this analysis was 2004 data.

[B] To prevent entities from circumventing Tier 2 light-duty vehicle standards, EPA capped at 50 each ICI's annual production of vehicles meeting the original production (OP) year standards when OP year standards are less stringent than standards that apply during the year of modification. This does not impact the number of vehicles an ICI may produce that are certified to the standards that apply during the year of modification.

Currently 10 ICIs hold EPA certificates, and EPA believes all 10 of these businesses would meet the small-entity criteria as defined by SBA. In 2004, collectively they had total U.S. sales of about 300 vehicles, and thus, they comprised about 0.002 percent of the total vehicle sales. ICIs modify vehicles for a small niche market, and many of these vehicles are high performance cars.

14.3.1.3 Alternative Fuel Vehicle Converters

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 would likely have minimal increased cost from the new light-duty vehicle standards.

As with SVMs and ICIs, 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. Based on information from a preliminary assessment, EPA identified a total of 10 alternative fuel vehicle converters. Together these 10 businesses had about 0.02 percent of the total vehicle sales in the U.S. for the year 2004. Out of these 10 businesses, 6 meet the SBA small-entity criteria. These 6 converters represent about 0.01 percent of the total vehicle sales. In addition, EPA believes three of the other converters fit the SBA small-entity definitions, but since they are foreign businesses, they cannot be considered in the SBREFA work.

14.3.2 Description of Gasoline Refiners

Information about the characteristics of gasoline refiners comes from sources including the Energy Information Administration within the U.S. Department of Energy, oil industry literature, and industry searches using Hoover's and Dun and Bradstreet. These refiners fall under the *Petroleum Refineries* category, NAICS code 324110.

Using our preliminary industry characterization, coupled with 2003 gasoline production data, we believe that there are about 116 domestic refineries producing gasoline (however, due to a lack of publicly available sales or employment data, some of these entities could not be confirmed for consideration in the analysis). Our current assessment is that 14 refiners, owning 16 refineries, meet SBA's employee count criterion of having 1,500 employees or less. Due to dynamics in the refining industry (i.e., mergers and acquisitions) and decisions by some refiners to enter or leave the gasoline market, the actual number of refiners producing gasoline (and, thus, the number of small refiners that ultimately qualify for small refiner status under this program) could be much different than these estimates.

14.3.3 Description of Portable Fuel Container Manufacturers

For manufacturers of portable fuel containers, the SBA size thresholds are 500 employees for manufacturers of plastic containers and 1,000 employees for metal fuel containers. The NAICS codes are 326199 - *All Other Plastics Product Manufacturing* and 332431 - *Metal Can Manufacturing*. Discussions with industry and searches in databases such as LexisNexis Academic and ReferenceUSA (electronic resources) enabled EPA to determine how many businesses would be impacted by the proposed rule and may meet the small-entity criteria. The latter two sources provided sales and employment data for the parent companies of these businesses.

As discussed earlier, annual sales nationwide of portable fuel containers are about 21 million units. 98 percent are plastic containers, and 2 percent are metal. Blow molding equipment is relatively costly and large production volumes are necessary to operate profitably. These factors seem to limit the number of companies engaged in producing fuel containers. EPA has identified 9 domestic manufacturers and 1 foreign manufacturer. Of these 9 U.S. manufacturers, 8 meet the SBA definition of a small entity. One small business accounted for over 50 percent of the U.S. sales in 2002, and the other small entities comprised about 10 percent of U.S. sales.

14.4 Issues Raised by Public Comments

During the public comment period we received numerous comments regarding various aspects of the proposed rule; however, we did not receive many comments on our proposed small business provisions. The comments relating to the small business provisions were mainly focused on those provisions proposed for small refiners, and are summarized below. More information on these comments can be found in the Final Summary and Analysis of Comments, which is a part of the rulemaking record.

We received comments from small refiners generally supporting the small refiner provisions. We also received comments from a few stakeholders regarding the small refiner employee count and crude capacity criteria. These commenters stated that they believed that EPA's criteria fail to provide relief to a small number of refiners whom they believe are similar in many respects to those refiners that will qualify as small under our criteria. The commenters pointed to recent Congressionally-enacted programs, specifically the Energy Policy Act of 2005 and the American Jobs Creation Act of 2004, which use definitions that are different from SBA's definition, and from the criteria that EPA is adopting in this rule. The Energy Policy Act focuses on refinery size rather than company size, and the American Jobs Creation Act focuses on refinery-only employees rather than employees company-wide. EPA has established the criteria for qualifying for small refiner relief based on the Small Business Administration's (SBA) small business definition (13 CFR 121.201). Further, we have used these criteria in previous and current fuels programs and we believe it is prudent to retain the criteria of 1,500 employees and 155,000 bpcd crude capacity limit for consistency with these programs.

We do not believe that it would be appropriate to change the small refiner employee count or crude capacity limit criteria to fit either the Energy Policy Act or the Jobs Creation Act definitions. Further, SBA established the small business standards to set apart those companies which were at an inherent economic disadvantage due to their size. We agree with SBA's assessment that refiners of this size should be afforded special consideration under regulatory programs that have a significant economic impact on them. We continue to believe that it is most appropriate to remain consistent with our previous fuels programs and retain the small refiner criteria that have been used in the past (with some minor clarifications to avoid confusion).

We also received comments from representatives of small refiners which stated that a maximum average benzene standard changes the economics of small refiner compliance and that it should (and must) be considered by an SBAR Panel before a rule is finalized. The commenters stated that they believe that the imposition of a 1.3 vol% refinery maximum average violates the Regulatory Flexibility Act because the Panel did not have the opportunity to review the impacts of such a standard on small businesses. The commenter stated that EPA needed to present the maximum average provision to the Panel for its consideration prior to including it as part of a final rule. The commenters added that the possibility of a maximum average was never raised during the Panel process and that had it been, the small refiner SERs would have opposed the concept as greatly damaging to their segment of the industry. The commenters expressed concerns with the 1.3 vol% refinery maximum average, and requested that small refiner provisions allowing flexibility in meeting this maximum average be included in the final rule. The commenters also expressed concerns such as maintaining octane levels, costs for transportation of extracted benzene, and ability to locate other treatment facilities. Lastly, the commenters stated that they have serious concerns about inability to use credits to meet levels above 1.3, thus they suggested that EPA should allow small refiners to use credits for compliance with the 1.3 vol% refinery maximum average, with either a PADD restriction on credit trading or discounting credits used to meet the 1.3 vol% standard.

We understand the commenters' concerns with regard to the comments on the small refiners' difficulty in meeting the 1.3 vol% refinery maximum average. As discussed further in section VI of the preamble to the final rule, as well as chapter 4 of the Summary and Analysis document, we disagree that adopting a refinery maximum average in the final rule without specifically presenting the option for consideration by the Panel, or without reconvening that panel, violates the requirements of the Regulatory Flexibility Act. EPA complied with all requirements under SBREFA, and we note that the statute in fact contemplates that there will be changes between proposed and final rules, and states that EPA's only procedural requirement in such a case is to describe that change in the Final Regulatory Flexibility Analysis. Further, EPA requested comment on the option of adopting a 1.3 vol% maximum average (71 FR 15869, 15903) and received comment on the issue (including from small refiners).

We do not agree with the suggestion for PADD-restricted trading. Such geographic restrictions on credit use can prove to be very problematic, and would necessitate that we set different standards in different PADDs, due to the different level of benzene reductions achievable considering cost and other factors in those PADDs. This would reduce the liquidity of the credit trading market, and thus drive up the costs of the program. We believe that even with a maximum average standard, the combination of provisions that we are finalizing will minimize the likelihood of extreme hardship for small refiners. As discussed below in section 14.6, we are finalizing several significant relief provisions that apply specifically to small refiners, namely four years of additional lead-time to meet the 1.3 vol% maximum average (until July 1, 2016). Further, the hardship provisions that we are finalizing are available to all refiners, and these provisions could apply to situations that the commenters identified may still occur.

14.5 Projected Reporting, Recordkeeping, and Other Compliance Requirements of the Regulation

For highway light-duty vehicles, EPA is continuing the reporting, recordkeeping, and compliance requirements prescribed for this category in 40 CFR part 86. These requirements include certification requirements and provisions related to reporting of production, emissions information, flexibility use, etc. The types of professional skills required to prepare reports and keep records are also similar to the types of skills set out in 40 CFR part 86.

For any fuel control program, EPA must have assurance that fuel produced by refiners meets the applicable standard, and that the fuel continues to meet this standard as it passes downstream through the distribution system to the ultimate end user. The recordkeeping, reporting and compliance provisions we are finalizing are fairly consistent with those currently in place for other fuel programs. For example, reporting will include the submission of pre-compliance reports, which are already required under the highway and nonroad diesel fuel programs, to give EPA general information on refiners' plans and projected credit availability. Refiners will be required to submit refinery batch reports under the MSAT2 program, as they currently are for our other fuel programs. As with previous fuel regulations, small refiners will be required to apply for small refiner status and small refiner baselines. Lastly, we are requiring that all records be kept for at least five years. This recordkeeping requirement should impose little additional burden, as five years is the applicable statute of limitations for current fuel programs.

For portable fuel containers, requirements are similar to those in the California program, such as submitting emissions testing information, reporting of certification families, and use of transition provisions. For more information on the specific compliance provisions that are being finalized today, please see section VII.D of the preamble to the final rule.

Section XI.B of the preamble to the final rule includes a discussion of the estimated burden hours and costs of the recordkeeping and reporting that will be required by this final rule. Detailed information on the reporting and recordkeeping measures associated with this rulemaking are described in the Information Collection Requests (ICRs), also located in the preamble to this rulemaking: EPA ICR #0783.50 for light-duty vehicles, EPA ICR #1591.20 for fuel-related items, and EPA ICR #2213.01 for portable fuel containers.

14.6 Steps to Minimize Significant Economic Impact on Small Entities

As a part of the SBREFA process, we conducted outreach to a number of small entities representing the various sectors covered in this rulemaking and convened a Panel to gain feedback and advice from these representatives. Prior to convening the Panel, we held outreach meetings with the SERs to learn the needs of small businesses and potential challenges that these entities may face. The outreach meetings also helped to provide the SERs an opportunity to gain a better understanding of the upcoming standards. The feedback that we received from SERs as a result of these meetings was used during the Panel process to develop regulatory alternatives to mitigate the impacts of the rulemaking on small businesses. General concerns raised by SERs during the SBREFA process were potential difficulty and costs of compliance with the upcoming standards.

The Panel consisted of members from EPA, the Office of Management and Budget (OMB), and the Small Business Administration's Office of Advocacy. Following the Panel convening, a Final Panel Report detailing all of the alternatives that were recommended by the Final Regulatory Support Document Panel (as well as individual Panel members) was issued. We either proposed or requested comment on the various recommendations put forth by the Panel. Below we discuss those flexibility options recommended in the Panel Report, our proposed regulatory alternatives, and those provisions which are being finalized. We are finalizing many of the provisions recommended by the Panel, with exceptions noted below. We believe that the provisions that we are finalizing will help to mitigate the burden imposed upon small entities in complying with this rule.

14.6.1 Regulatory Alternatives and Hardship Provisions for Highway Light-Duty Vehicle Manufacturers

The Panel developed a wide range of regulatory alternatives to mitigate the impacts of the rulemaking on small businesses, and recommended that we propose and seek comment on the flexibilities. Described below are the flexibility options recommended by the Panel and our proposed regulatory alternatives.

14.6.1.1 Panel Recommendations

For certification purposes, SVMs include ICIs and alternative fuel vehicle converters since they sell less than 15,000 vehicles per year. Similar to the flexibility provisions implemented in the Tier 2 rule, the Panel recommended that we allow SVMs (includes all vehicle small entities that would be affected by this rule, which are the majority of SVMs) the following flexibility options for meeting cold temperature VOC standards and evaporative emission standards:

For cold VOC standards, the Panel recommended that SVMs simply comply with the standards with 100 percent of their vehicles during the last year of the four-year phase-in period. For example, if the standard for light-duty vehicles and light light-duty trucks (0 to 6,000 pounds GVWR) were to begin in 2010 and end in 2013 (25%, 50%, 75%, 100% phase-in over 4 years), the SVM provision would be 100 percent in 2013. If the standard for heavy light-duty trucks and medium-duty passenger vehicles (greater than 6,000 pounds GVWR) were to start in 2012 (25%, 50%, 75%, 100% phase-in over four years), the SVM provision would be 100 percent in 2015.

In regard to evaporative emission standards, the Panel recommended that since the evaporative emissions standards will not have phase-in years, we allow SVMs to simply comply with standards during the third year of the program (we have implemented similar provisions in past rulemakings). For a 2009 start date for light-duty vehicles and light light-duty trucks, SVMs would need to meet the evaporative emission standards in 2011. For a 2010 implementation date for heavy light-duty trucks and medium-duty passenger vehicles, SVMs would need to comply in 2012.

In addition, the Panel recommended that hardship flexibility provisions be extended to SVMs for the cold temperature VOC and evaporative emission standards. The Panel recommended that SVMs be allowed to apply (EPA would need to review and approve application) for up to an additional 2 years to meet the 100 percent phase-in requirements for cold VOC and the delayed requirement for evaporative emissions. Appeals for such hardship relief must be made in writing, must be submitted before the earliest date of noncompliance, must include evidence that the noncompliance will occur despite the manufacturer's best efforts to comply, and must include evidence that severe economic hardship will be faced by the company if the relief is not granted.

14.6.1.2 What We Proposed

For cold VOC standards, we proposed the Panel’s recommendation that SVMs comply with the standards with 100 percent of their vehicles during the last year of the four-year phase-in period, which would be 100 percent in model year 2013. Also, since the proposed standard for heavy light-duty trucks and medium-duty passenger vehicles would start in 2012 (25%, 50%, 75%, 100% phase-in over four years), we proposed that the SVM provision would be 100 percent in model year 2015.

We agreed with the Panel’s recommendation regarding evaporative emission standards, therefore, for a 2009 model year start date for light-duty vehicles and light light-duty trucks, we proposed that SVMs meet the evaporative emission standards in model year 2011. For a model year 2010 implementation date for heavy light-duty trucks and medium-duty passenger vehicles, we proposed that SVMs comply in model year 2012.

Although the SBAR panel did not specifically recommend it, we also proposed to allow ICIs to participate in the averaging, banking, and trading program for cold temperature NMHC fleet average standards (as described in Table VI.B-1 of the preamble), but with appropriate constraints to ensure that fleet averages will be met. The existing regulations for ICIs specifically bar ICIs from participating in emission related averaging, banking, and trading programs unless specific exceptions are provided (see 40 CFR 85.1515(d)). The concern is that they may not be able to predict their sales and control their fleet average emissions because they are dependent upon vehicles brought to them by individuals attempting to import uncertified vehicles. However, an exception for ICIs to participate in an averaging, banking, and trading program was made for the Tier 2 NOx fleet average standards, and thus we proposed to apply a similar exception for the cold temperature NMHC fleet average standards.

If an ICI is able to purchase credits or to certify a test group to a family emission level (FEL) below the applicable cold temperature NMHC fleet average standard, we would permit the ICI to bank credits for future use. Where an ICI desires to certify a test group to a FEL above the applicable fleet average standard, we would permit them to do so if they have adequate and appropriate credits. Where an ICI desires to certify to an FEL above the fleet average standard and does not have adequate or appropriate credits to offset the vehicles, we would permit the manufacturer to obtain a certificate for vehicles using such a FEL, but would condition the certificate such that the manufacturer can only produce vehicles if it first obtains credits from other manufacturers or from other vehicles certified to a FEL lower than the fleet average standard during that model year.

We do not believe that ICIs can predict or estimate their sales of various vehicles well enough to participate in a program that would allow them leeway to produce some vehicles to a higher FEL now but sell vehicles with lower FELs later, such that they were able to comply with the fleet average standard. We also cannot reasonably assume that an ICI that certifies and produces vehicles one year would certify or even be in business the next. Consequently, we proposed that ICIs not be allowed to utilize the deficit carry-forward provisions of the proposed ABT program.

We proposed the Panel recommendation that hardship provisions be extended to SVMs for the cold temperature NMHC and evaporative emission standards as an aspect of determining the greatest emission reductions feasible. These entities could, on a case-by-case basis, face hardship more than major manufacturers (manufacturers with sales of 15,000 vehicles or more per year). We proposed this provision to provide what could prove to be a needed safety valve for these entities, and we are proposing that SVMs would be allowed to apply for up to an additional 2 years to meet the 100 percent phase-in requirements for cold NMHC and the delayed requirement for evaporative emissions. As with hardship provisions for the Tier 2 rule, we proposed that appeals for such hardship relief must be made in writing, must be submitted before the earliest date of noncompliance, must include evidence that the noncompliance will occur despite the manufacturer's best efforts to comply, and must include evidence that severe economic hardship will be faced by the company if the relief is not granted.

14.6.1.3 Provisions Being Finalized in this Rule

We are finalizing, as proposed, that the SVM provision will be 100 percent in model years 2013 and 2015. For a 2009 model year start date for LDVs and LLDTs, we are finalizing that SVMs must meet the evaporative emission standards in model year 2011. For a model year 2010 implementation date for HLDTs and MDPVs, we are finalizing that SVMs must comply in model year 2012.

We are also finalizing the proposed provision that ICIs may participate in the averaging, banking, and trading program for cold temperature NMHC fleet average standards, but with appropriate constraints to ensure that fleet averages will be met. Further, we are finalizing that ICIs not be allowed to utilize the deficit carry-forward provisions of the ABT program.

Lastly, we are finalizing the proposed hardship provisions described above. Sections V.E.1 through V.E.3 of the preamble to the final rule contain more detailed discussions on provisions for small volume manufacturers.

14.6.2 Regulatory Alternatives and Hardship Provisions for Gasoline Refiners

14.6.2.1 Panel Recommendations

Discussed below are the options that the Panel recommended during the SBREFA process.

Delay in Standards
The Panel recommended that a four-year delay period should be proposed for small refiners. Such a delay would be needed in order to allow for a review of the ABT program, as discussed below, to occur one year after implementation but still three years prior to the small refiner compliance deadline. It was also noted that a delay option would also allow for small refiners to be able to expand their production capacity. The Panel supported allowing for refinery expansion and recommended that refinery expansion be provided for in the rule.

Early ABT Credits
The Panel recommended that early credit generation be afforded to small refiners that take some steps to meet the benzene requirement prior to the effective date of the standard. Depending on the start date of the program, and coupled with the four-year delay option, a small refiner could have a total credit generation period of five to seven years. The Panel also stated that it supports allowing refiners (small, as well as non-small, refiners) to generate credits for reductions to their benzene emissions levels (unlike prior fuels programs which have given early credits only to refiners who have fully met the applicable standard early).

Extended Credit Life
The Panel recommended that EPA propose a program that does not place a limit on credit life. During Panel discussions, it was noted that some Panel members were not in support of limited credit life for the general program. When the Final Panel Report was written, EPA intended to proceed with a proposal that did not place a limit on credit life; therefore the Panel did not make a specific recommendation on the concept of extended credit life. However, based on discussions during the Panel process, the Panel would have recommended that extended credit life be offered to small refiners if the general ABT program were to include a limit on credit life.

Program Review

The Panel recommended a review of the credit trading program and small refiner flexibility options one year after the general program starts. Such a review could take into account the number of early credits generated, as well as the number of credits generated and sold during the first year of the program. Further, requiring the submission of pre-compliance reports from all refiners would likely aid EPA in assessing the ABT program prior to performing the review. The Panel noted that, combined with the recommended four-year delay, a review after the first year of the program would still provide small refiners with the three years that it was suggested would be needed for these refiners to obtain financing and perform engineering and construction for benzene reduction equipment. Should the review conclude that changes to either the program or the small refiner provisions are necessary, the Panel recommended that EPA also consider some of the suggestions provided by the small refiners (their comments are located in Appendix E of the Final Panel Report), such as:

- the general MSAT program should require pre-compliance reporting (similar to EPA's highway and nonroad diesel rules);
- following the review, EPA should revisit the small refiner provisions if it is found that the credit trading market does not exist, or if credits are only available at a cost that would not allow small refiners to purchase credits for compliance; and,
- the review should offer ways either to help the credit market, or help small refiners gain access to credits (e.g., EPA could 'create' credits to introduce to the market, EPA could impose additional requirements to encourage trading with small refiners, etc.).

In addition, the Panel recommended that EPA consider in this rulemaking establishing an additional hardship provision to assist those small refiners that cannot comply with the MSAT with a viable credit market. (This suggested hardship provision was also suggested by the small refiners in their comments, located in Appendix E of the Final Panel Report). This hardship provision could address concerns that, for some small refineries, compliance may be technically feasible only through the purchase of credits and it may not be economically feasible to purchase those credits. This flexibility could be provided to a small refiner on a case-by-case basis following the review and based on a summary, by the refiner, of technical or financial infeasibility (or some other type of similar situation that would render its compliance with the standard difficult). This hardship provision might include further delays and/or a slightly relaxed standard on an individual refinery basis for a duration of two years; in addition, this provision might allow the refinery to request, and EPA grant, multiple extensions of the flexibility until the refinery's material situation changes. The Panel also stated that it understood that EPA may need to modify or rescind this provision, should it be implemented, based on the results of the program review.

During the Panel process, we stated that we intended to propose the extreme unforeseen circumstances hardship and extreme hardship provisions (for all gasoline refiners and importers), similar to those in prior EPA fuels programs. A hardship based on extreme unforeseen circumstances would provide short term relief due to unanticipated circumstances beyond the control of the refiner, such as a natural disaster or a refinery fire. An extreme hardship would provide short-term relief based on extreme circumstances (e.g., extreme financial problems, extreme operational or technical problems, etc.) that impose extreme hardship and thus significantly affect a refiner's ability to comply with the program requirements by the applicable dates. The Panel agreed with the proposal of such provisions and recommended that we include them in the MSAT rulemaking.

14.6.2.2 What We Proposed

In general, we proposed the Panel’s recommended regulatory flexibility provisions. The following is a discussion of the proposed provisions, as well as an additional provision that we proposed based on additional analysis following the SBREFA Panel process.

Delay in Standards
We proposed the Panel’s recommendation that small refiners be allowed to postpone compliance with the proposed benzene standard until January 1, 2015, which is four years after the general program begins. While all refiners are allowed some lead time before the general proposed program begins, we believe that in general small refiners would still face disproportionate challenges. Previous EPA fuel programs have included two to four year delays in the start date of the effective standards for small refiners, consistent with the lead time we believe appropriate here. The proposed four-year delay for small refiners would help mitigate these challenges. Further, a four-year delay would be needed in order to allow for a review of the ABT program, as discussed below, to occur one year after the general MSAT program implementation but still roughly three years prior to the small refiner compliance deadline.

Early ABT Credit Generation Opportunities
We are proposing the Panel’s recommendation that early credit generation be afforded to small refiners that take steps to meet the benzene requirement prior to their effective date. While we have anticipated that many small refiners would likely find it more economical to purchase credits for compliance, some have indicated they will make reductions to their gasoline benzene levels to meet the proposed benzene standard. Further, a few small refiners indicated that they would likely do so earlier than would be required by the January 1, 2015 proposed small refiner start date. Small refiner credit generation would be governed by the same rules as the general program, described in the preamble to the proposed rule in Section VII.E. The only difference is that small refiners would have an extended early credit generation period of up to seven years. Early credits could be generated by small refiners making qualifying reductions from June 1, 2007 through December 31, 2014, after which program credits could be generated indefinitely for those that over-comply with the standard.

Extended Credit Life
As discussed in the preamble, we proposed a limit on credit life. However, in order to encourage the trading of credits to small refiners and increase the certainty that credits would be available (as it would provide a viable outlet for credits facing expiration), we proposed that the useful life of credits be extended by 2 years if they are generated or

used by small refiners. This is meant to directly address concerns expressed by small refiners during the Panel process that they would be unable to rely on the credit market to avoid large capital costs for benzene control. While this flexibility option was not specifically recommended by the Panel, we believe that the Panel would be in support of such an option.

ABT Program Review

We proposed the Panel's recommendation that a review of the ABT program be performed within the first year of the general MSAT program (i.e., by 2012). To aid the review, we also proposed the requirement that all refiners submit refinery pre-compliance reports annually beginning June 1, 2008. In order for EPA to carry out this review, we believe that refiners' 2011 annual compliance report would also need to contain additional information, including credits generated, credits used, credits banked, credit balance, cost of credits purchased, and projected credit generation and use through 2015. When combined with the four-year delay option, this would afford small refiners with the knowledge of the credit trading market's status before they would need to invest capital.

As suggested by the Panel, we requested comment on elements to be included in the ABT program review, and suggested actions that could be taken following such a review. Such elements could include:

- Revisiting the small refiner provisions if it is found that the credit trading market does not exist to a sufficient degree to allow them to purchase credits, or that credits are only available at a cost-prohibitive price.
- Options to either help the credit market, or help small refiners gain access to credits.

In addition, we proposed the Panel's recommendation of the inclusion of an additional hardship provision that could be applied for following, and based on the results of, the ABT program review.

We did in fact propose the two hardship provisions stated above that the Panel recommended (the extreme unforeseen circumstances hardship and extreme hardship provisions). In addition, we proposed that these hardship provisions would be available to all refiners, regardless of size. These provisions would, at our discretion, permit a refiner to seek a temporary waiver from the MSAT benzene standard under certain rare circumstances.

14.6.2.3 Provisions Being Finalized in This Rule

We are finalizing a four-year period of additional lead time for small refiners to comply with the 0.62 vol% benzene requirement, until January 1, 2015. Consistent with the general program allowance of an additional 18 months (beyond the 0.62 vol% benzene standard compliance date) for compliance with the 1.3 vol% refinery maximum average, we are also finalizing 18 months of additional lead-time for small refiners to comply with the 1.3 vol% maximum average, until July 1, 2016 (and thus, small refiners will also receive an additional four years of lead-time from the general program start date for the 1.3 vol% refinery maximum average). We believe that this lead-time will provide these refiners with sufficient time to complete any necessary capital projects.

We are also finalizing the early credit generation provision for small refiners. This is similar to the general early credit generation provision that is provided to all refiners, except that small refiners may generate early credits until January 1, 2015. As discussed further in section VI.A.2.b.ii of the preamble to the final rule, refineries must reduce their 2004-2005 benzene levels by at least ten percent to generate early credits. This ten percent threshold is being set to ensure that changes in gasoline benzene levels are representative of real refinery process improvements, not just normal fluctuations in benzene level at a given refinery (allowed under MSAT1). The small refiner early credit generation period will be from June 1, 2007 to December 31, 2014, after which credits may be generated indefinitely for those that overcomplied with the standard. We are finalizing a modified version of the proposed extended credit life provision. The two-year credit life extension will pertain to standard credits only (since refiners already have an incentive to trade early credits to small refiners), and the extension will only apply to those standard credits traded to small refiners. There is no need to extend credit life for credits generated by small refiners, because in this event, the small refiner would already have the utmost certainly that the credits would be available for use.

We are also finalizing as proposed the ABT program review after the first year of the overall program. In part to support this review, we are requiring that refiners submit pre-compliance reports, similar to those required under the highway and nonroad diesel programs. If, following the review, EPA finds that the credit market is not adequate to support the small refiner provisions, we will revisit the ABT provisions to determine whether or not they should be altered or whether EPA can assist the credit market (and small refiners' access to credits) to enable a successful ABT program. We are finalizing an additional hardship provision to assist small refiners if it is found that some small refiners still cannot comply with the benzene standard even with a viable credit market. This hardship provision would be for the case of a small refiner for which compliance with the 0.62 vol% benzene standard would be feasible only through the purchase of credits, but it was not economically feasible for the refiner to do so. This hardship provision will only be afforded to a small refiner on a case-by-case basis, and will only be available following the ABT program review. The hardship application must be based on a summary by the refiner of the practical or financial difficulty with compliance with the 0.62 vol% benzene standard (or some other type of similar situation that would render its compliance with the standard) difficult. The relief offered under this hardship provision is a further delay, on an individual refinery basis, for up to two years. Following the two years, a small refiner will be allowed to request one or more extensions of the hardship until the refinery's material situation has changed.

We are finalizing the extreme hardship provision and the extreme unforeseen circumstances hardship provision with some modifications, as this final rule includes a 1.3 vol% refinery maximum average benzene standard. As discussed in more detail in section VI.A.3.b of the preamble to the final rule, relief will be granted on a case-by-case basis, however it may differ somewhat depending upon whether a refiner applies for hardship relief for the 0.62 vol% benzene standard or for the 1.3 vol% refinery maximum average standard. This is partly due to the fact that a refiner may use credits to meet the 0.62 vol% benzene standard, but credits cannot be used for compliance with the 1.3 vol% refinery maximum average.

Extreme hardship circumstances could exist based on severe economic or physical lead time limitations of the refinery to comply with the required benzene standards at the start of the program. For relief from the 0.62 vol% benzene standard in extreme hardship circumstances, relief will likely be in the form of an extension of the one-year deficit carry-forward allowed by the rule. Hardship relief from the 1.3 vol% refinery maximum average benzene standard in extreme hardship circumstances would consist of additional time to comply with the 1.3 vol% refinery maximum average. Refiners must apply by January 1, 2008 (or, January 1, 2013 for approved small refiners) for extreme hardship relief from the 1.3 vol% refinery maximum average, as this provision is intended to address unusual circumstances that should be apparent now or well before the effective date of the standard.

The extreme unforeseen circumstances hardship is available to both refiners and importers, and is intended to provide relief in extreme and unusual circumstances outside the refiner or importer’s control that could not have been avoided through the exercise of due diligence. Hardship relief for the 0.62 vol% benzene standard will allow a deficit to be carried forward for an extended, but limited, time period (more than the one year allowed by the rule). Hardship relief from the 1.3 vol% refinery maximum average benzene standard based on unforeseen circumstances will be granted on a case-by-case basis, following an assessment of the hardship application.

14.6.3 Portable Fuel Container Manufacturers

14.6.3.1 Panel Recommendations

Since nearly all portable fuel container manufacturers are small entities and they account for about 60 percent of sales, the Panel suggested that the flexibility options be offered to all portable fuel container manufacturers. The flexibilities that the Panel recommended are detailed below.

> *Design Certification*
>
> The Panel recommended that we propose to permit portable fuel container manufacturers to use design certification in lieu of running any or all of the durability aging cycles. Manufacturers could demonstrate the durability of their portable fuel containers based in part on emissions test data from designs using the same permeation barriers and materials. Under a design-based certification program a manufacturer would provide evidence in the application for certification that their container would meet the applicable standards based on its design (e.g., use of a particular permeation barrier). The manufacturer would submit adequate engineering and other information about its individual design such that EPA could determine that the emissions performance of their individual design would not be negatively impacted by slosh, UV exposure, and/or

pressure cycling (whichever tests the manufacturer is proposing to not run prior to emissions testing).

Broaden Certification Families

This approach would relax the criteria used to determine what constitutes a certification family. It would allow small businesses to limit their certification families (and therefore their certification testing burden), rather than testing all of the various size containers in a manufacturer's product line. Some small entities may be able to put all of their various size containers into a single certification family. Manufacturers would then certify their containers using the "worst case" configuration within the certification family. To be grouped together, containers would need to be manufactured using the same materials and processes even though they are of different sizes. The Panel recommended that EPA propose this approach.

Additional Lead-time

It was recognized that time would be needed for the portable fuel container SERs to gather information to fully evaluate whether or not additional lead-time might be needed beyond the proposed 2009 start date, the Panel recommended that we discuss lead-time in the proposal and request comment on the need for additional lead-time to allow manufacturers to ramp up to a nationwide program.

Product Sell-through

As with past rulemakings for other source sectors, the Panel recommended that EPA propose to allow normal sell through of portable fuel containers as long as manufacturers do not create stockpiles of noncomplying portable fuel containers prior to the start of the program.

Following the SBREFA process, the Panel recommended that we propose two types of hardship programs for small portable fuel container manufacturers. These suggested provisions were:

- Allow small manufacturers to petition EPA for limited additional lead-time to comply with the standards. A manufacturer would have to make the case that it has taken all possible business, technical, and economic steps to comply but the burden of compliance costs or would have a significant adverse effect on the company's solvency. Hardship relief could include requirements for interim emission reductions. The length of the hardship relief would be established during the initial review and would likely need to be reviewed annually thereafter.
- Permit small manufacturers to apply for hardship relief if circumstances outside their control cause the failure to comply (i.e., supply contract broken by parts supplier) and if failure to sell the subject containers would have a major impact on the company's solvency. The terms and timeframe of the relief would depend on the

> specific circumstances of the company and the situation involved. As part of its application, a company would be required to provide a compliance plan detailing when and how it would achieve compliance with the standards under both types of hardship relief.

14.6.3.2 What We Proposed

Based upon the comments received from portable fuel container small entity representatives during the SBREFA Panel process, we decided to propose the Panel-recommended flexibility and hardship provisions for portable fuel container manufacturers. As stated previously, nearly all portable fuel container manufacturers (8 of 10 manufacturers as defined by SBA) are small entities and they account for about 60 percent of sales, the Panel recommended to extend the flexibility options and hardship provisions to all portable fuel container manufacturers, thus we proposed that these flexibilities be offered to all portable fuel container manufacturers. Moreover, implementation of the program would be much simpler by doing so.

Further, we proposed that the two types of hardship provisions recommended by the Panel be extended to portable fuel container manufacturers.

14.6.3.3 Provisions Being Finalized in This Rule

We are finalizing, as proposed, the flexibility provisions described above for portable fuel container manufacturers. We are also finalizing the hardship provisions described above for these entities. These entities could, on a case-by-case basis, face hardship, and we are finalizing these provisions to provide what could prove to be needed safety valves for these entities. For both types of hardship provisions, the length of the hardship relief will be established, during the initial review, for not more than one year and will be reviewed annually thereafter as needed. Section VII.F of the preamble to the final rule contains a more detailed discussion of these hardship provisions.

14.7 Related Federal Rules

The primary federal rules that are related to this rule are the first mobile source air toxics rule (66 FR 17230, March 29, 2001), the Tier 2 Vehicle/Gasoline Sulfur rulemaking (65 FR 6698, February 10, 2000), the fuel sulfur rules for highway diesel (66 FR 5002, January 18, 2001) and nonroad diesel (69 FR 38958, June 29, 2004), the Reformulated Gasoline and Anti-dumping rule (59 FR 7813 and 59 FR 7860, February 16, 1994), and the Cold Temperature Carbon Monoxide Rulemaking (57 FR 31888, July 17, 1992).

In addition, the Evaporative Emissions Streamlining Direct Final Rulemaking was issued on December 8, 2005 (70 FR 72917). For portable fuel containers, the Occupational Safety and Health Organization (OSHA) has safety regulations for gasoline containers used in workplace settings. Containers meeting OSHA requirements, commonly called safety cans, are exempt from the California program, and EPA is planning to exempt them from the EPA program.

Section 1501 of the Energy Policy Act of 2005 (EPAct) requires that EPA implement a Renewable Fuels Standard (RFS) program. Beginning in 2006, this program will require increasing volumes of renewable fuel to be used in gasoline, until a total of 7.5 billion gallons is required in 2012. The most prevalent renewable fuel to be used in gasoline is expected to be ethanol.

There are a wide variety of potential impacts of ethanol blending on MSAT emissions that will be evaluated as part of the RFS rulemaking process. In general, as ethanol use increases, other sources of octane in gasoline can decrease. Depending on these changes, the impact on benzene emissions will vary. The specific effects of ethanol on benzene are addressed in this Regulatory Impact Analysis, and will also be addressed and in future rulemakings such as the RFS rule.

14.8 Conclusions

Throughout the entire rulemaking process, we conducted substantial outreach-- including convening a Panel during the SBREFA process as well as meetings with other stakeholders-- to gather information about the effect of this final rule on small entities. We used this information, and performed cost-to-sales ratio tests (a ratio of the estimated annualized compliance costs to the value of sales per company) to determine the impacts of the rule on small entities.

In regard to the highway light-duty manufacturers, we found that small vehicle entities (which include manufacturers, ICIs and converters) in general would likely be impacted similarly as large entities. As we discussed earlier in Chapter 5 (Vehicle Feasibility) and Chapter 8 (Vehicle Costs), we are aligning the EPA evaporative emission standards with California LEV II standards, and essentially all manufacturers certify 50-state evaporative systems that meet both sets of standards. We do not expect additional costs from this requirement since we expect that manufacturers will continue to produce 50-state evaporative systems. In limited cases where vehicle small entities may not currently produce 50-state systems, the flexibilities and hardship relief for small entities, as described earlier, will reduce the burden on these entities.

In addition, as described earlier in Chapters 5 and 8, the cold temperature exhaust (VOC) emission standards for light-duty vehicles can be achieved through calibration alone. It will only require up-front research and development costs, and certification burden is likely to be small due to existing cold carbon monoxide testing requirements. Therefore, the new cold temperature VOC standard is expected to add less than $1 on average to the cost of vehicles. In general, small vehicle entities will likely experience similar impacts as large entities. Also, as described earlier, the flexibility and hardship provisions will reduce the burden of the new cold VOC standard on small vehicle entities.

With respect to small refiners, these entities in general would likely experience a significant and disproportionate financial hardship in complying with the requirements in this rule. Refinery modeling (of all refineries), indicates higher refining costs for small refiners. Chapter 9 of this RIA contains a detailed discussion of our analysis and projected costs for U.S. refiners in complying with the benzene control program.

Of the small refiners with publicly available sales data, we were able to estimate annual costs, and use this information to complete a cost-to-sales ratio test. Our current estimate for the 14 small refiners (owning 16 refineries) that we believe will be subject to this rulemaking is as follows: 37.5 percent (6 refineries) would be affected at less than 1 percent of their sales (i.e., the estimated costs of compliance with the proposed rule would be less than 1 percent, of their sales), 37.5 percent (6 refineries) would be affected at greater than 1 percent but less than 3 percent, and 25 percent (4 refineries) would be affected at greater than 3 percent of their sales. Therefore, we believe that the flexibility provisions are necessary to help mitigate these impacts to small refiners. Our cost analysis, however, does not consider benzene control options which could dramatically reduce compliance costs for these small refineries, particularly those refineries affected by the 1.3 vol% maximum average standard. The costs for these small refineries are high because of their poorer economies of scale for installed capital. We believe that these refiners can avoid high per-gallon costs by installing a reformate splitter. The reformate splitter is a relatively low capital and operating cost unit that would allow them to remove a benzene-rich stream from the rest of their reformate, resulting in a final gasoline that would be in compliance with the maximum average standard. The benzene-rich stream can be sold to another refinery with gasoline benzene levels below the cap standard and so can absorb this small benzene-rich volume. This sort of trading is similar to the credit trading program, except that actual benzene is being traded instead of paper credits.

For portable fuel containers, as discussed earlier, nearly all manufacturers are small entities, thus the flexibility and hardship provisions afforded in this rule will be offered to all portable fuel container manufacturers. Moreover, small portable fuel container manufacturers will likely be impacted by the new standards similarly as the large manufacturers. Automatically-closing spouts and permeation control are expected to be utilized to meet the evaporative emissions standard for portable fuel containers. As discussed in Chapters 10 (Portable Fuel Container Costs) and Chapter 13 (Economic Impact Analysis), all portable fuel containers range in price from $3 to $7, and the added variable and fixed costs for the new portable fuel containers with auto-close spouts and permeation control is estimated to be about $2.70 per unit on average. We continue to believe that manufacturers will be able to pass on these costs without a significant impact on portable fuel container sales. In addition, the flexibilities and hardship relief for all portable fuel container manufacturers would reduce the burden of the new standards on small and large manufacturers.