

# **Draft Regulatory Impact Analysis: Control of Hazardous Air Pollutants from Mobile Sources**

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

## *NOTICE*

*This Technical Report does not necessarily represent final EPA decisions or positions.  
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The purpose in the release of such reports is to facilitate an exchange of  
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## List of Acronyms

µg/kg-day	Micrograms per kilogram day
µg/m <sup>3</sup>	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
APHEA	Air Pollution and Health: A European Approach
API	American Petroleum Institute
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
C <sub>6</sub> or C <sub>6</sub>	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
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
CO <sub>2</sub>	Carbon Dioxide
COI	Cost-of-Illness
COPD	Chronic Obstructive Pulmonary Disease
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
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
EPAct	Energy Policy Act of 2005
ETBE	Ethyl Tertiary Butyl Ether
ETC	Electronic Throttle Control
ETS	Environmental Tobacco Smoke
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
FHWA	Federal Highway Administration
FOEB	Fuel Oil Equivalent Barrel
FRM	Final Rulemaking
F RTP	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 <sub>2</sub>	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
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
ISC	Integrated Source Complex
ISCST	Industrial Source Complex Short Term
JAMA	Journal of the American Medical Association
K	Thousand
KBBL	Thousand barrels
KWH	Kilowatt Hour
LB	Pound
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
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)
MAF	(Engine) Mass Air Flow
MAP	(Engine) Manifold Absolute Pressure
MDPV	Medium-Duty Passenger Vehicle
mg/m <sup>3</sup>	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 <sub>2</sub>	Nitrogen Dioxide
NONROAD	EPA's Non-road Engine Emission Model
NONROAD2005	EPA's Non-road Engine Emission Model Released in 2005
NO <sub>x</sub>	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
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
PM	Particulate Matter
PM/NMHC	Particulate Matter to Non-Methane Hydrocarbon Ratio
PM <sub>10</sub>	Coarse Particle
PM <sub>2.5</sub>	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
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
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 <sub>x</sub> Emission Control Area
SER	Small Entity Representative
SFTP	Supplemental Federal Test Procedure
SHED	Sealed Housing for Evaporative Determination
SI	Spark Ignition
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
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 proposing new standards to reduce emissions of Mobile Source Air Toxics (MSATs) including benzene and overall hydrocarbons from motor vehicles, motor vehicle fuels, and portable gasoline containers (gas cans). This Regulatory Impact Analysis provides technical, economic, and environmental analyses of the proposed 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 proposing, providing a technical justification for the feasibility of the standards for vehicles, fuels, and gas cans, respectively. Chapters 8 through 10 present cost estimates of complying with the proposed standards for vehicles, fuels, and gas cans, 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 proposed 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 proposing and the estimated impacts.

### Emissions Standards

#### *Vehicles*

We are proposing new standards for both exhaust and evaporative emissions from passenger vehicles. The new exhaust emissions standards would 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. These cold-temperature NMHC controls would also result in lower direct PM emissions at cold temperatures.

Accordingly, we are proposing that light-duty vehicles, light-duty trucks, and medium-duty passenger vehicles would be subject to a new non-methane hydrocarbon (NMHC) exhaust emissions standard at 20° F. Vehicles at or below 6,000 pounds gross vehicle weight rating (GVWR) would 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 would be subject to a sales-weighted fleet average NMHC level of 0.5 grams/mile. For lighter vehicles, the standard would phase in between 2010 and 2013. For heavier vehicles, the new standards would phase in between 2012 and 2015. We are also proposing 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 proposing a set of nominally more stringent evaporative emission standards for all light-duty vehicles, light-duty trucks, and medium-duty passenger vehicles. The proposed 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 we propose today would codify the approach that manufacturers are already taking for 50-state evaporative systems, and thus the standards would prevent backsliding in the future. We are proposing to implement the evaporative emission standards in 2009 for lighter vehicles and in 2010 for the heavier vehicles.

#### *Gasoline Fuel Standards*

We are proposing that beginning January 1, 2011, refiners and fuel importers would meet an 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 proposed fuel standard would result in air toxics emissions reductions that are greater than required under all existing gasoline toxics programs. As a result, EPA is proposing that upon full implementation in 2011, the regulatory provisions for the benzene control program would become the single regulatory mechanism used to implement the RFG and Anti-dumping annual average toxics requirements. The current RFG and Anti-dumping annual average provisions would be replaced by the proposed benzene control program. The MSAT2 benzene control program would also replace the MSAT1 requirements. In addition, the program would satisfy certain fuel MSAT conditions of the Energy Policy Act of 2005. In all of these ways, we would significantly consolidate and simplify the existing national fuel-related MSAT regulatory program.

We are also proposing 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 could generate benzene credits by taking early steps to reduce gasoline benzene levels. Beginning in 2011 and continuing indefinitely, refiners could generate credits by producing gasoline with benzene levels below the 0.62% average standard. Refiners could 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 proposed program. Under this program, refiners could use credits to achieve compliance with the benzene content standard.

### *Portable Gasoline Container (Gas Can) Controls*

Portable gasoline containers, or gas cans, are consumer products used to refuel a wide variety of gasoline-powered equipment, including lawn and garden equipment, recreational equipment, and passenger vehicles that have run out of gas. We are proposing standards that would reduce hydrocarbon emissions from evaporation, permeation, and spillage. These standards would significantly reduce benzene and other toxics, as well as VOC more generally. VOC is an ozone precursor.

We propose 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 would apply to gas cans manufactured on or after January 1, 2009. We also propose test procedures and a certification and compliance program, in order to ensure that gas cans would meet the emission standard over a range of in-use conditions. The proposed standards would 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 gas cans in 2001, and since then, several other states have adopted the program. Last year, California adopted a revised program, which will take effect July 1, 2007. The revised California program is very similar to the program we are proposing. Although a few aspects of the program we are proposing are different, we believe manufacturers would be able to meet both EPA and California requirements with the same gas can 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*

Air toxic emissions from light-duty vehicles depend on both fuel benzene content and vehicle hydrocarbon emission controls. Similarly, the air toxic emissions from gas cans depend on both fuel benzene content and the gas can emission controls. Tables 1 and 2 below summarize the expected reductions in benzene and total MSAT emissions, respectively, from our proposed vehicle, fuel, and gas can controls. Although the proposal does not apply to nonroad engines or the gasoline distribution industry, the fuels controls would reduce benzene emissions from these sources as well due to lower benzene levels in gasoline. In 2030, annual benzene emissions from gasoline on-road mobile sources would be 44% lower as a result of this proposal. Annual benzene emissions from gasoline light-duty vehicles would be 45% lower in 2030 as a

result of this proposal. Gasoline would have 37% lower benzene overall. Finally, this proposal would reduce annual emissions of benzene from gas cans by 78% in 2030.

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

	2020	2030
Fuels	18,145	20,272
Vehicles	28,105	47,689
Gas Cans	1,567	1,772
Total	45,241	65,282

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

	2020	2030
Fuels	18,145	20,272
Vehicles	181,509	308,887
Gas Cans	24,158	27,342
Total	221,081	351,894

## VOC

VOC emissions would be reduced by the hydrocarbon emission standards for both light-duty vehicles and gas cans. Annual VOC emission reductions from these sources would be 35% lower in 2030 because of this proposal.

**Table 3: Estimated Reductions in VOC Emissions from Light-Duty Gasoline Vehicles and Gas Cans, 2020 and 2030 (tons)**

	2020	2030
Vehicles	536,484	913,439
Gas Cans	192,683	218,080
Total	729,167	1,131,519

## *PM<sub>2.5</sub>*

We expect that only the proposed vehicle control would reduce emissions of direct PM<sub>2.5</sub>. As shown in Table 4, we expect this control to reduce direct PM<sub>2.5</sub> emissions by about 20,000 tons in 2030. In addition, the VOC reductions from the proposed vehicle and gas can standards would also reduce secondary formation of PM<sub>2.5</sub>.

**Table 4. Estimated National Reductions in Direct PM<sub>2.5</sub> Exhaust Emissions from Light-Duty Gasoline Vehicles and Trucks, 2020 and 2030 (tons)**

	2020	2030
PM <sub>2.5</sub> Reductions from Proposed Vehicle Standards (tons)	11,803	20,096

## *Costs*

### *Fuels*

The refinery model estimates that the proposed benzene standard would cost 0.13 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 would be 0.19 cents per gallon.) This per-gallon cost would result from an industry-wide investment in capital equipment of \$500 million to reduce gasoline benzene levels. This would amount to an average of \$5 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 Proposed Benzene Standard, 2020 and 2030**

	2020	2030
Fuels program	\$212,606,000	\$248,421,000

## *Vehicles*

We project that the average incremental costs associated with the new cold temperature standards would be less than \$1 per vehicle. We are not projecting changes to vehicle hardware as a result of the proposed standard. Costs would be 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 proposed 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 would streamline certification and be an “anti-backsliding” measure. It also would 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, the costs would be fully amortized by 2020.

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

	2020	2030
Vehicles program	\$0	\$0

### *Gas Cans*

Table 7 summarizes the projected near-term and long-term per unit average costs to meet the new emission standards. Long-term impacts on gas cans 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 gas can.

**Table 7 Estimated Average Gas Can Costs and Lifetime Fuel Savings**

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

We have also estimated aggregate costs and fuel savings which are projected to peak in 2013 at about \$51 million and then drop to about \$29 million once fixed costs are recovered. The aggregate annual costs and fuel savings estimates for 2020 and 2030 are provided in Table 8.

**Table 8. Estimated Aggregate Annual Cost and Fuel Savings for the Proposed Gas Can Standards, 2020 and 2030**

	2020	2030
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Gas Can Costs	\$31,767,000	\$38,724,000
Gas Can Fuel Savings	\$98,861,000	\$111,210,000

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### Cost Per Ton

We have calculated the cost per ton of HC, benzene, total MSATs, and PM emissions reductions associated with the proposed fuel, vehicle, and gas can programs. We have calculated the costs per ton using the net present value of the annualized costs of the program, including gas can 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 gas cans 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)**

	<b>Discounted Lifetime Cost per ton at 3%</b>	<b>Discounted Lifetime Cost per ton at 7%</b>	<b>Long-Term Cost per Ton in 2020</b>	<b>Long-Term Cost per Ton in 2030</b>
Vehicles	\$14	\$18	\$0	\$0
Gas Cans (without fuel savings)	\$230	\$250	\$160	\$180
Gas Cans (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)**

	<b>Discounted Lifetime Cost per ton at 3%</b>	<b>Discounted Lifetime Cost per ton at 7%</b>	<b>Long-Term Cost per Ton in 2020</b>	<b>Long-Term Cost per Ton in 2030</b>
Fuels	\$11,700	\$11,900	\$11,700	\$12,300
Vehicles	\$260	\$340	\$0	\$0
Gas Cans (without fuel savings)	\$27,800	\$30,900	\$20,000	\$21,600
Gas Cans (with fuel savings)	\$0	\$0	\$0	\$0
Combined (with fuel savings)	\$3,700	\$4,000	\$3,200	\$2,700

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

	<b>Discounted Lifetime Cost per ton at 3%</b>	<b>Discounted Lifetime Cost per ton at 7%</b>	<b>Long-Term Cost per Ton in 2020</b>	<b>Long-Term Cost per Ton in 2030</b>
Fuels	\$11,700	\$11,900	\$11,700	\$12,300
Vehicles	\$40	\$53	\$0	\$0
Gas Cans (without fuel savings)	\$1,800	\$2,000	\$1,300	\$1,400
Gas Cans (with fuel savings)	\$0	\$0	\$0	\$0
Combined (with fuel savings)	\$770	\$850	\$660	\$500

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

	<b>Discounted Lifetime Cost per ton at 3%</b>	<b>Discounted Lifetime Cost per ton at 7%</b>	<b>Long-Term Cost per Ton in 2020</b>	<b>Long-Term Cost per Ton in 2030</b>
Vehicles	\$620	\$820	\$0	\$0

### Benefits

This analysis projects significant benefits throughout the period from initial implementation of the proposed standards through 2030. When translating emission benefits to health effects and monetized values, however, we only quantify the PM-related benefits associated with the proposed cold temperature vehicle standards. The reductions in PM from the proposed cold temperature vehicle standards would 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 proposed 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 \$6.5 billion using a 3 percent discount rate and \$5.9 billion using a 7 percent discount rate, assuming a background PM threshold of 3  $\mu\text{g}/\text{m}^3$  in the calculation of PM mortality. There are no compliance costs associated with the proposed 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 proposal, which

include both the proposed gasoline container and vehicle fuel standards, are \$205 million in 2030 (in 2003\$, including fuel savings).

EPA's consistent approach has 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 has been shaped and supported by advice from EPA's technical peer review panel, the Science Advisory Board's Health Effects Subcommittee (SAB-HES). Note, however, that it is not certain whether there exists a threshold below which there would be no benefit to further reductions in PM<sub>2.5</sub>. We consider the impact of a threshold in the PM-mortality concentration response function in Section 12.6.1.1 of the RIA.

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

	Total Benefits <sup>a, b, c</sup> (billions 2003\$)	
	2020	2030
Using a 3% discount rate	\$3.4 + B	\$6.5 + B
Using a 7% discount rate	\$3.1 + B	\$5.9 + B

<sup>a</sup> 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<sup>3</sup>). 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 12.6.1.1 of the RIA.

<sup>b</sup> 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 13-2 of the RIA.

<sup>c</sup> 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 three significant digits for ease of presentation and computation.

### Economic Impact Analysis

We prepared a draft Economic Impact Analysis (EIA) to estimate the economic impacts of the proposed emission control program on the gas can, gasoline fuel, and light-duty vehicle markets. We estimate the net social costs of the proposed program for 2020 and 2030 are provided in Table 14 below. These estimates reflects the estimated costs associated with the gasoline, gas can, and vehicle controls and the expected fuel savings from better evaporative controls on gas cans. The results of the economic impact modeling performed for the gasoline fuel and gas can control programs suggest that the social costs of those two programs are expected to be about \$244.3 million in 2020 with consumers of these products expected to bear about 60 percent of these costs. We estimate fuel savings of about \$72.8 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 Proposed Program (Millions of 2003\$)**

	2020	2030
Net Social Costs	171.5	205.2

### Impact on Small Businesses

We prepared a Regulatory Flexibility Analysis, which evaluates the potential impacts of new standards and fuel controls on small entities. Before issuing our proposal, we analyzed the potential impacts 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 either are proposing or requesting comment on the Panel's recommendations. These provisions would reduce the burden on small entities that would be subject to this rule's requirements. We have proposed provisions that give small light-duty vehicle manufacturers, small gasoline refiners, and small gas can manufacturers several compliance options aimed specifically at reducing the burden on these small entities. In general, for vehicles and fuels, the options proposed are similar to small entity provisions adopted in prior rulemakings where EPA set vehicle and fuel standards. The options proposed for small gas can manufacturers are unique to this rulemaking since we are proposing gas can standards for the first time. The small entity provisions for the three industry sectors would reduce the burden on small entities that would be required to meet this proposed rule's requirements.

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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 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).<sup>1</sup> 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 ([www.epa.gov/otaq/toxics.htm](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 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.<sup>2</sup>

#### **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.<sup>A</sup> We also conducted a national-scale assessment for future years, which is discussed more fully in Chapters 2 and 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.<sup>B</sup>

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

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<sup>A</sup> 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).

<sup>B</sup> The discussion here considers risks other than those attributed to ambient levels of criteria pollutants.

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

<b>Cancer <sup>1</sup></b>	<b>Noncancer</b>
<b>National drivers <sup>2</sup></b>	<b>National drivers <sup>4</sup></b>
Benzene	Acrolein
<b>Regional drivers <sup>3</sup></b>	<b>Regional drivers <sup>5</sup></b>
Arsenic compounds	Antimony
Benzidine	Arsenic compounds
1,3-Butadiene	1,3-Butadiene
Cadmium compounds	Cadmium compounds
Carbon tetrachloride	Chlorine
Chromium VI	Chromium VI
Coke oven	Diesel PM
Ethylene oxide	Formaldehyde
Hydrazine	Hexamethylene 1-6-diisocyanate
Naphthalene	Hydrazine
Perchloroethylene	Hydrochloric acid
Polycyclic organic matter	Maleic anhydride
	Manganese compounds
	Nickel compounds
	2,4-Toluene diisocyanate
	Triethylamine

<sup>1</sup> 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.

<sup>2</sup> At least 25 million people exposed to risk >10 in 1 million

<sup>3</sup> 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

<sup>4</sup> At least 25 million people exposed to a hazard quotient > 1.0

<sup>5</sup> At least 10,000 people exposed to a hazard quotient > 1

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 in

risk 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.

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

<b>1999 NATA Risk Drivers</b>	<b>Percent Contribution from All Mobile Sources</b>	<b>Percent Contribution from On-road Mobile Sources</b>
Benzene	68%	49%
1,3-Butadiene	58%	41%
Formaldehyde	47%	27%
Acrolein	25%	14%
Polycyclic organic matter*	6%	3%
Naphthalene	27%	21%
Diesel PM and Diesel exhaust organic gases	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.

## **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<sup>3</sup> which was incorporated into the 1986 EPA risk guidance<sup>4</sup> and revised in 2005 in the EPA Guidelines for Carcinogen Risk Assessment and Supplemental Guidance for Assessing Susceptibility from Early-Life Exposure to Carcinogens.<sup>5</sup> 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*<sup>6</sup> (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  $1 \mu\text{g}/\text{m}^3$  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.<sup>7</sup> 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 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 all 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,<sup>8</sup> developmental toxicity,<sup>9</sup> neurotoxicity<sup>10</sup>; and reproductive toxicity.<sup>11</sup> For identification of hazards resulting from long-term (chronic) exposures, available data on different health endpoints and target organs are ordered and discussed, and the effects (and their attendant dose/exposure levels) are described. Particular attention is given 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 primary 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.<sup>12</sup> 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.<sup>13</sup>

### **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.<sup>14</sup> 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.<sup>15</sup> 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.

### 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.<sup>16</sup> 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 inhalation occupational exposure to benzene has been shown to cause cancers of the hematopoietic (blood cell) system in adults. Among these are acute nonlymphocytic leukemia,<sup>C</sup> and chronic lymphocytic leukemia.<sup>17,18</sup> A doubling of risk for acute nonlymphocytic leukemia and myelodysplastic syndrome was found at average exposure levels under 10 ppm (32 mg/m<sup>3</sup>).<sup>19</sup> 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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<sup>C</sup> 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 cells that are responsible for the 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<sup>20, 21</sup> and increased proliferation of mouse bone marrow cells.<sup>22, 23</sup>

The latest assessment by EPA places the excess risk of developing acute nonlymphocytic leukemia from inhalation exposure to benzene at  $2.2 \times 10^{-6}$  to  $7.8 \times 10^{-6}$  per  $\mu\text{g}/\text{m}^3$ . In other words, there is a risk of about two to eight excess leukemia cases in one million people exposed to  $1 \mu\text{g}/\text{m}^3$  of benzene over a lifetime.<sup>24</sup> This range of unit risks are 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 5<sup>th</sup> and 95<sup>th</sup> percentile values are about a factor of 5 lower and higher than the best fit value. The upper end of the MLE range 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.<sup>25</sup> Since the mode of action for benzene carcinogenicity is unknown, the current cancer unit risk estimate assumes linearity of the low-dose response. 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. They support the inference that cancer risks are as high, or higher than the estimates provided in the existing EPA assessment.<sup>26</sup> 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 ( $80,000 \mu\text{g}/\text{m}^3$ ).<sup>27</sup> 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.<sup>28</sup> 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".<sup>29, 30</sup> 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 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.

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.<sup>31,32</sup> Data from animal studies have shown benzene exposures result in damage to the hematopoietic (blood cell formation) system during development.<sup>33, 34, 35</sup> Also, key changes related to the development of childhood leukemia occur in the developing fetus.<sup>36</sup> 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.<sup>37</sup> 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.<sup>38,39</sup> People with long-term occupational exposure to benzene have experienced harmful effects on the blood-forming tissues, especially in 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,<sup>D</sup> a condition characterized by decreased numbers of circulating erythrocytes (red blood cells), leukocytes (white blood cells), and thrombocytes (blood platelets).<sup>40, 41</sup> 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.<sup>42, 43</sup> The most sensitive noncancer effect observed in humans, based on current data, is the depression of the absolute lymphocyte count in blood.<sup>44, 45</sup>

EPA's inhalation reference concentration (RfC) for benzene is 30  $\mu\text{g}/\text{m}^3$ . 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 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

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<sup>D</sup> 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 vertebra, sternum, ribs, and pelvis. 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.

hematological endpoints that are triggered at occupational exposures of less than 5 ppm (about 16 mg/m<sup>3</sup>)<sup>46</sup> and, more significantly, at air levels of 1 ppm (about 3 mg/m<sup>3</sup>) or less among genetically susceptible populations.<sup>47</sup> 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.<sup>48</sup> 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<sup>3</sup> 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.<sup>49, 50</sup> 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<sup>-5</sup> per µg/m<sup>3</sup> (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<sup>3</sup> 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.<sup>51</sup> 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. Confidence in the excess cancer risk estimate of 0.08 per ppm is moderate.<sup>52</sup>

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.<sup>53</sup> 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<sup>3</sup>). 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.<sup>54</sup> Recently released research conducted by the National Cancer Institute (NCI) found an increased risk of nasopharyngeal cancer among workers exposed to formaldehyde.<sup>55, 56</sup> 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.<sup>57</sup> 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.”

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.<sup>58, 59, 60</sup> CIIT’s risk assessment of formaldehyde incorporated mechanistic and dosimetric information on formaldehyde. The risk assessment analyzed carcinogenic risk from 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.<sup>61</sup> 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).<sup>62</sup> 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.

#### 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 moderately toxic by inhalation.<sup>63</sup> Based on nasal tumors in rodents, the upper confidence limit estimate of a lifetime extra cancer risk from continuous acetaldehyde exposure is about  $2.2 \times 10^{-6}$  per  $\mu\text{g}/\text{m}^3$ . In other words, it is estimated that about 2 persons in one million exposed to  $1 \mu\text{g}/\text{m}^3$  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.<sup>64, 65</sup> Data from these studies showing degeneration of the olfactory epithelium were found to be sufficient for EPA to develop an RfC for acetaldehyde of  $9 \mu\text{g}/\text{m}^3$ . 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.<sup>66</sup> 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.<sup>67</sup> Some asthmatics have been shown to be a sensitive subpopulation to decrements in functional expiratory volume (FEV1 test) and bronchoconstriction upon acetaldehyde inhalation.<sup>68</sup>

#### 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.<sup>69</sup> 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.<sup>70</sup> The Agency has developed an RfC for acrolein of 0.02  $\mu\text{g}/\text{m}^3$  and an RfD of 0.5  $\mu\text{g}/\text{kg}\cdot\text{day}$ .<sup>71</sup> 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.<sup>72</sup>

### **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 (External Review Draft, IRIS Reassessment of the Inhalation Carcinogenicity of Naphthalene, U. S. EPA. <http://www.epa.gov/iris>) of a reassessment of the inhalation carcinogenicity of naphthalene.<sup>73</sup> The draft reassessment completed external peer review in 2004 by Oak Ridge Institute for Science and Education.<sup>74</sup> Based on external comments, additional analyses are being considered. California EPA has also released a new risk assessment for naphthalene with a cancer unit risk estimate of  $3 \times 10^{-5}$  per  $\mu\text{g}/\text{m}^3$ .<sup>75</sup> 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.<sup>76</sup> Noncancer data on hyperplasia and metaplasia in nasal tissues form the basis of the inhalation RfC of 3  $\mu\text{g}/\text{m}^3$ .<sup>77</sup> A low to medium confidence rating was given to this RfC, in part because it cannot be said with certainty that this RfC will be protective for hemolytic anemia and cataracts, the more well-known human effects from naphthalene exposure.

### **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<sup>78</sup>. 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<sub>2u</sub>-globulin protein and hyaline droplet accumulation in the proximal tubules of the kidneys<sup>79</sup>. These effects were not seen in the female rat test subjects. 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.<sup>80</sup> 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.<sup>81</sup>

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  $1 \times 10^3$  ug/m<sup>3</sup> 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.

#### **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.<sup>82</sup>

Under the 2005 Guidelines for Carcinogen Risk Assessment, there is inadequate information to assess the carcinogenic potential of n-hexane.<sup>83</sup> 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<sup>3</sup> for n-hexane exposure.<sup>84</sup> 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 and mucous membranes. Nervous system effects include dizziness, giddiness, slight nausea, and headache in humans.

#### **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."<sup>85</sup> 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."<sup>86</sup> 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<sup>87</sup>. These effects are cited as the basis for EPA's current inhalation reference concentration (RfC) of 3 mg/m<sup>3</sup> 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<sup>3</sup> 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.<sup>88, 89</sup>

### **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 and animal studies have generally been negative.<sup>90</sup>

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.<sup>91</sup>

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<sup>3</sup> 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.<sup>92</sup> 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.<sup>93</sup>

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.<sup>94</sup> 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<sup>3</sup> 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.<sup>95</sup>

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.

### **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. Many of the compounds included in the class of compounds known as POM are classified by EPA as probable human carcinogens based on animal data. One of these compounds, naphthalene, is discussed separately 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.<sup>96</sup> These studies are discussed later in Chapter 3.

### **1.3.15. Diesel Particulate Matter (DPM) and Diesel Exhaust Organic Gases (DEOG)**

In EPA's Diesel Health Assessment Document (HAD),<sup>97</sup> 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. The possible risk range analysis was developed 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.

The acute and chronic exposure-related effects of 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.<sup>98, 99, 100, 101</sup> The RfC is  $5 \mu\text{g}/\text{m}^3$  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 Diesel HAD also briefly summarizes health effects associated with ambient PM and the EPA's annual National Ambient Air Quality Standard (NAAQS) of  $15 \mu\text{g}/\text{m}^3$ . 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 RfC is not meant to say that  $5 \mu\text{g}/\text{m}^3$  provides adequate public health protection for ambient  $\text{PM}_{2.5}$ . In fact, there may be benefits to reducing diesel PM below  $5 \mu\text{g}/\text{m}^3$  since diesel PM is a major contributor to ambient  $\text{PM}_{2.5}$ .

## **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, in contrast to diesel exhaust, which has been evaluated in IRIS. However, there is 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.<sup>102</sup> Their results demonstrate that emissions from gasoline engines are mutagenic and can induce inflammation and have cytotoxic effects. 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.<sup>103</sup> 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<sub>2.5</sub>.<sup>104</sup> 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).

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 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 in 2006. Some source apportionment studies show gasoline and diesel PM can result in larger contributions to ambient PM than predicted by EPA emission inventories.<sup>105,106</sup> 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 that is formed 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.<sup>107,108,109,110,111,112,113</sup>

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 (and probably higher molecular weight non-aromatic hydrocarbons).

Also, there is strong indication that benzene forms SOA. In other ongoing research, EPA scientists are investigating SOA formation from benzene, which has been recently detected for the first time in European smog chamber experiments.<sup>114</sup>

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 NO<sub>x</sub>, 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  $\beta$ -caryophyllene, the latter three of which are emitted by vegetation. The tracers provide a means to identify the hydrocarbon SOA precursors present in ambient PM<sub>2.5</sub> samples and show promise for estimating their contributions to the organic carbon concentrations.

The results of a recent EPA field study, not yet 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  $\mu\text{g}/\text{m}^3$  during smog events in July/August. The level of toluene-derived SOA is the lowest in the November-February time frame (0.2  $\mu\text{g}/\text{m}^3$ ) with intermediate levels in the other months. Currently, EPA is conducting similar analyses of ambient PM<sub>2.5</sub> 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, which along with most of the other state of the science air quality models, predict low levels of aromatic SOA, need to be modified.

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 over-estimate 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. 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.

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: 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 rule proposal, because of the lead time required to conduct air quality, exposure, and risk analyses. Thus, these inventories do not include revised estimates of emissions at cold temperature in vehicles, emissions from portable fuel containers, or revisions in the gasoline distribution inventory to reflect changes made for the 2002 National Emissions Inventory. 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**

##### **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).<sup>1</sup> MOBILE6.2 uses emission factors obtained through the analysis of emissions data collected from vehicle emission research<sup>2</sup>. 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. This is the same approach used in the Clean Air Interstate Air Quality (CAIR) rule.<sup>3</sup>

Analysis of vehicle emission certification data submitted to EPA as part of requirements to comply with requirements for cold temperature carbon monoxide (CO) standards by vehicle manufacturers, as well as surveillance testing data from the California Air Resources Board, indicated that MOBILE6.2 was substantially underestimating start emission at cold temperatures for Tier 1 and later vehicles. This data was supplemented with test data collected by the Office of Transportation and Air Quality (OTAQ) at Southwest Research Institute (SwRI)<sup>4</sup> 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.<sup>5</sup>

EPA cold CO certification data was paired as 20 °F versus 75 °F tests per engine family to calculate the additional hydrocarbon (HC) emissions due to lower temperature. The bag emission data where available indicated that at 20 °F, as in the standard FTP at 75 °F, 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 °F emission standard requirement and that data, also supplied by manufacturers, reflects the same trend over the smaller temperature difference (Table 2.1.-2).

The testing done by OTAQ 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 °F. A summary of the hydrocarbon data is found in Table 2.1.-3.

<b>Table 2.1.-1. FTP HC Data From Federal Certified Vehicles (grams per mile)</b>					
		75°		20°	
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

<b>Table 2.1.-2. FTP HC Emissions Data from California Certified Vehicles (grams per mile)</b>						
		75°		50°		
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

<b>Table 2.1.-3. SwRI FTP (Bag 1 Only) Emissions from Four Tier 2 Vehicles</b>			
Temperature in °F	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 °F	1	14.446	32.699

MOBILE6.2 currently has engine start emission factors based on 75° 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<sup>6</sup>. 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 °F 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 °F from the FTP emissions at 75 °F using the certification and SwRI test data. For emissions at temperature points where data was not available (i.e., 50 °F for Tier 2 vehicles), linear interpolation between the 20 and 75 °F 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 results in extremely high and unrealistic emission rates. Therefore we have used the MOBILE6.2 estimate of FTP emissions at 20 °F for model year 2005 high-emitting vehicles in calendar year 2005 as 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.

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

<b>Table 2.1.-5. Tier 2 High Emitter HC Adjustment Based on 2005 Model Year MOBILE6.2 Results in Calendar Year 2005</b>				
Temperature °F	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 proposed 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. No modification to any other components of NMIM is needed to calculate these inventories.

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

Index	Tier 2 Cars & Light Trucks <6,000 lbs GVWR By Model Year	°F			Phase In Fraction
		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
Index	Tier 2 Light Trucks >6,000 lbs GVWR By Model Year	°F			Phase In Fraction
		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 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 NONROAD 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) 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. 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.<sup>7</sup>

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.

Six states (California, Delaware, Maine, Maryland, New York, and Pennsylvania) have implemented controls on the design of PFCs that will reduce HC emissions. The California program began in 2001. The other states started their programs in 2005. Additionally, seven other states plus the District of Columbia (Connecticut, Massachusetts, New Jersey, Rhode Island, Texas, Vermont, Virginia, and Washington DC) are also planning to adopt the California PFC program.

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 gas cans assuming the proposed rules are implemented, we made the following three changes to our inventory estimates:

1. Since the proposed rule makes it unlikely for a newly designed gas can 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 13 states plus the District of Columbia that

are adopting the California gas can rules already had this change applied. So, this affected the VOC emissions from only gas cans in the other 37 states.)

2. This proposed rule also produces changes (to the design of the individual gas cans) that are expected to reduce the spillage by 50 percent (when these gas cans 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 gas cans in the remaining 37 states contributed to our estimated reductions of spillage.
3. Finally, the proposed rule includes a maximum emission rate of 0.3 grams per gallon per day for the new gas cans. We used this emission standard to estimate the total permeation plus evaporative emissions from each newly designed gas can. Only California has adopted (or plans to adopt) this requirement. Thus, the effect of this proposed 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.

### **2.1.2 Emission Reductions of Proposed Controls**

*Light-Duty Gasoline Vehicles* -- We are proposing 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. 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 to generate county and nationwide inventories of the control case. When the standard is fully phased in we expect a 60 % reduction in start emissions in gasoline fuel vehicles that have a gross vehicle weight rating (GVWR) of less than or equal to 6000 lbs and a 30 % in 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 2.1-7. PFC Emissions (Tons per Year) by Source Type (for 1990)**

	Refilling PFC at Pump			Refueling Equipment			
<u>State</u>	<u>Vapor Displ</u>	<u>Spillage</u>	<u>Spillage During Transport</u>	<u>Vapor Displ</u>	<u>Spillage</u>	<u>Permeation Plus Evaporation</u>	<u>Totals by State</u>
AL	159.6	13.2	395.5	159.6	871.3	3,572.3	5,171.4
AK	17.5	1.4	46.8	17.5	83.3	548.0	714.6
AZ	273.4	23.5	655.2	273.4	1,665.4	2,910.4	5,801.2
AR	88.3	7.0	218.5	88.3	428.9	2,467.9	3,299.0
CA	1,602.2	136.0	3,815.5	1,602.2	9,452.1	21,553.8	38,161.8
CO	209.9	17.0	485.9	209.9	1,174.2	3,025.9	5,123.0
CT	148.9	12.8	367.9	148.9	884.4	2,230.0	3,793.0
DE	33.6	3.0	87.8	33.6	210.5	450.8	819.5
DC	5.7	0.5	18.2	5.7	37.1	176.1	243.3
FL	817.5	72.2	2,026.0	817.5	4,998.5	10,172.5	18,904.2
GA	305.6	29.2	838.6	305.6	1,971.4	4,107.6	7,558.0
HI	51.9	3.9	110.6	51.9	273.4	972.6	1,464.3
ID	43.6	4.6	135.9	43.6	301.8	663.6	1,193.0
IL	383.4	39.7	1,148.0	383.4	2,673.0	4,385.3	9,012.8
IN	213.7	20.7	606.1	213.7	1,406.0	2,981.2	5,441.4
IA	105.7	9.5	283.9	105.7	625.7	1,876.5	3,007.0
KS	93.7	9.2	269.7	93.7	614.6	1,620.4	2,701.3
KY	107.4	10.2	311.8	107.4	656.2	2,233.4	3,426.3
LA	132.1	11.0	339.7	132.1	694.8	3,697.3	5,006.9
ME	47.7	4.1	125.6	47.7	285.5	979.6	1,490.3
MD	248.2	21.5	604.5	248.2	1,521.8	2,950.2	5,594.5
MA	230.9	20.1	584.2	230.9	1,372.7	3,390.3	5,829.1
MI	452.7	33.4	993.3	452.7	2,253.8	10,004.8	14,190.8
MN	155.6	14.8	444.2	155.6	940.8	2,657.3	4,368.2
MS	70.3	6.5	204.2	70.3	412.9	1,852.0	2,616.3
MO	193.4	18.0	536.6	193.4	1,182.5	3,161.3	5,285.1
MT	23.7	2.3	72.7	23.7	143.5	511.9	777.7
NE	53.9	5.6	166.4	53.9	367.6	786.8	1,434.1
NV	81.0	7.8	217.1	81.0	550.7	709.2	1,646.8
NH	51.4	4.2	125.7	51.4	283.1	939.0	1,454.8
NJ	351.5	31.0	889.5	351.5	2,093.1	5,136.2	8,852.8
NM	56.3	5.0	147.9	56.3	338.8	1,019.5	1,623.8
NY	479.6	45.6	1,339.2	479.6	2,918.2	7,196.1	12,458.3
NC	368.1	28.6	828.9	368.1	1,937.1	6,327.8	9,858.5
ND	17.7	1.8	53.6	17.7	105.1	355.5	551.3
OH	523.5	42.1	1,223.4	523.5	2,886.9	8,553.9	13,753.4
OK	124.9	10.0	304.0	124.9	669.3	3,094.2	4,327.4
OR	165.0	13.3	383.2	165.0	915.1	2,601.9	4,243.4
PA	396.8	39.1	1,164.9	396.8	2,670.4	6,988.9	11,656.9
RI	29.9	3.2	92.9	29.9	217.2	367.6	740.6

	Refilling PFC at Pump		Refueling Equipment	Refueling Equipment			
State	Vapor Displ	Spillage	Spillage During Transport	Vapor Displ	Spillage	Permeation Plus Evaporation	Totals by State
SC	161.1	14.1	407.3	161.1	974.5	2,519.7	4,237.8
SD	18.8	1.9	59.4	18.8	118.3	359.8	577.1
TN	181.5	16.6	496.5	181.5	1,086.4	3,789.5	5,751.9
TX	743.1	68.1	1,968.7	743.1	4,654.3	11,008.5	19,185.9
UT	63.6	6.5	192.0	63.6	419.2	941.6	1,686.4
VT	21.8	2.0	60.7	21.8	134.2	380.2	620.7
VA	295.4	26.2	752.9	295.4	1,845.0	4,211.6	7,426.5
WA	245.8	20.5	595.4	245.8	1,411.9	3,627.0	6,146.4
WV	51.8	4.4	141.9	51.8	279.8	1,502.9	2,032.6
WI	190.2	16.9	505.2	190.2	1,118.3	3,547.8	5,568.4
WY	14.5	1.4	44.3	14.5	90.5	269.1	434.4
50-State	10,903.6	961.1	27,887.6	10,903.6	65,221.2	171,387.4	287,264.5

**Table 2.1.-8. Proposed 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 °F FTP Emission Standard for Non-Methane Hydrocarbons.**

Year	Tons Without Standard	Tons With Standard	Reduction
1999	4,899,891	N. A.	N.A.
2010	2,936,905	2,790,971	145,934
2015	2,625,076	2,305,203	319,874
2020	2,556,751	2,020,267	536,484
2030	2,889,269	1,985,830	913,439

These benefits are primarily realized in regions of the country with colder winter temperatures. Table 2.1.-10 shows the impacts on a State by State basis in year 2030.

Test data show that the proposed 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 pyrolyzed 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<sub>2.5</sub>. 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<sub>2.5</sub> could be attributed to cold start light-duty gasoline vehicle emissions.<sup>8</sup>

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 in this proposal, 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.<sup>9</sup> 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.

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

	Reference Case Tons	Control Case Tons	Reduction in Tons	Percent Reduction
AL	49,848	38,155	11,692	23
AK	11,377	6,130	5,247	46
AZ	50,563	38,008	12,556	25
AR	28,603	21,104	7,499	26
CA	249,670	178,119	71,552	29
CO	59,856	38,363	21,493	36
CT	28,578	17,443	11,135	39
DE	7,573	4,883	2,690	36
DC	3,462	2,329	1,133	33
FL	110,729	100,275	10,454	9
GA	99,741	75,155	24,586	25
HI	6,979	6,820	158	2
ID	20,716	13,068	7,648	37
IL	117,780	73,217	44,563	38
IN	87,191	57,078	30,113	35
IA	36,930	23,614	13,315	36
KS	34,192	22,590	11,602	34
KY	49,849	33,028	16,821	34
LA	35,684	28,657	7,026	20
ME	17,412	10,288	7,124	41
MD	49,383	31,758	17,625	36
MA	49,937	30,477	19,460	39
MI	141,535	88,464	53,072	37
MN	87,180	52,242	34,938	40
MS	23,418	17,721	5,697	24
MO	73,449	49,197	24,252	33
MT	17,728	10,506	7,222	41
NE	23,655	15,038	8,617	36
NV	26,445	18,852	7,593	29
NH	18,650	11,440	7,210	39
NJ	57,554	36,810	20,744	36
NM	27,037	19,911	7,126	26
NY	155,448	97,923	57,525	37
NC	89,150	64,947	24,202	27
ND	12,087	7,041	5,045	42
OH	119,496	77,175	42,321	35
OK	44,642	32,578	12,064	27
OR	53,308	34,494	18,814	35
PA	116,128	74,186	41,942	36
RI	7,615	4,729	2,886	38
SC	46,158	33,346	12,812	28
SD	12,261	7,441	4,820	39
TN	67,115	47,317	19,799	29

	Reference Case Tons	Control Case Tons	Reduction in Tons	Percent Reduction
TX	176,753	146,569	30,184	17
UT	28,151	17,576	10,575	38
VT	11,451	6,993	4,458	39
VI	79,427	54,082	25,345	32
WA	72,891	44,616	28,275	39
WV	16,139	10,259	5,881	36
WI	77,447	47,205	30,242	39
WY	10,900	6,614	4,286	39

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

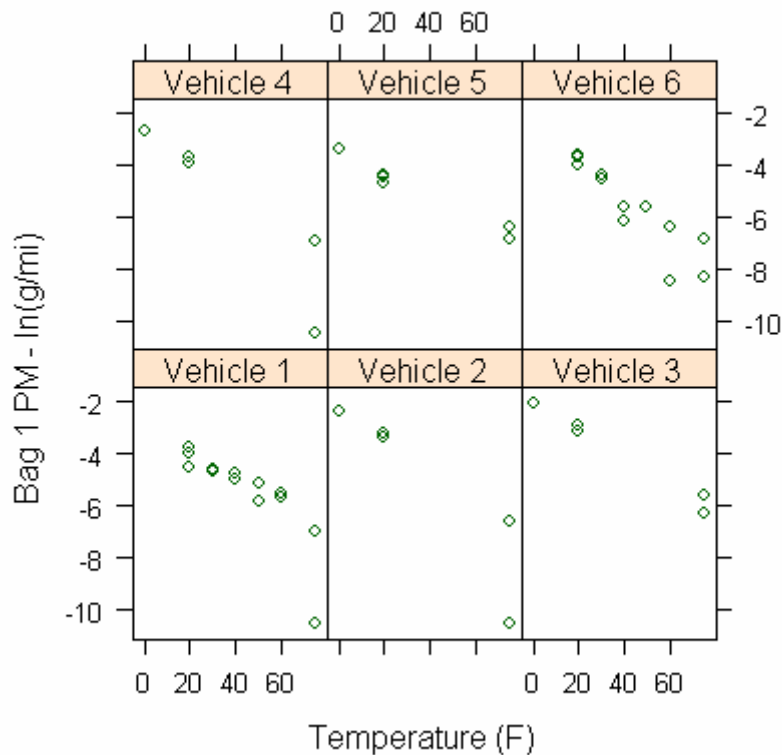
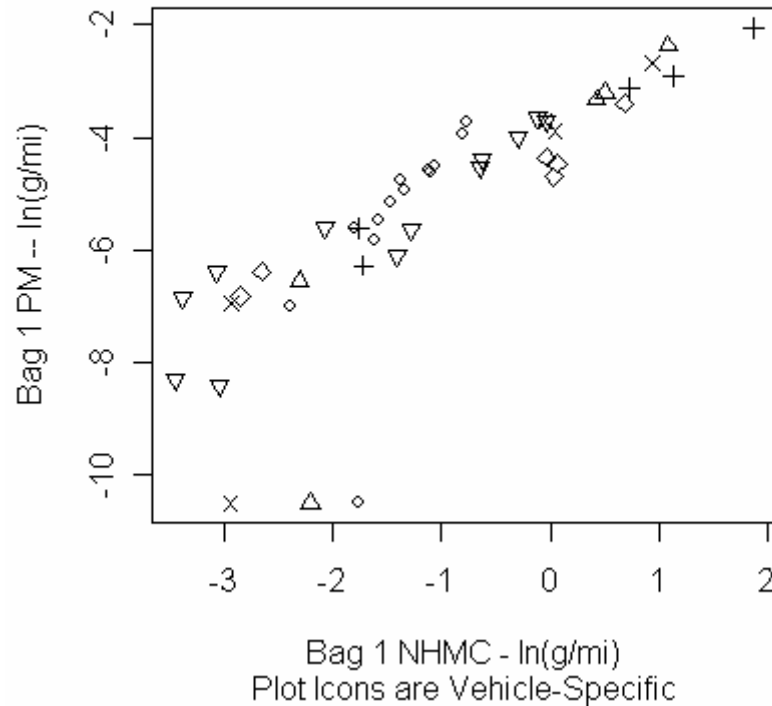


Figure 2.1.-2 illustrates the relationship between FTP Bag 1 NMHC and PM emission factors in this test program. Lower temperature tests are found to the upper right corner, corresponding to elevated emissions of both NMHC and PM. The symbol used for each data point represents the different vehicles in 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.<sup>10</sup> 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:

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

Here,  $\mathbf{Y}$  is a matrix of dependent variables (emission factors);

$\boldsymbol{\mu}$  is the intercept term or “grand mean”;

$\mathbf{b}$  is the change in emission factor associated with discrete testing temperatures;

$\boldsymbol{\tau}$  is the vehicle effect, normally distributed around zero;

$\mathbf{e}$  is the random error term (normally distributed).

Tests in which temperature was treated as a continuous variable were also employed.

Overall, the  $\mathbf{b}$  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  $\mathbf{b}$  term became insignificant when it was allowed to vary randomly by vehicle. In addition, because the proposed 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 7,037 tons in 2015, 11,803 tons in 2020 and 20,096 tons in 2030. These calculations provide initial evidence that the potential public health impacts of this proposal are substantial.

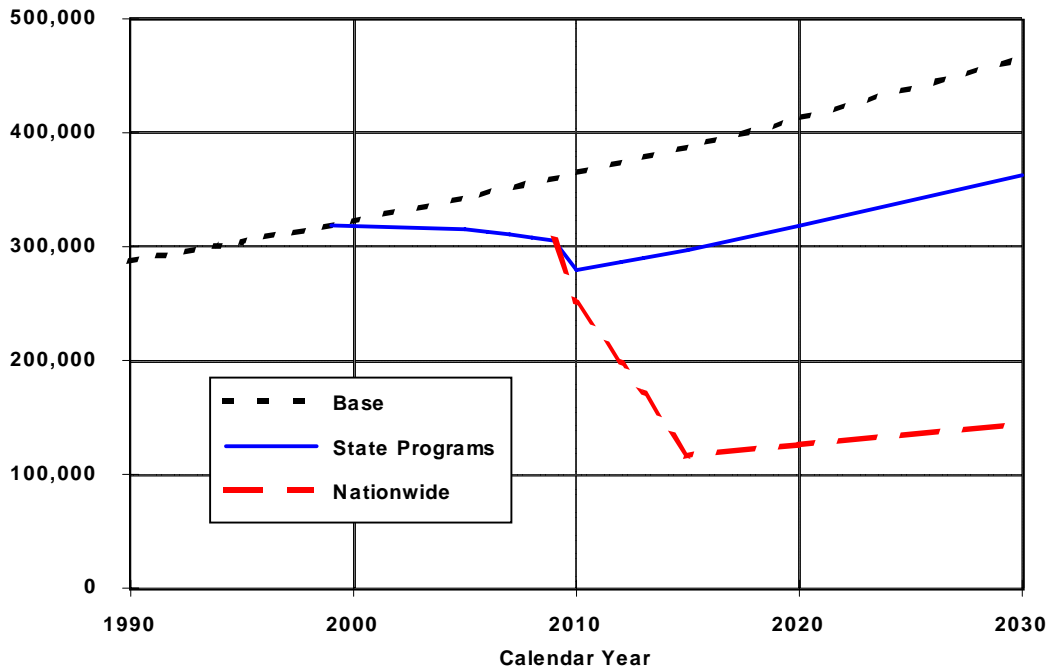
In a subsequent test program in which the feasibility of the NMHC standards in today's proposal was demonstrated, the test vehicle exhibited substantial reductions in PM emission as well. These PM emission reductions at 20° F were of similar magnitude as those predicted by the above calculation. However, in that test program, the average PM/NHMC ratio was slightly smaller than in the SwRI test program. The vehicle tested in the feasibility program 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. The feasibility program was a "proof of concept" type study that did not have the ability to fully explore ideal control coordination and sizing of the emission control system. PM reductions would very likely have been even greater if this coordination was possible. 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 SwRI test program, 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).

*Portable Fuel Containers* -- The portable fuel container controls proposed in this rule will also reduce emissions of hydrocarbons. As noted in Section 2.1.1.2, thirteen states plus the District of Columbia have adopted controls on PFCs independent of the controls proposed in this RIA. 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,
- a scenario in which only those 13 states plus DC have implemented PFC controls illustrated with the solid (blue) line, and
- a scenario in which the PFC controls proposed in this RIA 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 proposed control program to a reference case scenario that includes only State level controls.

**Table 2.1.-11. Nationwide Annual Gas Can VOC Emissions (tons)**

<b>Calendar Year</b>	<b>With <u>NO</u> EPA PFC Controls</b>	<b>With EPA PFC Controls</b>	<b><u>Reduction</u></b>
1999	318,596	NA	NA
2007	310,744	NA	NA
2010	279,374	250,990	28,384
2015	296,927	116,431	180,496
2020	318,384	125,702	192,683
2030	362,715	144,634	218,080

### 2.1.3 Strengths and Limitations of Criteria Pollutant Inventories

*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.<sup>11,12</sup>

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.

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 20°F 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.

*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 rest of the country might not be exactly like California (relative to PFCs), 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.<sup>13</sup> 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 rule are discussed in detail in the EPA Technical Report, “National Scale Modeling of Air Toxics for the Mobile Source Air Toxics Rule; Technical Support Document,” Report Number EPA-454/R-06-002. In addition, the reference case emissions modeling (i.e., emissions modeling without proposed controls) has been externally peer-reviewed in a journal article currently in press.<sup>14</sup> All underlying data and summary statistics are included in the docket for this rule. The following sections summarize the methods used to develop these inventories and present 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 2007 and 2010 in order to better assess emission trends over time. Inventories for 1990 and 1996 which are methodologically consistent with later year inventories are also discussed to put emission trends for later years into perspective. Control case modeling was done for proposed fuel benzene standards in 2015, 2020 and 2030. Inventories which included revised estimates of cold temperature hydrocarbon and air toxics emissions and portable fuel container emissions were not completed in time to be included in this modeling. 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

For modeling calendar year 1999, we used the 1999 National Emissions Inventory (NEI), final version 3.<sup>15</sup> This inventory was also used in the 1999 National-Scale Air Toxics Assessment. This inventory estimated highway vehicle emissions using the MOBILE6.2 emission factor model.<sup>16, 17</sup> The 1999 NEI includes vehicle refueling emissions as part of the stationary source inventory; thus, in developing inventories for air quality, exposure and risk modeling these emissions were treated as stationary sources.

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 within the MOBILE6.2 scenario descriptions. These 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.<sup>A</sup> Since these fuel parameters are area-specific, EPA developed county-level inputs for each of these parameters by season. 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 surveys. Documentation for the NEI 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/>

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 files 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.

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<sup>A</sup> E200 and E300, represent the percentage of vapor that gasoline produces at 200 and 300 °F, respectively.

**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

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 gasoline and gasoline oxygenated with MTBE or ethanol, separate ADDITIONAL HAPS input files 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). The documentation for the NEI provides more information on the development of HAP inventories using this command. ADDITIONAL HAPs inputs (including PAHs) for the 1999 NEI, final version 3 can be obtained at the same link given above for the final 1999 NEI fuel parameter files.

Although fuel parameter data were prepared for only two seasons (summer and winter), four seasonal scenarios were developed. The months corresponding to each season were selected to best coincide with seasonal fuel requirements. Summer fuel parameters were applied in the fall scenarios and winter fuel parameters were applied in the spring scenarios.

The number of MOBILE6.2 input files required to model all counties in a State were determined based on unique combinations of control programs and fuel parameters.

For counties where there was more than one fuel type sold, such as reformulated gasolines with MTBE and ethanol, two sets of MOBILE6.2 input files were developed, and resulting emission factors were weighted by gasoline market shares to derive overall county-level emission factors. The county level emission factors were multiplied by VMT from the Highway Performance Monitoring System (HPMS), as described in the documentation for the 1999 NEI. It should also be noted that California provided its own air toxic emissions estimates for 1999, which replaced those generated by EPA.

To develop projection year inventories for highway vehicles, we used NMIM.<sup>18, 19</sup> 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. Projection year fuel parameters were developed using results of several refinery modeling analyses conducted to assess impacts of fuel control programs on fuel properties.<sup>20, 21, 22</sup>

The projection year fuel parameters were calculated by applying adjustment factors to the base year parameters.<sup>23</sup> In addition, NMIM uses monthly rather than seasonal fuel parameters, and parameters for spring and fall months are estimated by interpolating from summer and winter data. 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). The database used for this assessment assumes no Federal ban on MTBE, but does include State bans. Also, it did not include the renewable fuels mandate in the recent Energy Policy Act. Vehicle miles traveled used in this assessment were those developed for the Clean Air Interstate Air Quality Rule (CAIR).<sup>24</sup>

NMIM 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:

$$PF_{20XX} = \frac{E_{NMIM, 20XX}}{E_{NMIM, 1999}} \quad (1)$$

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. NMIM results were provided for the following emission types – exhaust, non-refueling evaporative and refueling evaporative.  $E_{NMIM}$  was computed as the sum of non-refueling evaporative and exhaust emissions for pollutants with both an exhaust and evaporative emissions component (benzene, 2,2,4-trimethylpentane, naphthalene, toluene, xylenes, n-hexane, and ethylbenzene). Separate ratios were developed for each vehicle class, pollutant and county combination. In addition, separate ratios were developed for vehicle refueling, and these ratios were used to project refueling emissions in the stationary source inventory.

In cases where the 1999 NEI included aggregated or different categories other than those in NMIM, we aggregated NMIM results prior to applying ratios. For example, California reported heavy duty diesel vehicle (HDDV) emissions in the 1999 NEI as an aggregated HDDV “total” vehicle type rather than the specific HDDV classes (e.g., Class 2B, Class 3, 4, and 5). Thus, we aggregated NMIM HDDV results for California in order to apply a projection ratio to the HDDV “total” emissions. In the event that the NEI had HAPs not covered by NMIM (resulting from a state or local agency inventory submission), we developed ratios based on NMIM PM or VOC results.

For years 2015, 2020, and 2030, inventories were developed that reflected the impacts of the fuel benzene standard proposed in this rule. These control case inventories included the following pollutants: benzene, 1,3-butadiene, formaldehyde, acetaldehyde and acrolein. In MOBILE6.2, emissions of other pollutants are not affected by changes in fuel benzene or aromatics levels.

To develop these inventories, NMIM was rerun with revised gasoline fuel parameter inputs for fuel benzene and aromatics levels. These inputs were revised based on refinery modeling done for the rule. As part of the refinery modeling, average fuel properties under the new standards 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 proposed 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. The refinery modeling also indicated that the reduction in fuel benzene levels would result in small decreases in aromatics levels as well.<sup>25</sup> Thus aromatics levels were adjusted using the additive factors calculated as follows:

$$\text{Additive Factor} = 0.77 * (\text{BZ}(\text{control}) - \text{BZ}(\text{ref})) \quad (2)$$

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 proposed 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 the same data files used in original reference case runs. Output included total exhaust and non-refueling evaporative emissions, exhaust emissions, non-refueling evaporative emissions, and refueling evaporative emissions. Projection factors for each emissions type, by gasoline vehicle class, county and pollutant, were calculated as follows:

$$PF_{20XX} = \frac{E_{NMIM\ Control20XX}}{E_{NMIM\ Reference20XX}} \quad (3)$$

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

		<b>PADD 1</b>	<b>PADD 2</b>	<b>PADD 3</b>	<b>PADD 4</b>	<b>PADD 5</b>	<b>Calif.</b>
<b>Reference Case</b>	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%
<b>Control Case</b>	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%
<b>Multiplicative Factor</b>	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

PF<sub>20XX</sub> is the projection factor for 2015, 2020, or 2030, and E<sub>NMIM Control20XX</sub> is the NMIM emissions for the control scenario. It includes exhaust and non-refueling evaporative emissions, but not refueling emissions. E<sub>NMIMReference20XX</sub> is the NMIM reference case MSAT emissions, and includes exhaust and non-refueling evaporative emissions, but not refueling emissions. Although vehicle refueling was estimated as part of the stationary source inventory, changes in MOBILE6.2 vehicle refueling emissions with fuel benzene

control were used to adjust the reference case refueling inventory to obtain the control case inventory.

#### 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 modeling calendar year 1999, we used the 1999 National Emissions Inventory (NEI), final version 3. This inventory used NONROAD2004, which was also used in the recent Clean Air Nonroad Diesel Rule.<sup>26</sup> 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. The projection of the portion of the nonroad inventory included in the NONROAD model followed a similar methodology as for the on-road. Projection factors were developed using the 1999 and future year NMIM runs and were applied to nonroad categories in the 1999 NEI. Retrospective inventories for nonroad equipment in 1990 and 1996 are available at the same link given for the 1990 and 1996 highway inventories and are described in the documentation for the 1999 NEI.

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 emissions of nonroad gasoline equipment were proportional to changes in highway light duty gasoline vehicle exhaust emissions, and changes in county level evaporative emissions of nonroad gasoline equipment were proportional to changes in highway light duty gasoline vehicle evaporative (refueling and non-refueling) emissions:

$$PF_{nonroad\ exhaust}_{20XX} = \frac{ELDGV_{exhaust\ NMIM\ Control\ 20XX}}{ELDGV_{Exhaust\ NMIM\ Reference\ 20XX}} \quad (4)$$

$$PF_{nonroad\ evap}_{20XX} = \frac{ELDGV_{evap\ NMIM\ Control\ 20XX}}{ELDGV_{Evap\ NMIM\ Reference\ 20XX}} \quad (5)$$

#### 2.2.1.1.3 Commercial Marine Vessels, Locomotives and Aircraft

These source sectors will not be impacted by the fuel benzene standards being proposed in this rule.

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.<sup>27</sup> More detailed information on methods used to develop air toxic inventories for these sectors can be found in the documentation for the 1999 NEI.<sup>28</sup> 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.<sup>29</sup> 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 Stationary Sources

Stationary source estimates for 1990, 1996, and 1999 were obtained from the National Emissions Inventories for those years.<sup>30,31, 32, 33</sup>

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.<sup>34</sup> 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:

$$\text{Future Year Emissions} = \text{Base Year Emissions} * \text{Growth Factor} * (100\% - \% \text{ Reduction})/100$$

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 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<sup>®</sup> model, version 5.5;<sup>35, 36</sup>
- Regional and National fuel-use forecast data from the Energy Information Administration, U.S. Department of Energy, Annual Energy Outlook (AEO)<sup>37</sup>
- 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.<sup>38</sup>

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.

For refueling emissions, which are related to mobile sources but inventoried as stationary sources, we developed SCC-based growth factors based on changes in refueling emissions predicted using MOBILE6.2.

*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.

*Impact of Fuel Benzene Controls* – The fuel benzene controls in this rule will reduce emission from vehicle refueling, and also emissions from gasoline distribution. Gasoline distribution emissions include emissions at bulk terminals, bulk plants, and service stations, and emissions during transport by trucks, marine vessels, and rail. Reductions in emissions from all these sources were assumed to be proportional to reductions in vehicle refueling emissions.

#### 2.2.1.1.5 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.-3, 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.<sup>39</sup> For mobile sources, precursor emissions were projected to future years using ratios of VOCs for future years versus 1999. Stationary source precursor emissions were assumed to remain at 1999 levels since the impact of growth and control is unknown.

#### 2.2.1.1.6 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.<sup>40</sup>

**Table 2.2.-3. Precursor Pollutants.**

<b>Pollutant</b>	<b>Precursor for</b>	<b>Pollutant</b>	<b>Precursor for</b>
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)

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

*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.

*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**

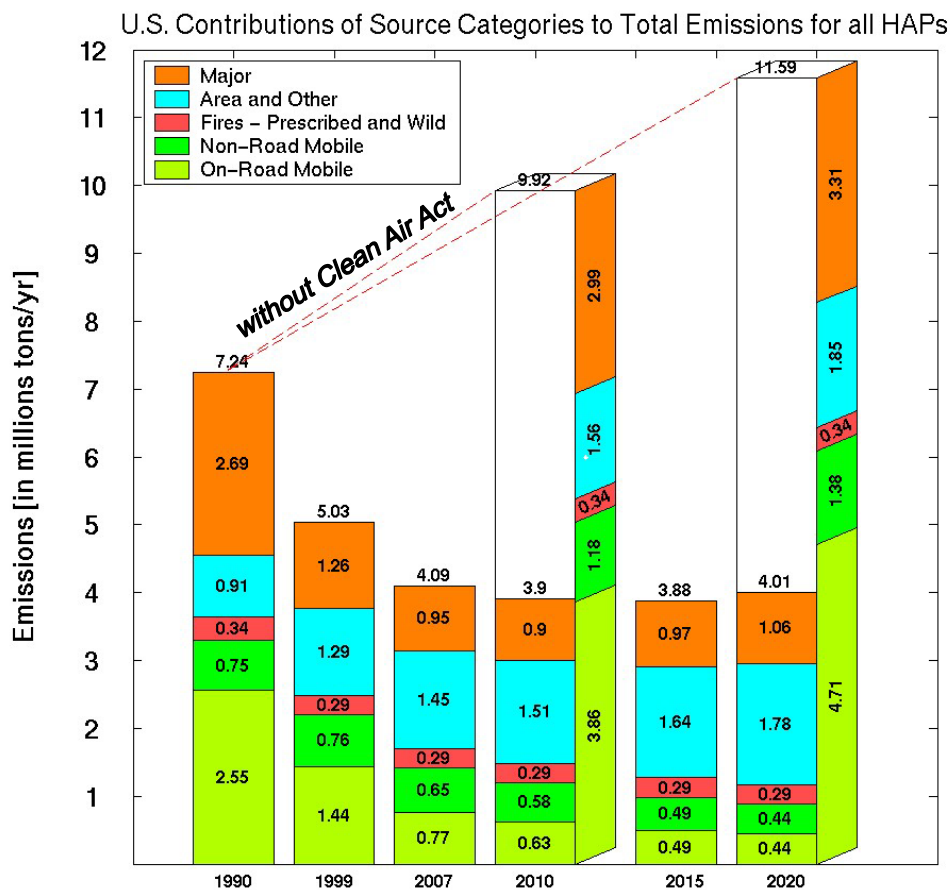
#### **2.2.1.2.1 Emission Trends Without Proposed Controls**

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.-1). 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.

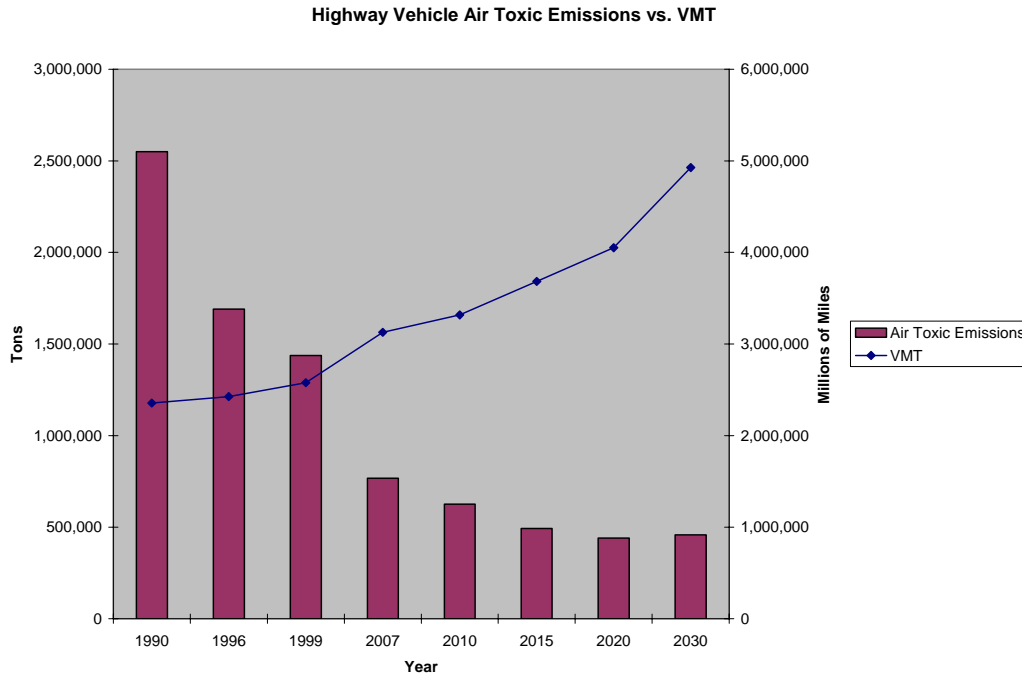
Overall, air toxic emissions are projected to decrease from 5,030,000 tons in 1999 to 4,010,000 tons in 2020, as a result of existing and planned emission controls on major, area, and mobile sources. In the absence of Clean Air Act emission controls currently in place, EPA estimates air toxic emissions would total 11,590,000 tons in 2020 (Figure 2.2.-1). As indicated in Figure 2.2.-1, mobile source air toxic emissions will be reduced 60% between 1999 and 2020 without the controls in this proposal, from 2.2 million to 880,000 tons. This reduction will occur despite a projected 57% increase in vehicle miles traveled, and a 63% projected increase in nonroad activity (See Figures 2.2.-2 and 2.2.-3). It should be noted, however, that EPA anticipates mobile source air toxic emissions will begin to increase after 2020, from about 880,000 tons in 2020 to 920,000 tons in 2030. Benzene emissions from all sources decrease from about 347,000 tons in 1999 to 222,000 tons in 2020, and as is the case with total air toxic emissions, begin to increase slightly between 2020 and 2030 (Figure 2.2.-4).

None of the inventory trends data presented in this section includes revised estimates of emissions at cold temperature in vehicles, addition of emissions from portable fuel containers, and revisions in the gasoline distribution inventory used to estimate emission benefits of the rule and cost-effectiveness. These revisions are discussed in Section 2.2.2.

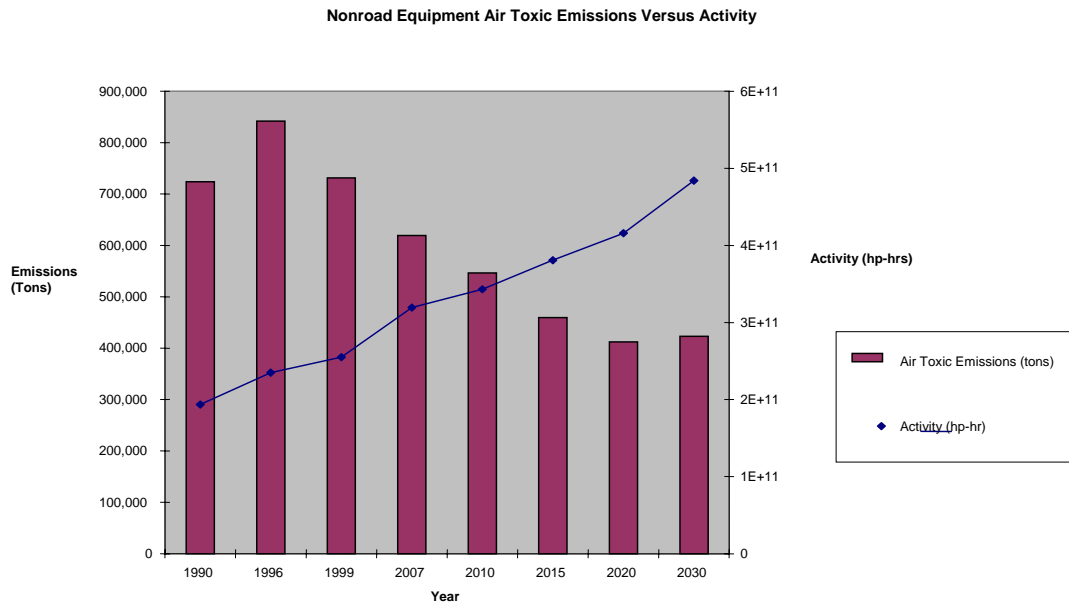
**Figure 2.2.-1. Contribution of Source Categories to Air Toxic Emissions, 1990 to 2020 (not Including Diesel Particulate Matter). Dashed Line Represents Projected Emissions without Clean Air Act Controls.**



**Figure 2.2.-2. Trend in Highway Vehicle Air Toxic Emissions Versus VMT, 1990 to 2030.**

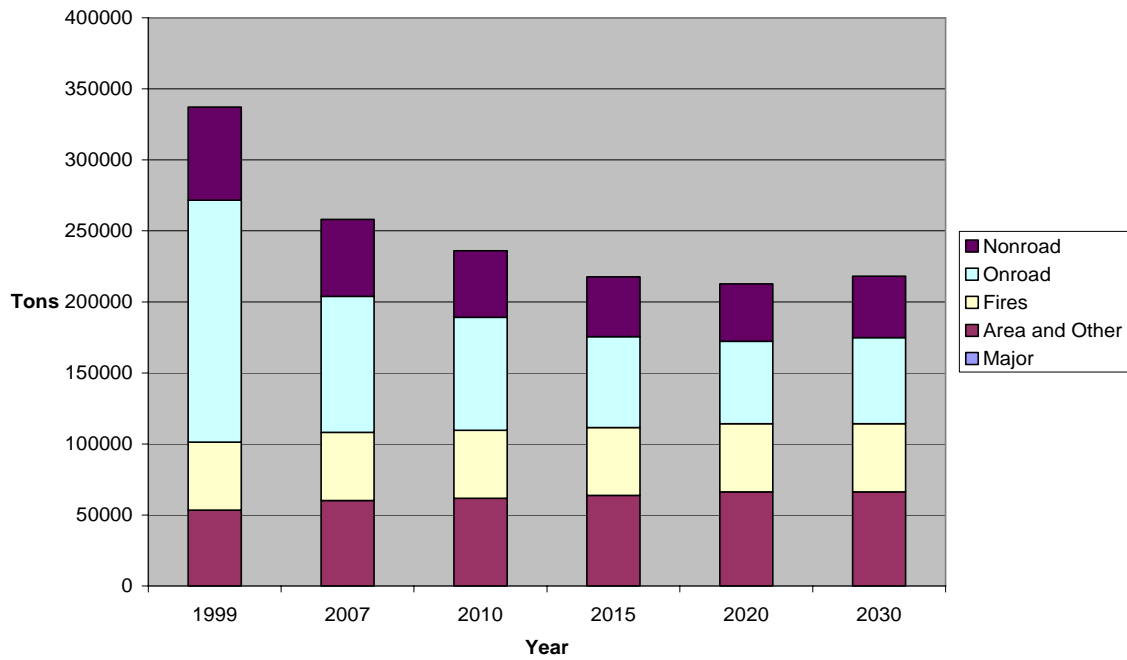


**Figure 2.2.-3. Trend in Emissions of Nonroad Equipment Air Toxic Emissions (Excluding Commercial Marine Vessels, Locomotives and Aircraft) versus Activity, 1990 to 2030.**



**Figure 2.2.-4**

**Trend in Benzene Emissions -- 1999 to 2030**



*Highway Vehicle Trends* – Table 2.2.-3 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, eighteen percent of the chromium was assumed to be the highly toxic hexavalent form, based on combustion data from stationary combustion turbines that burn diesel fuel.<sup>41</sup>

**Table 2.2.-3. Nationwide Emissions (Tons) of Individual Air Toxic Pollutants from Highway Vehicles.**

<b>Pollutant</b>	<b>1999</b>	<b>2007</b>	<b>2010</b>	<b>2015</b>	<b>2020</b>	<b>2030</b>
1,3-Butadiene	23623	10876	8807	6913	6468	6864
2,2,4-Trimethylpentane	166208	90621	73768	58013	51820	53786
Acetaldehyde	29928	17049	13909	11317	10721	11651
Acrolein	3993	1974	1570	1242	1170	1263
Benzene	170355	95766	79550	63920	58109	60660
Chromium VI	4	5	5	6	6	8
Ethyl Benzene	69480	37951	30838	24165	21472	22229
Formaldehyde	80677	40168	32240	26150	24879	27188
n-Hexane	65164	43107	35832	27727	23087	23292
MTBE	82570	33458	28026	21124	16117	15225
Manganese	16	20	22	25	28	36
Naphthalene	3978	2490	2229	2007	1976	2255
Nickel	16	19	20	23	26	32
POM	460	256	228	208	211	243
Propionaldehyde	4209	2343	1953	1621	1553	1693
Styrene	13168	6570	5284	4200	3910	4132
Toluene	456344	242800	196528	154225	138365	143714
Xylenes	267324	142123	115004	90182	80799	83948

Table 2.2.-4 summarizes total tons of air toxic emissions from highway vehicles by vehicle class in 1999, 2007, 2010, 2015, 2020, and 2030. Table 2.2.-5 provides the percentage of total highway vehicle emissions associated with each vehicle class. In 1999, 54% 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 27% of highway vehicle HAP emissions will be from LDGVs and 63% 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.-4. Tons of Air Toxic Emissions from Highway Vehicle Classes, 1999 to 2030 (Not Including Diesel Particulate Matter).**

Vehicle Type	Emissions (tons/yr)					
	1999	2007	2010	2015	2020	2030
HDDV	38,534	26,923	23,707	20,570	20,435	23,336
HDGV	80,227	35,096	24,838	17,342	13,666	12,023
LDDT	1,279	766	617	552	491	402
LDDV	977	139	60	34	23	22
LDGT1	342,839	239,534	208,636	177,486	170,855	179,122
LDGT2	186,078	139,447	126,396	114,204	105,843	102,085
LDGV	778,772	317,021	232,547	153,050	118,762	128,305
MC	8,826	8,691	9,035	9,854	10,673	12,957
<b>Total Highway</b>	<b>1,437,532</b>	<b>767,617</b>	<b>625,836</b>	<b>493,092</b>	<b>440,748</b>	<b>458,252</b>
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.-5. Percent Contribution of Vehicle Classes to Highway Vehicle Air Toxic Emissions, 1999 to 2020 (Not Including Diesel Particulate Matter).**

Vehicle	1999	2007	2010	2015	2020	2030
LDGV	54%	41%	37%	31%	27%	28%
LDGT1 and 2	37%	49%	53%	59%	63%	61%
HDGV	6%	5%	4%	4%	3%	3%
HDDV	3%	4%	4%	4%	5%	5%
Other (motorcycles and light duty diesel vehicles and trucks)	1%	1%	1%	2%	2%	3%

Tables 2.2.-6 through 2.2.-11 summarize total tons of emissions nationwide for benzene, 1,3-butadiene, formaldehyde, acetaldehyde, naphthalene, and acrolein from highway vehicles. About 87% 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.-6. Tons of Benzene Emissions from Highway Vehicle Classes, 1999 to 2030.**

Vehicle Type	Emissions (tons/yr)					
	1999	2007	2010	2015	2020	2030
HDGV	7967	4041	2970	2152	1760	1539
HDDV	2674	1872	1650	1434	1426	1628
LDDT	167	100	82	74	67	57
LDDV	120	17	7	4	3	3
LDGT1	42433	30773	27498	23835	23346	24856
LDGT2	20638	17701	16805	15694	14897	14505
LDGV	95591	40478	29722	19835	15643	16895
MC	764	784	817	892	967	1177
Total Highway	170355	95766	79550	63920	58109	60660

**Table 2.2.-7. Tons of 1,3-Butadiene Emissions from Highway Vehicle Classes, 1999 to 2030.**

Vehicle Type	Emissions (tons/yr)					
	1999	2007	2010	2015	2020	2030
HDGV	1507	483	260	130	103	84
HDDV	1430	995	877	760	755	859
LDDT	64	38	31	29	26	23
LDDV	44	6	3	1	1	1
LDGT1	5132	3218	2801	2307	2291	2447
LDGT2	3483	1919	1735	1524	1503	1486
LDGV	11743	3983	2855	1895	1500	1614
MC	220	234	244	266	288	350
Total Highway	23623	10876	8807	6913	6468	6864

**Table 2.2.-8. Tons of Formaldehyde Emissions from Highway Vehicle Classes, 1999 to 2030.**

Vehicle Type	Emissions (tons/yr)					
	1999	2007	2010	2015	2020	2030
HDGV	6648	2242	1309	741	599	498
HDDV	19887	13921	12272	10663	10601	12109
LDDT	495	297	238	211	186	148
LDDV	391	56	24	14	9	9
LDGT1	14907	8540	6787	5572	5516	5975
LDGT2	9809	5264	4164	3628	3513	3509
LDGV	27957	9239	6811	4628	3705	4028
MC	582	609	635	693	751	912
Total Highway	80677	40168	32240	26150	24879	27188

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

Vehicle Type	Emissions (tons/yr)					
	1999	2007	2010	2015	2020	2030
HDGV	1569	722	465	297	245	209
HDDV	7568	5310	4682	4071	4049	4633
LDDT	200	120	96	84	73	57
LDDV	164	24	10	6	4	4
LDGT1	5766	3947	3265	2714	2682	2899
LDGT2	3433	2411	2023	1789	1726	1710
LDGV	11057	4311	3155	2123	1690	1831
MC	171	204	214	233	253	309
Total Highway	29928	17049	13909	11317	10721	11651

**Table 2.2.-10. Tons of Acrolein Emissions from Highway Vehicle Classes, 1999 to 2030.**

Vehicle Type	Emissions (tons/yr)					
	1999	2007	2010	2015	2020	2030
HDGV	714	177	79	25	18	12
HDDV	807	561	494	429	425	483
LDDT	24	14	12	11	10	9
LDDV	16	2	1	1	0	0
LDGT1	661	434	368	306	302	326
LDGT2	357	255	222	198	191	188
LDGV	1396	511	374	251	199	215
MC	18	19	20	22	24	29
Total Highway	3993	1974	1570	1242	1170	1263

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

Vehicle Type	Emissions (tons/yr)					
	1999	2007	2010	2015	2020	2030
HDGV	752	540	388	241	189	170
HDDV	172	98	67	33	20	16
LDDT	6	3	2	1	1	1
LDDV	7	1	0	0	0	0
LDGT1	766	612	645	702	774	906
LDGT2	491	260	268	274	281	316
LDGV	1758	950	831	726	678	807
MC	26	27	28	30	33	40
Total Highway	3978	2490	2229	2007	1976	2255

*Nonroad Equipment Trends* -- Table 2.2.-12 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.-13 summarizes total tons of air toxic emissions from categories of nonroad equipment by equipment type in 1999, 2007, 2010, 2015, 2020, and 2030. Table 2.2.-14 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 almost 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.-12. Nationwide Emissions of Individual Air Toxics from Nonroad Equipment, from 1999 to 2030.**

Pollutant	Annual Total Nonroad Emissions (tons)					
	1999	2007	2010	2015	2020	2030
1,3-Butadiene	9718	7906	6799	6298	6237	6765
2,2,4-Trimethylpentane	94546	81056	71985	59516	51944	51957
Acetaldehyde	23479	19333	17390	15425	14516	14988
Acrolein	3083	2655	2496	2360	2330	2505
Benzene	65360	54232	46951	42031	40444	43252
Chromium VI	4	4	4	4	4	5
Ethyl Benzene	42731	36719	32395	27587	25260	26660
Formaldehyde	56254	45526	41214	36911	34979	36320
n-Hexane	28765	25230	22784	19872	18451	19464
Lead	550	551	565	587	609	654
MTBE	24338	10922	9569	8819	8664	9459
Manganese	5	6	6	7	7	8
Naphthalene	1254	1236	1214	1258	1318	1465
Nickel	34	36	38	39	41	45
POM	356	320	302	290	284	300
Propionaldehyde	4735	3792	3358	2956	2765	2827
Styrene	4254	3604	3091	2735	2606	2802
Toluene	205186	192855	173428	143943	125562	127370
Xylenes	193016	160347	140968	118662	107495	112660

**Table 2.2.-13. Tons of Air Toxic Emissions from Nonroad Equipment Types, 1999 to 2030 (Not Including Diesel Particulate Matter).**

Equipment type	Emissions (tons/yr)					
	1999	2007	2010	2015	2020	2030
Agriculture	23,098	15,954	13,476	10,546	8,530	7,129
Aircraft	14,276	14,315	14,965	16,081	17,256	19,603
Airport Support	421	311	251	206	191	205
Commercial	46,990	33,732	27,281	29,004	31,451	36,981
Commercial Marine Vessel	8,736	9,557	9,742	10,213	10,973	13,354
Construction	39,675	25,138	21,702	17,937	15,609	14,303
Industrial	14,559	7,456	5,114	3,157	2,573	2,382
Lawn/Garden	196,257	115,652	99,485	101,535	109,328	125,823
Logging	3,816	2,325	2,339	2,394	2,562	3,054
Pleasure Craft	258,190	172,930	144,245	122,057	111,936	108,260
Railroad	4,416	4,143	3,984	3,896	3,758	3,531
Recreational	146,526	244,129	231,291	171,593	128,661	124,142
Underground Mining	176	155	138	112	100	104
Total Nonroad	759,565	647,754	575,831	490,454	444,625	460,627

**Table 2.2.-14. Contribution of Equipment Types to Nonroad Air Toxic Emissions, 1999 to 2020 (not Including Diesel Particulate Matter).**

Equipment Type	1999	2007	2010	2015	2020	2030
Lawn and Garden	26%	18%	17%	21%	25%	27%
Pleasure Craft	34%	27%	25%	25%	25%	24%
Recreational	19%	38%	40%	35%	29%	27%
All Others	21%	17%	18%	19%	21%	22%

Almost 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, almost 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.-15 through 2.2.-20 summarize total tons of emissions nationwide for benzene, 1,3-butadiene, formaldehyde, acetaldehyde, naphthalene, and acrolein from nonroad equipment types.

**Table 2.2.-15. Tons of Benzene Emissions from Nonroad Equipment Types, 1999 to 2030.**

Equipment Type	Emissions (tons/yr)					
	1999	2007	2010	2015	2020	2030
Agriculture	2203	1569	1323	1058	877	744
Aircraft	1102	1114	1163	1247	1335	1511
Airport Support	44	33	26	21	20	22
Commercial	6809	5323	4206	4529	4964	5906
Commercial Marine Vessel	644	705	719	753	809	982
Construction	3601	2310	1957	1639	1450	1348
Industrial	1976	986	633	368	291	258
Lawn/Garden	20451	14729	12112	12039	12960	14941
Logging	267	185	180	177	187	221
Pleasure Craft	20304	14177	12113	10507	9787	9598
Railroad	162	150	144	140	134	125
Recreational	7781	12938	12365	9544	7622	7587
Underground Mining	15	13	12	10	9	9
Total Nonroad	65360	54232	46951	42031	40444	43252

**Table 2.2.-16. Tons of 1,3-Butadiene Emissions from Nonroad Equipment Types, 1999 to 2030.**

Equipment Type	Emissions (tons/yr)					
	1999	2007	2010	2015	2020	2030
Agriculture	243	176	148	120	101	85
Aircraft	824	821	859	924	993	1131
Airport Support	7	5	3	3	3	3
Commercial	1140	892	683	738	813	972
Commercial Marine Vessel	6	6	6	6	6	7
Construction	407	259	214	182	165	156
Industrial	302	143	88	50	39	33
Lawn/Garden	3423	2445	1933	1887	2030	2342
Logging	44	29	29	29	31	36
Pleasure Craft	2071	1423	1201	1018	928	895
Railroad	114	107	104	102	99	94
Recreational	1136	1600	1530	1238	1029	1009
Underground Mining	1	1	1	1	1	1
Total Nonroad	9718	7906	6799	6298	6237	6765

**Table 2.2.-17. Tons of Formaldehyde Emissions from Nonroad Equipment Types, 1999 to 2030.**

Equipment Type	Emissions (tons/yr)					
	1999	2007	2010	2015	2020	2030
Agriculture	9816	6671	5630	4288	3363	2749
Aircraft	6549	6505	6809	7333	7885	8990
Airport Support	139	105	90	71	63	65
Commercial	3418	2907	2435	2236	2131	2128
Commercial Marine Vessel	4715	5153	5252	5499	5899	7152
Construction	12417	8958	7742	5937	4779	4074
Industrial	3046	1790	1404	963	832	837
Lawn/Garden	6867	4727	3830	3678	3856	4371
Logging	432	248	214	167	155	163
Pleasure Craft	4136	2848	2447	2105	1932	1879
Railroad	1901	1793	1730	1690	1629	1529
Recreational	2731	3743	3562	2890	2404	2333
Underground Mining	87	77	68	55	50	51
Total Nonroad	56254	45526	41214	36911	34979	36320

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

Equipment Type	Emissions (tons/yr)					
	1999	2007	2010	2015	2020	2030
Agriculture	4493	3058	2581	1966	1542	1260
Aircraft	2019	2004	2098	2259	2430	2770
Airport Support	63	49	42	33	29	30
Commercial	1400	1270	1071	975	920	906
Commercial Marine Vessel	2364	2588	2639	2768	2974	3619
Construction	5723	4138	3578	2745	2210	1883
Industrial	1350	857	676	459	389	381
Lawn/Garden	2478	1920	1548	1480	1546	1748
Logging	176	102	85	62	55	55
Pleasure Craft	1703	1179	1002	854	782	757
Railroad	853	805	776	758	731	686
Recreational	820	1330	1264	1041	886	870
Underground Mining	39	34	31	25	22	23
Total Nonroad	23479	19333	17390	15425	14516	14988

**Table 2.2.-19. Tons of Acrolein Emissions from Nonroad Equipment Types, 1999 to 2030.**

Equipment Type	Emissions (tons/yr)					
	1999	2007	2010	2015	2020	2030
Agriculture	285	194	164	125	98	81
Aircraft	968	960	1005	1083	1165	1329
Airport Support	6	4	4	3	3	3
Commercial	156	127	105	99	98	102
Commercial Marine Vessel	98	109	112	118	129	161
Construction	392	280	241	186	151	130
Industrial	119	71	55	38	33	34
Lawn/Garden	388	252	207	201	212	241
Logging	16	9	8	7	7	8
Pleasure Craft	316	212	179	152	139	134
Railroad	131	124	120	117	113	107
Recreational	206	312	295	228	180	176
Underground Mining	2	2	2	1	1	1
Total Nonroad	3083	2655	2496	2360	2330	2505

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

Equipment Type	Emissions (tons/yr)					
	1999	2007	2010	2015	2020	2030
Agriculture	49	36	32	26	21	15
Aircraft	456	475	496	530	566	638
Airport Support	1	1	1	1	1	1
Commercial	98	106	98	108	119	142
Commercial Marine Vessel	65	69	68	72	79	102
Construction	61	46	42	32	23	16
Industrial	30	18	15	9	6	4
Lawn/Garden	261	245	224	232	251	289
Logging	4	4	4	4	4	5
Pleasure Craft	112	103	100	101	104	110
Railroad	61	51	44	42	40	35
Recreational	56	81	90	101	105	109
Underground Mining	0	0	0	0	0	0
Total Nonroad	1254	1236	1214	1258	1318	1465

*Diesel Particulate Matter* -- If diesel particulate matter emissions were added to the mobile source total mass of air toxic emissions, mobile sources would account for 48% of a total 5,398,000 tons in 1999. Table 2.2.-21 summarizes the trend in diesel particulate matter between 1999 and 2030, by source category. As controls on highway diesel engines and nonroad diesel engines phase in, diesel-powered locomotives and commercial marine vessels increase from 11% of the inventory in 1999 to 27% in 2020.

**Table 2.2.-21. Percent Contribution of Mobile Source Categories to Diesel Particulate Matter Emissions, 1999 to 2020 in Tons Per Year (Percent of Total).**

Source	1999	2007	2010	2015	2020
Highway Vehicles	144,000 (39%)	85,000 (33%)	63,000 (30%)	38,000 (25%)	30,000 (26%)
Commercial Marine Vessels	20,000 (5%)	19,000 (7%)	18,000 (8%)	17,000 (11%)	17,000 (15%)
Locomotives	21,000 (6%)	18,000 (7%)	15,000 (7%)	14,000 (9%)	14,000 (12%)
Other Nonroad Equipment	183,000 (50%)	134,000 (52%)	118,000 (55%)	83,000 (55%)	53,000 (46%)

#### 2.2.1.2.2 Impact on Inventory of Proposed Fuel Benzene Control

The fuel benzene control proposed in this rule would reduce benzene emissions from highway gasoline vehicles, nonroad gasoline equipment, gasoline distribution and portable fuel containers. The total benzene emissions reduced in the inventories used for

air quality modeling for these sectors are 12,800 tons, or 6 percent of the national benzene inventory from all sources. It should be emphasized that the air quality, exposure and risk modeling inventory underestimates the total emissions benefit since it does not account for portable fuel container emissions and underestimates cold temperature emissions for highway vehicles. For inventories which include these emissions, see Section 2.2.2.2.

Table 2.2.-22 summarizes the nationwide impact of the proposed benzene standard on emissions of key air toxics from highway vehicles in 2015, 2020, and 2030. Although EPA's MOBILE emissions model estimates very small increases in emissions of 1,3-butadiene, formaldehyde, and acetaldehyde, the reductions in benzene emissions are dramatic, roughly 11 to 12%. Similar impacts are projected for nonroad equipment (Tables 2.2.-23 and 2.2.-24). In addition, fuel benzene controls would reduce emissions within the gasoline distribution sector, and during vehicle refueling. Table 2.2.-25 presents estimated reductions for these sources in 2015 and 2020, which total over 2000 tons per year. These vehicle refueling and gasoline distribution reductions are also based on inventory projections from the 1999 NEI, as discussed above. However, subsequent to the air quality, exposure and risk modeling for this rule, new emission estimates for this sector were released as part of the 2002 NEI<sup>42</sup>. These revisions are discussed in Section 2.2.2, and were used in developing estimates of emission benefits for this rule. 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.-22. Nationwide Impact of the Proposed Benzene Control on Emissions of Key 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	6913	6926	-14	6468	6480	-13	6864	6877	-13
Acetaldehyde	11317	11336	-19	10721	10738	-17	11651	11669	-18
Acrolein	1242	1242	0	1170	1170	0	1263	1263	0
Benzene	63920	56596	7324	58109	51711	6398	60660	54154	6506
Formaldehyde	26150	26195	-45	24879	24921	-41	27188	27231	-43
<b>5 MSAT Total</b>	<b>109542</b>	<b>102295</b>	<b>7247</b>	<b>101347</b>	<b>95020</b>	<b>6327</b>	<b>107626</b>	<b>101194</b>	<b>6433</b>

**Table 2.2.-23. Nationwide Impact of the Proposed Benzene Control on Emissions of Key Air Toxics from all Nonroad Equipment 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	6298	6310	-12	6237	6249	-12	6765	6778	-13
Acetaldehyde	15425	15435	-10	14516	14525	-9	14988	14998	-10
Acrolein	2360	2360	0	2330	2330	0	2505	2505	0
Benzene	42031	37531	4500	40444	36022	4422	43252	38489	4763
Formaldehyde	36911	36940	-29	34979	35007	-28	36320	36350	30
<b>5 MSAT Total</b>	<b>103025</b>	<b>98576</b>	<b>4449</b>	<b>98505</b>	<b>94132</b>	<b>4373</b>	<b>103830</b>	<b>99120</b>	<b>4710</b>

**Table 2.2.-24. Nationwide Impact of the Proposed Benzene Control on Emissions of Key Air Toxics from Gasoline Nonroad Equipment in 2015, 2020, and 2030.**

<b>Annual Emissions (tons) for Gasoline Nonroad Equipment</b>									
<b>Pollutant</b>	<b>2015 Reference Case</b>	<b>2015 Control Case</b>	<b>2015 Reduction</b>	<b>2020 Reference Case</b>	<b>2020 Control Case</b>	<b>2020 Reduction</b>	<b>2030 Reference Case</b>	<b>2030 Control Case</b>	<b>2030 Reduction</b>
1,3-Butadiene	5071	5083	-12	4982	4994	-12	5401	5413	-13
Acetaldehyde	3663	3672	-10	3558	3567	-9	3807	3817	-10
Acrolein	632	632	0	591	591	0	625	625	0
Benzene	37747	33247	4500	36440	32018	4422	39163	34399	4763
Formaldehyde	9423	9452	-29	9103	9131	-28	9740	9770	-30
<b>5 MSAT Total</b>	<b>56535</b>	<b>52087</b>	<b>4448</b>	<b>54675</b>	<b>50302</b>	<b>4373</b>	<b>58736</b>	<b>54025</b>	<b>4711</b>

**Table 2.2.-25. Nationwide Impact of the Proposed Controls on Emissions of Benzene from Vehicle Refueling and Gasoline Distribution in 2015 and 2020 (2030 Assumed to be the Same as 2020).**

	<b>2015 Reference Case</b>	<b>2015 Control Case</b>	<b>2015 Reduction</b>	<b>2020 Reference Case</b>	<b>2020 Control Case</b>	<b>2020 Reduction</b>
Vehicle Refueling	724	459	265	720	459	261
Gasoline Distribution	5419	3663	1756	5606	3804	1802

## **2.2.2 Emission Reductions from Proposed Controls**

Section 2.2.2 describes revisions made to emission inventories subsequent to development of MSAT inventories for air quality modeling. These include revised estimates of emissions at cold temperature in vehicles, addition of emissions from portable fuel containers, and revisions in the gasoline distribution inventory to reflect changes made for the 2002 National Emissions Inventory. The revised inventories were used to estimate emission benefits of the rule and cost-effectiveness.

### **2.2.2.1 Methodology Changes from Air Quality Inventories**

#### **2.2.2.1.1 Highway Vehicles**

Section 2.1.1.1 describes the changes made to hydrocarbon emission rates in MOBILE6.2 to reflect the higher measured emissions during cold starts at cold temperature for Tier 1 and later vehicles. 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 °F in EPA's Office of Research and Development in the late 1980's.<sup>43, 44</sup> 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 later model vehicles as the same temperature ranges cited above.<sup>45,46,47</sup> 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,

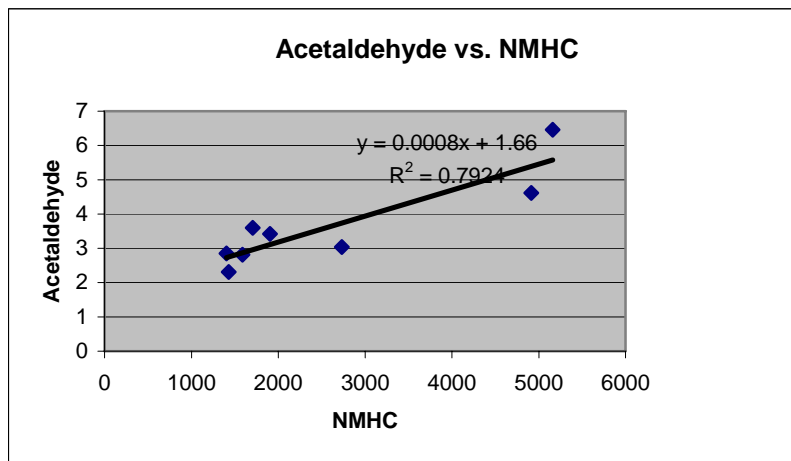
correlations were not as strong with aldehydes. Results from the 1993 Cavalier and 1993 Taurus found a statistically significant correlation for acetaldehyde but not for formaldehyde, whereas analysis of data from the other vehicles found a correlation for formaldehyde but not acetaldehyde.

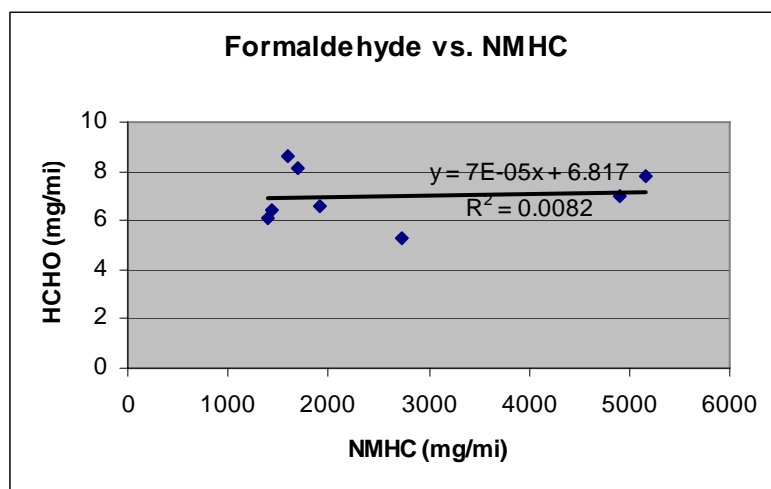
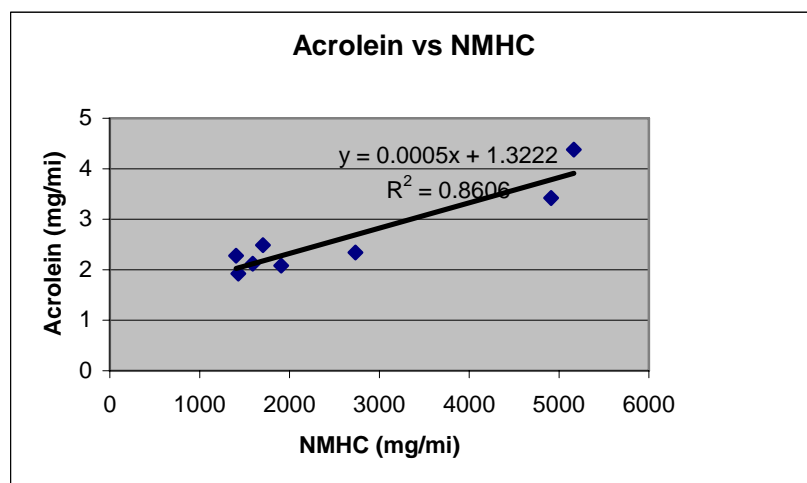
A major vehicle manufacturer also recently tested two Tier 2 compliant vehicles at 75 and 20 °F. Although the data are confidential, they show emission of air toxics increase at the same rate as hydrocarbons, with a very high correlation.

A third source of data is testing done by Southwest Research Institute for U. S. EPA, Office of Transportation and Air Quality on four model year 2005 vehicles – a Ford F-150, a Mazda 3, a Honda Odyssey and a Chevrolet Equinox.<sup>48</sup> The four vehicles were tested at 0, 20 and 75 °F. 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 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 proposed 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.-5 depicts the relationship between carbonyl compounds and NMHC.

**Figure 2.2.-5. 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.

#### 2.2.2.1.2 Nonroad Equipment

No changes were made from the inventory estimates of nonroad equipment that were developed for air quality modeling. In estimating the emission reductions from proposed controls, no changes were made from the inventory estimates, with and without the proposed fuel benzene control, developed for air quality modeling. It should be noted, however, that EPA recently released newer versions of NONROAD and NMIM, NONROAD2005 and NMIM2005 that include a number of significant revisions.<sup>49,50</sup> Most importantly, there are new evaporative categories for tank permeation, hose permeation, hot soak, and running loss emissions. If these revisions were included in the estimation of emission reductions from the proposed fuel benzene control, the estimated reductions would be larger.

#### 2.2.2.1.3 Portable Fuel Containers

Any MSATs contained in the liquid gasoline will be present as a component of the VOCs associated with the PFCs. 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
- 2,2,4-trimethylpentane

We estimated only nationwide emission totals for all MSATs except benzene, where State level totals were estimated.

For all compounds except benzene and MTBE, the fraction of total PFC emissions that is composed of each of those HAPs is assumed to be directly proportional to the ratio of each of those HAPs in total evaporative emissions from light-duty gasoline vehicles. 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). Based on the sales of the various gasoline blends, we generated the ratios given in Table 2.2.-26.

<b>Table 2.2.-26. Ratios of Pollutants to Total Evaporative VOC Emissions.</b>				
<b>Pollutant Name</b>	<b>Baseline</b>	<b>10% Gasohol</b>	<b>MTBE Gasoline</b>	<b>Weighted Ratios</b>
Naphthalene	0.0004	0.0004	0.0004	0.0004
Ethyl Benzene	0.0077	0.0045	0.0063	0.0067
Toluene	0.0413	0.0195	0.0276	0.0337
n-Hexane	0.0234	0.0096	0.0087	0.0175
2,2,4-Trimethylpentane	0.0158	0.0158	0.0158	0.0158
Xylenes	0.0223	0.0119	0.0188	0.0192

In this table, the weighted ratios are based on the estimate that the nationwide distribution of gasoline is 58.3 percent baseline, 23.5 percent gasohol (i.e., E10), and the

remainder (18.2 percent) oxygenated with MTBE. This estimate is based on 2003 sales data for ethanol oxygenated gasoline compiled by the Federal Highway Administration, estimates of reformulated gasoline sales from the Energy Information Administration, and estimates of the amount of MTBE oxygenated gasoline sold as part of the Federal Reformulated Gasoline Program from Federal Reformulated Gasoline surveys.<sup>51, 52</sup>

Because of the localized use of MTBE in gasoline, we used a different approach to estimate nationwide emissions of this pollutant. The nationwide quantity of MTBE emitted by PFCs by permeation or evaporation was estimated based on the ratio of nationwide MTBE refueling emissions in the 2002 NEI to total VOC refueling emissions. The resulting ratio was 0.024. Since several States have eliminated the use of MTBE in reformulated gasoline, and further reductions in the use of MTBE are anticipated in the future, this approach likely overestimates MTBE emissions from PFCs in future years.

Another approach was used to estimate emissions of benzene with and without PFC control, and also with and without the fuel benzene standard proposed in this rule. We assumed that the fraction of PFC emissions that is benzene is proportional to the benzene fraction in refueling emissions. First, we divided State-level benzene refueling emissions by State-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.

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. Thus, we also needed to split the "permeation plus evaporation" estimates in Table 2.1.-1. Analyses (referenced in Section 2.1.1.2) suggest that the permeation emissions account for 33.87 percent of the combined permeation plus evaporation for the sealed PFCs. As noted, a recent study<sup>53</sup> 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.

It should be noted that because the PFC inventories for air toxics include emissions spillage while refueling nonroad equipment, and because estimates of nonroad equipment evaporative emissions in NONROAD also include this source of emissions, there is some double counting of overall air toxics emissions and emission benefits from fuel benzene control (This is not an issue for estimates of VOCs). However, the spillage component of evaporative emissions in NONROAD is significantly smaller than the estimates in the PFC inventory, and the double counting accounts for well under 1% of the total emission benefits of fuel benzene control.

#### 2.2.2.1.4 Gasoline Distribution

Subsequent to the development of the gasoline distribution inventories used in the modeling of air quality, exposure, and risk from mobile source air toxics, EPA improved its methodology for estimating gasoline distribution emissions in the 2002 National Emissions Inventory (NEI). The key changes were:

- 1) Vehicle refueling emissions were estimated as part of the highway vehicle inventory using NMIM. Details of how the modeling was done can be found in the documentation for the mobile source 2002 NEI.<sup>54</sup> The previous methodology is described in the nonpoint 1999 NEI documentation.<sup>55</sup> 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 used 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.<sup>56</sup>

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.-27 compares benzene estimates in the 1999 NEI, final version 3, and the final 2002 NEI.

**Table 2.2.-27. 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 proposed fuel benzene control in this rule, EPA developed updated air toxic inventories for vehicle refueling and gasoline distribution to reflect the changes made in the 2002 NEI. The changes were made as follows:

- 1) Vehicle refueling emissions were estimated using NMIM projections. Refueling emissions were estimated for reference case inventories in 1999, 2007, 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 the 2007 projection for air quality, exposure and risk modeling
- 3) EPA developed new county level reference case inventories for these pollutants by applying these adjustment factors to county-level gasoline distribution emissions. Revised inventories were developed for years 1999, 2007, 2010, 2015, 2020, and 2030.
- 4) 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 original control scenario/emissions original reference case

#### **2.2.2.2 Estimated Reductions for Air Toxic Pollutants of Greatest Concern**

##### **2.2.2.2.1 Fuel Benzene Standard**

*Highway Gasoline Vehicles* – The proposed fuel benzene standard will reduce emissions from light-duty gasoline vehicles and trucks, motorcycles, and heavy-duty gasoline trucks. Tables 2.2-28, 2.2-29, and 2.2-30 present nationwide benzene emissions for these vehicle classes with and without the proposed 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.-28. Impact of Fuel Benzene Control on Benzene Emissions from Highway Vehicle Classes, 2015.**

<b>Vehicle Class</b>	<b>Reference Case Tons</b>	<b>Control Case Tons</b>	<b>Reduction</b>
LDGV	39,485	35,253	4,232
LDGT1	41,796	37,296	4,500
LDGT2	20,074	17,834	2,240
MC	728	626	102
HDGV	1,715	1,503	212

**Table 2.2.-29. Impact of Fuel Benzene Control on Benzene Emissions from Highway Vehicle Classes, 2020.**

<b>Vehicle Class</b>	<b>Reference Case Tons</b>	<b>Control Case Tons</b>	<b>Reduction</b>
LDGV	37,635	33,730	3,905
LDGT1	47,352	42,391	4,961
LDGT2	21,083	18,822	2,261
MC	787	677	110
HDGV	1,399	1234	165

**Table 2.2.-30. Impact of Fuel Benzene Control on Benzene Emissions from Highway Vehicle Classes, 2030.**

<b>Vehicle Class</b>	<b>Reference Case Tons</b>	<b>Control Case Tons</b>	<b>Reduction</b>
LDGV	44,871	40,271	4,600
LDGT1	56,290	50,520	5,770
LDGT2	23,737	21,245	2,492
MC	947	816	131
HDGV	1,213	1067	146

Reductions from the proposed 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.-31 summarizes impacts of fuel benzene control on the benzene emission inventory for gasoline vehicles in each State in 2030.

**Table 2.2.-31. 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	2183	1961	222	10
ALASKA	1270	879	390	31
ARIZONA	1936	1783	153	8
ARKANSAS	1275	1137	138	11
CALIFORNIA	9115	8489	625	7
COLORADO	2870	2503	367	13
CONNECTICUT	1023	1009	13	1
DELAWARE	281	277	4	1
DISTRICT OF COLUMBIA	122	120	2	1
FLORIDA	4220	3754	466	11
GEORGIA	4210	3821	389	9
HAWAII	194	193	1	0
IDAHO	1224	1039	185	15
ILLINOIS	4744	4359	385	8
INDIANA	3895	3426	469	12
IOWA	1704	1471	233	14
KANSAS	1833	1548	285	16
KENTUCKY	2351	2083	268	11
LOUISIANA	1543	1364	179	12
MAINE	765	731	34	4
MARYLAND	1860	1809	51	3
MASSACHUSETTS	1874	1849	25	1
MICHIGAN	6974	6030	944	14
MINNESOTA	4129	3480	649	16
MISSISSIPPI	1000	890	110	11
MISSOURI	3439	3018	421	12
MONTANA	1057	904	153	14
NEBRASKA	1195	1022	174	15
NEVADA	1086	1034	51	5
NEW HAMPSHIRE	797	769	27	3
NEW JERSEY	2068	2041	27	1
NEW MEXICO	1402	1169	234	17
NEW YORK	6601	6236	365	6
NORTH CAROLINA	3738	3363	375	10
NORTH DAKOTA	656	553	103	16
OHIO	5263	4597	666	13
OKLAHOMA	1942	1740	202	10
OREGON	3190	2684	507	16
PENNSYLVANIA	5023	4685	338	7
RHODE ISLAND	271	268	3	1
SOUTH CAROLINA	2034	1837	197	10
SOUTH DAKOTA	619	534	85	14
TENNESSEE	2896	2612	284	10
TEXAS	6544	5949	595	9
UTAH	1473	1276	197	13
VERMONT	541	500	41	8
VIRGINIA	3061	2891	170	6
WASHINGTON	4450	3709	741	17
WEST VIRGINIA	792	700	92	12
WISCONSIN	3657	3253	404	11
WYOMING	671	571	100	15

*Gasoline Nonroad Equipment* – Table 2.2.-24 summarizes the nationwide impact of the proposed 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.-32, these benefits vary from 1 to 32% by State in 2030.

*Portable Fuel Containers* –Table 2.2.-33 summarizes MSAT emissions from PFCs with no fuel benzene or Federal PFC control (but including State control programs). The proposed fuel benzene control will reduce benzene emissions from portable fuel containers. Table 2.2.-34 summarizes the nationwide impact of fuel benzene control on PFC benzene emissions. Again, emission benefits vary across the U. S., as seen in Table 2.2.-35.

*Gasoline Distribution* – Table 2.2.-36 presents revised national reference case inventory estimates for gasoline distribution. Vehicle refueling emissions are included in the highway vehicle inventory. Table 2.2.-37 presents the benzene inventory from gasoline distribution (not including refueling) in 2015 and 2020 with and without the proposed fuel benzene control. Table 2.2.-38 presents the inventory for 2020 at the State level with and without proposed fuel benzene control. More detailed inventory estimates by county are available in the docket for the rule.

**Table 2.2.-32. Gasoline Nonroad Equipment Emission Reductions (Tons) from Proposed Fuel Control by State, 2030.**

<b>State</b>	<b>2030 Reference Case</b>	<b>2030 Control Case</b>	<b>2030 Reductions</b>	<b>% Change</b>
ALABAMA	707	605	102	14
ALASKA	160	109	51	32
ARIZONA	631	561	70	11
ARKANSAS	443	375	68	15
CALIFORNIA	3018	2705	314	10
COLORADO	578	493	85	15
CONNECTICUT	468	459	8	2
DELAWARE	132	130	3	2
DISTRICT OF COLUMBIA	20	19	0	2
FLORIDA	3085	2662	424	14
GEORGIA	1136	987	148	13
HAWAII	102	102	1	1
IDAHO	279	229	49	18
ILLINOIS	1371	1266	104	8
INDIANA	763	653	110	14
IOWA	452	375	77	17
KANSAS	364	298	66	18
KENTUCKY	514	441	73	14
LOUISIANA	782	650	131	17
MAINE	288	269	19	6
MARYLAND	739	707	32	4
MASSACHUSETTS	756	742	14	2
MICHIGAN	1829	1521	308	17
MINNESOTA	1055	873	182	17
MISSISSIPPI	450	377	73	16
MISSOURI	856	734	122	14
MONTANA	153	128	25	17
NEBRASKA	248	204	43	17
NEVADA	242	221	20	8
NEW HAMPSHIRE	237	221	16	7
NEW JERSEY	1118	1097	21	2
NEW MEXICO	203	164	40	19
NEW YORK	2050	1920	129	6
NORTH CAROLINA	1187	1023	164	14
NORTH DAKOTA	128	105	24	18
OHIO	1542	1298	244	16
OKLAHOMA	486	411	76	16
OREGON	589	483	107	18
PENNSYLVANIA	1496	1368	128	9
RHODE ISLAND	111	109	2	2
SOUTH CAROLINA	641	549	91	14
SOUTH DAKOTA	124	103	21	17
TENNESSEE	793	682	111	14
TEXAS	3378	2978	400	12
UTAH	350	296	54	15
VERMONT	113	101	12	11
VIRGINIA	839	780	58	7
WASHINGTON	869	708	161	19
WEST VIRGINIA	249	212	37	15
WISCONSIN	934	807	128	14
WYOMING	104	86	18	17

**Table 2.2.-33. MSAT Emissions (Tons) from Uncontrolled PFCs.**

<b>Pollutant</b>	<b>1999</b>	<b>2007</b>	<b>2010</b>	<b>2015</b>	<b>2020</b>	<b>2030</b>
2,2,4-Trimethylpentane	5023	4899	4405	4682	5020	5719
Benzene	2229	2254	2118	2262	2423	2757
Ethylbenzene	2132	2080	1870	1987	2131	2428
n-Hexane	5570	5432	4884	5191	5566	6341
MTBE	7646	7458	6705	7126	7641	8705
Naphthalene	127	124	112	119	127	145
Toluene	10,731	10,467	9,410	10,002	10,724	12,218
Xylenes	6,123	5,972	5,369	5,707	6,119	6,971

**Table 2.2.-34. Reduction in Benzene PFC Emissions (Tons) with Proposed Fuel Control (No Control on PFC Emissions).**

<b>Year</b>	<b>Reference Case</b>	<b>Control Case</b>	<b>Reduction</b>
1999	2229	N. A.	N.A.
2015	2262	1359	903
2020	2423	1456	967
2030	2757	1657	1100

**Table 2.2.-35. Reduction in Benzene PFC Emissions (Tons) with Proposed Fuel Control in 2030 by State (No Control on PFC Emissions).**

State	Reference Case Tons	Control Case Tons	Reduction	% Change
AK	42	8	34	81
AL	65	15	50	77
AR	47	9	38	80
AZ	45	15	29	65
CA	92	92	0	1
CO	83	24	59	71
CT	11	8	3	27
DC	1	0	0	31
DE	3	2	1	24
FL	224	74	150	67
GA	84	27	57	67
HI	8	2	6	75
IA	42	12	30	72
ID	28	9	19	68
IL	98	37	61	62
IN	68	22	45	67
KS	46	14	33	70
KY	50	13	36	73
LA	68	14	54	80
MA	18	13	5	26
MD	20	15	5	23
ME	5	4	2	31
MI	219	48	171	78
MN	67	20	47	70
MO	80	24	56	70
MS	35	8	27	77
MT	18	5	13	73
NC	115	30	86	74
ND	10	3	7	72
NE	23	8	15	66
NH	12	3	9	74
NJ	26	19	7	26
NM	31	9	22	72
NV	13	5	8	61
NY	47	36	11	23
OH	167	46	121	73
OK	51	11	40	78
OR	92	25	66	72
PA	45	34	11	25

State	Reference Case Tons	Control Case Tons	Reduction	% Change
RI	2	2	0	15
SC	49	14	35	71
SD	9	3	6	70
UT	34	11	23	68
VA	30	22	7	25
VT	3	2	1	25
WA	135	40	95	70
WI	78	21	57	73
WV	33	7	26	79
WY	10	3	7	71

**Table 2.2.-36. Emissions of Mobile Source Air Toxics from Gasoline Distribution in tons (2030 assumed to be same as 2020).**

Pollutant	1999	2007	2010	2015	2020
2,2,4-trimethylpentane	5,473	5,646	5,825	5,981	6,174
Benzene	5,502	5,695	5,863	5,999	6,207
Ethyl Benzene	1,444	1,547	1,622	1,710	1,824
n-Hexane	10,700	10,925	11,174	11,309	11,607
MTBE	16,934	17,346	17,879	18,113	18,543
Naphthalene	427	446	460	471	489
Toluene	10,693	11,121	11,473	11,771	12,219
Xylenes	6,452	6,859	7,137	7,449	7,871

**Table 2.2.-37. Nationwide Impact of the Proposed 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	5,999	4,054	1,945	6,207	4,210	1,997

**Table 2.2.-38. Reduction in Gasoline Distribution Emissions of Benzene (Tons) with Proposed Fuel Benzene Control by State, 2020.**

<b>State</b>	<b>Reference Case</b>	<b>Control Case</b>	<b>Reduction</b>	<b>% Change</b>
ALABAMA	89	51	39	43
ALASKA	9	5	3	40
ARIZONA	81	48	32	40
ARKANSAS	42	24	18	43
CALIFORNIA	246	242	4	2
COLORADO	66	42	24	37
CONNECTICUT	48	44	4	8
DELAWARE	8	8	1	8
DISTRICT OF COLUMBIA	9	8	1	8
FLORIDA	236	143	94	40
GEORGIA	107	65	42	40
HAWAII	8	5	3	40
IDAHO	56	35	20	37
ILLINOIS	241	172	69	29
INDIANA	97	56	41	42
IOWA	94	51	43	46
KANSAS	158	86	73	46
KENTUCKY	119	70	49	41
LOUISIANA	284	162	123	43
MAINE	55	42	13	24
MARYLAND	71	60	10	15
MASSACHUSETTS	67	61	6	8
MICHIGAN	208	112	96	46
MINNESOTA	127	68	58	46
MISSISSIPPI	105	60	45	43
MISSOURI	66	42	24	36
MONTANA	30	19	11	37
NEBRASKA	26	14	12	46
NEVADA	18	11	7	40
NEW HAMPSHIRE	10	8	2	17
NEW JERSEY	78	72	7	8
NEW MEXICO	77	44	33	43
NEW YORK	819	707	112	14
NORTH CAROLINA	99	60	39	40
NORTH DAKOTA	23	12	11	46
OHIO	208	112	96	46
OKLAHOMA	151	82	70	46
OREGON	137	82	55	40
PENNSYLVANIA	194	124	70	36
RHODE ISLAND	12	11	1	8
SOUTH CAROLINA	50	30	20	40
SOUTH DAKOTA	15	8	7	46
TENNESSEE	119	64	55	46
TEXAS	935	666	269	29
UTAH	63	40	23	37
VERMONT	4	2	1	40
VIRGINIA	111	80	32	28
WASHINGTON	79	47	32	40
WEST VIRGINIA	151	91	60	40
WISCONSIN	67	42	24	37
WYOMING	31	20	11	37

#### 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 in these vehicles 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 during them. The emissions reduced are those created in the engine start following the vehicle soak. These parameters are currently modeled by vehicle class and vehicle age in MOBILE6.2.<sup>57, 58, 59, 60</sup> 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  $\leq$  6000 lbs and 30% from gasoline fueled highway vehicles with GVWR > 6000 lbs. Effects on the trends in the inventories for the affected MSATs are shown in Table 2.2.-39 through Table 2.2.-44.

**Table 2.2.-40. Reference Case, Light Duty Gasoline Vehicles and Trucks, 1999 MSAT Inventory.**

Pollutant	Emissions in Tons
1,3-Butadiene	20,868
2,2,4-Trimethylpentane	170,366
Acetaldehyde	21,035
Acrolein	2,234
Benzene	171,154
Ethyl Benzene	67,091
Formaldehyde	54,104
n-Hexane	55,360
MTBE	51,457
Styrene	13,070
Toluene	453,141
Xylenes	255,940
Total MSATS	1,341,572

**Table 2.2.-41. 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	10,091	9,347	744	7
2,2,4-Trimethylpentane	96,626	90,312	6,314	7
Acetaldehyde	12,218	11,215	1003	8
Acrolein	1,191	1,104	87	7
Benzene	104,779	96,980	7,799	7
Ethyl Benzene	38,003	35,567	2,436	6
Formaldehyde	25,180	23,110	2,070	8
n-Hexane	34,639	33,415	1,223	4
MTBE	26,271	25,931	340	1
Styrene	7,096	6,533	563	8
Toluene	253,844	236,623	17,221	7
Xylenes	143,177	133,474	9,703	7
Total MSATs	756,352	706,745	49,607	7

**Table 2.2.-42. 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	9,585	7,964	1,621	17
2,2,4-Trimethylpentane	90,361	76,521	13,840	15
Acetaldehyde	11,901	9,695	2,206	19
Acrolein	1,140	948	192	17
Benzene	101,355	84,496	16,859	17
Ethyl Benzene	35,418	30,079	5,339	15
Formaldehyde	24,201	19,753	4,448	18
n-Hexane	29,589	26,911	2,679	9
MTBE	20,319	19,594	725	4
Styrene	6,901	5667	1234	18
Toluene	239,097	201,351	37,746	16
Xylenes	134,834	113,568	21,266	16
Total MSATs	707,877	599,492	108,385	15

**Table 2.2.-43. 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	10,189	7,470	2,719	27
2,2,4-Trimethylpentane	92,586	69,374	23,212	25
Acetaldehyde	12,703	9,006	3,697	29
Acrolein	1,204	882	322	27
Benzene	106,071	77,966	28,105	27
Ethyl Benzene	36,175	27,213	8,962	25
Formaldehyde	25,661	18,323	7,338	29
n-Hexane	27,287	22,801	4,486	16
MTBE	16,056	14,909	1,147	7
Styrene	7,364	5,292	2,072	28
Toluene	246,984	183,618	63,366	26
Xylenes	139,250	103,549	35,701	26
Total MSATs	724,840	543,332	181,508	25

**Table 2.2.-44. 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	12,067	7,379	4,688	39
2,2,4-Trimethylpentane	107,911	68,389	39,522	37
Acetaldehyde	15,165	8,938	6,227	41
Acrolein	1,422	875	547	39
Benzene	124,898	77,208	47,690	38
Ethyl Benzene	42,092	26,807	15,285	36
Formaldehyde	30,486	18,218	12,268	40
n-Hexane	29,958	22,322	7,636	25
MTBE	15,670	13,793	1,877	12
Styrene	8,760	5,228	3,532	40
Toluene	289,066	180,996	108,070	37
Xylenes	162,961	102,072	60,889	37
Total MSATs	844,366	535,479	308,887	37

State level reductions in calendar year 2030 benzene inventories are reported in Table 2.2.-45. Reductions are higher in States with cold winter temperatures, such as Alaska, where the reduction is 50%, and lowest in States with no winter or mild winters, such as Hawaii and Florida, where reductions are 4% and 14%, respectively.

**Table 2.2.-45. 2030 Light-Duty Gasoline Vehicle Benzene Reference and Vehicle Control Cases by State.**

State	2030 Reference Case Benzene Tons in Calendar 2030	2030 Control Case Benzene Tons in Calendar 2030	Reduction in Tons	Percent Reduction
Alabama	2128	1495	633	30%
Alaska	1260	639	620	49%
Arizona	1886	1241	646	34%
Arkansas	1252	854	398	32%
California	8984	5436	3548	39%
Colorado	2817	1645	1172	42%
Connecticut	1010	535	475	47%
DC	120	69	51	42%
Delaware	275	155	120	44%
Florida	4081	3512	569	14%
Georgia	4117	2807	1309	32%
Hawaii	188	181	7	4%
Idaho	1208	707	501	41%
Illinois	4674	2652	2022	43%
Indiana	3837	2315	1522	40%
Iowa	1682	1000	682	41%
Kansas	1809	1110	698	39%
Kentucky	2315	1409	907	39%
Louisiana	1509	1124	385	26%
Maine	754	413	340	45%
Maryland	1829	1041	788	43%
Massachusetts	1838	975	863	47%
Michigan	6885	4043	2842	41%
Minnesota	4086	2277	1809	44%
Mississippi	980	674	307	31%
Missouri	3385	2083	1302	38%
Montana	1047	586	461	44%
Nebraska	1180	702	479	41%
Nevada	1053	664	390	37%
New Hampshire	788	454	334	42%
New Jersey	2030	1118	912	45%
New Mexico	1363	926	437	32%
New York	6520	3721	2799	43%
North Carolina	3660	2393	1268	35%
North Dakota	650	359	291	45%
Ohio	5177	3029	2148	41%
Oklahoma	1906	1295	611	32%
Oregon	3131	1864	1268	40%
Pennsylvania	4947	2852	2095	42%
Rhode Island	267	143	124	46%

State	2030 Reference Case Benzene Tons in Calendar 2030	2030 Control Case Benzene Tons in Calendar 2030	Reduction in Tons	Percent Reductions
South Carolina	1999	1328	671	34%
South Dakota	612	348	263	43%
Tennessee	2843	1807	1036	36%
Texas	6373	4918	1455	23%
Utah	1442	822	621	43%
Vermont	536	305	231	43%
Virginia	3021	1863	1158	38%
Washington	4383	2431	1952	45%
West Virginia	784	454	330	42%
Wisconsin	3612	2056	1556	43%
Wyoming	663	379	285	43%
<b>2030 Benzene Totals</b>	<b>124898</b>	<b>77208</b>	<b>47670</b>	<b>38%</b>

#### 2.2.2.2.3 Portable Fuel Container Control

The effect of PFC control on nationwide MSAT emissions are reported in Tables 2.2.-46 through 2.2.-49. Table 2.2.-50 reports reductions in benzene with PFC control by State in 2030. Similar patterns are expected for other MSATs, although State level inventories were not developed.

**Table 2.2.-46. Estimated Reductions in MSAT Emissions from PFC Control, 2010.**

Pollutant	Reference Case	Control Case	Reduction in Tons	Percent Reduction
Benzene	2118	1885	233	11
Naphthalene	112	100	11	10
Ethyl Benzene	1870	1680	190	10
Toluene	9410	8454	956	10
n-Hexane	4884	4388	496	10
2,2,4-Trimethylpentane	4405	3957	448	10
Xylenes	5369	4824	546	10
MTBE	6705	6024	681	10
<b>Total</b>	<b>34873</b>	<b>31312</b>	<b>3561</b>	<b>10</b>

**Table 2.2.-47. Estimated Reductions in MSAT Emissions from PFC Control, 2015.**

<b>Pollutant</b>	<b>Reference Case</b>	<b>Control Case</b>	<b>Reduction in Tons</b>	<b>Percent Reduction</b>
Benzene	2262	794	1468	65
Naphthalene	119	47	72	61
Ethyl Benzene	1987	779	1208	61
Toluene	10002	3922	6080	61
n-Hexane	5191	2035	3155	61
2,2,4-Trimethylpentane	4682	1836	2846	61
Xylenes	5707	2238	3469	61
MTBE	7126	2794	4332	61
<b>Total</b>	<b>37075</b>	<b>14445</b>	<b>22630</b>	<b>61</b>

**Table 2.2.-48. Estimated Reductions in MSAT Emissions from PFC Control, 2020.**

<b>Pollutant</b>	<b>Reference Case</b>	<b>Control Case</b>	<b>Reduction in Tons</b>	<b>Percent Reduction</b>
Benzene	2423	856	1567	65
Naphthalene	127	50	77	61
Ethyl Benzene	2131	841	1290	61
Toluene	10724	4234	6490	61
n-Hexane	5566	2197	3368	61
2,2,4-Trimethylpentane	5020	1982	3038	61
Xylenes	6119	2416	3703	61
MTBE	7641	3017	4624	61
<b>Total</b>	<b>39752</b>	<b>15594</b>	<b>24157</b>	<b>61</b>

**Table 2.2.-49. Estimated Reductions in MSAT Emissions from PFC Control, 2030.**

<b>Pollutant</b>	<b>Reference Case</b>	<b>Control Case</b>	<b>Reduction in Tons</b>	<b>Percent Reduction</b>
Benzene	2757	985	1772	64
Naphthalene	145	58	87	60
Ethyl Benzene	2428	968	1460	60
Toluene	12218	4872	7346	60
n-Hexane	6341	2528	3812	60
2,2,4-Trimethylpentane	5719	2280	3438	60
Xylenes	6971	2780	4191	60
MTBE	8705	3471	5234	60
<b>Total</b>	<b>45283</b>	<b>17942</b>	<b>27341</b>	<b>60</b>

**Table 2.2.-50. Reductions in Benzene Emissions (Tons) with PFC Control by State, 2030.**

State	Reference Case	Control Case	Reduction	% Change
ALABAMA	65	39	26	40
ALASKA	42	25	17	40
ARIZONA	45	27	18	40
ARKANSAS	47	27	20	43
CALIFORNIA	92	55	37	40
COLORADO	83	52	31	37
CONNECTICUT	11	10	1	9
DELAWARE	3	3	0	0
DISTRICT OF COLUMBIA	1	1	0	0
FLORIDA	224	134	90	40
GEORGIA	84	50	34	40
HAWAII	8	8	0	0
IDAHO	28	18	10	36
ILLINOIS	98	64	34	35
INDIANA	67	37	30	45
IOWA	42	23	19	45
KANSAS	46	25	21	46
KENTUCKY	50	29	21	42
LOUISIANA	68	39	29	43
MAINE	5	4	1	20
MARYLAND	20	16	4	20
MASSACHUSETTS	18	20	-2	-11
MICHIGAN	219	118	101	46
MINNESOTA	67	36	31	46
MISSISSIPPI	35	20	15	43
MISSOURI	80	46	34	43
MONTANA	18	11	7	39
NEBRASKA	23	13	10	43
NEVADA	13	10	3	23
NEW HAMPSHIRE	12	9	3	25
NEW JERSEY	26	24	2	8
NEW MEXICO	31	18	13	42
NEW YORK	47	32	15	32
NORTH CAROLINA	115	69	46	40
NORTH DAKOTA	10	6	4	40
OHIO	167	90	77	46
OKLAHOMA	51	28	23	45
OREGON	92	55	37	40
PENNSYLVANIA	45	29	16	36
RHODE ISLAND	2	2	0	0
SOUTH CAROLINA	49	29	20	41
SOUTH DAKOTA	9	5	4	44
TENNESSEE	69	42	27	39
TEXAS	104	65	39	38
UTAH	34	21	13	38
VERMONT	3	2	1	33
VIRGINIA	30	21	9	30
WASHINGTON	135	81	54	40
WEST VIRGINIA	33	20	13	39
WISCONSIN	78	46	32	41
WYOMING	10	7	3	30

#### 2.2.2.2.4 Cumulative Reductions of Proposed 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 gas cans depend on both fuel benzene content and the gas can emission controls. Tables 2.2.-51 and 2.2.-52 summarize the expected reductions in benzene and MSAT emissions, respectively, from the combined effects of our proposed vehicle, fuel, and gas can controls.

Table 2.2.-53 summarizes the cumulative benzene emission reductions from these controls on highway gasoline vehicles, nonroad gasoline vehicles, gas cans, and gasoline distribution at the State level in 2030.

Table 2.2.-54 presents the impact of proposed controls on total benzene emissions from mobile sources and portable fuel containers, and the impacts on total benzene emissions from all sources. Table 2.2.-55 presents the cumulative impact of proposed controls on total emissions of mobile source air toxics from mobile source and portable fuel containers, as well as the impact on total emissions of mobile source air toxics from both mobile and stationary sources. As discussed previously, the fuel benzene control reduces stationary source emissions of benzene associated with gasoline distribution.

**Table 2.2-51. Estimated Reductions in Benzene Emissions from All Proposed Control Measures by Sector, 2015 to 2030.**

<b>Benzene</b>	<b>1999</b>	<b>2015</b>			<b>2020</b>			<b>2030</b>		
		Without Rule (tons)	With Rule (tons)	Reductions (tons)	Without Rule (tons)	With Rule (tons)	Reductions (tons)	Without Rule (tons)	With Rule (tons)	Reductions (tons)
<b>Gasoline On-road Mobile Sources</b>	178,465	103,798	77,155	26,643	108,256	71,326	36,930	127,058	70,682	56,376
<b>Gasoline Nonroad Mobile Sources</b>	58,710	37,747	33,247	4,500	36,440	32,018	4,422	39,162	34,400	4,762
<b>Gas Cans</b>	2,229	2,262	492	1,770	2,423	531	1,892	2,757	610	2,147
<b>Gasoline Distribution</b>	5,502	5,999	4,054	1,945	6,207	4,210	1,997	6,207	4,210	1,997
<b>Total</b>	244,905	149,806	114,948	34,858	153,326	108,085	45,241	175,184	109,902	65,282

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

MSAT	1999	2015			2020			2030		
		Without Rule (tons)	With Rule (tons)	Reductions (tons)	Without Rule (tons)	With Rule (tons)	Reductions (tons)	Without Rule (tons)	With Rule (tons)	Reductions (tons)
<b>Gasoline On-road Mobile Sources</b>	1,415,502	731,283	613,227	118,056	745,769	555,541	190,228	865,767	548,298	317,469
<b>Gasoline Nonroad Mobile Sources</b>	673,922	432,953	428,506	4,447	390,468	386,095	4,373	405,119	400,408	4,711
<b>Gas Cans</b>	39,581	37,076	14,143	22,933	39,751	15,268	24,483	45,284	17,567	27,717
<b>Gasoline Distribution</b>	50,625	62,804	60,859	1,945	64,933	62,936	1,997	64,933	62,936	1,997
<b>Total</b>	2,179,630	1,264,116	1,116,735	147,381	1,240,921	1,019,840	221,081	1,381,103	1,029,209	351,894

**Table 2.2.-53. Cumulative Benzene Emission Reductions From All Proposed Controls at the State level in 2030.**

	Gasoline Highway Vehicles		Nonroad Gasoline Engines		Gas Cans		Gasoline Distribution		Total	
	Tons Reduced	%	Tons Reduced	%	Tons Reduced	%	Tons Reduced	%	Tons Reduced	%
ALABAMA	801	37	102	14	56	86	39	43	998	34
ALASKA	821	65	51	32	37	89	3	40	912	64
ARIZONA	756	39	70	11	35	79	32	40	893	34
ARKANSAS	500	39	68	15	42	89	18	43	628	36
CALIFORNIA	3979	44	314	10	37	40	4	2	4334	35
COLORADO	1402	39	85	15	68	81	24	37	1579	37
CONNECTICUT	482	47	8	2	4	33	4	8	498	35
DELAWARE	122	44	3	2	1	30	1	8	127	30
DISTRICT OF COLUMBIA	51	42	0	2	0	37	1	8	52	43
FLORIDA	989	23	424	14	180	80	94	40	1687	21
GEORGIA	1599	38	148	13	68	80	42	40	1857	34
HAWAII	8	4	1	1	6	75	3	40	18	6
IDAHO	614	50	49	18	23	80	20	37	706	47
ILLINOIS	2261	48	104	8	74	75	69	29	2508	40
INDIANA	1826	47	110	14	55	82	41	42	2032	43
IOWA	829	49	77	17	36	85	43	46	985	45
KANSAS	881	48	66	18	39	84	73	46	1059	47
KENTUCKY	1081	46	73	14	42	85	49	41	1245	42
LOUISIANA	527	34	131	17	60	88	123	43	841	33
MAINE	359	47	19	6	3	51	13	24	394	36
MARYLAND	820	44	32	4	7	37	10	15	869	32
MASSACHUSETTS	877	47	14	2	6	31	6	8	903	35
MICHIGAN	3428	49	308	17	193	88	96	46	4025	43
MINNESOTA	2187	53	182	17	56	84	58	46	2483	47
MISSISSIPPI	388	39	73	16	30	87	45	43	536	36

	Gasoline Highway Vehicles		Nonroad Gasoline Engines		Gas Cans		Gasoline Distribution		Total	
	Tons Reduced	%	Tons Reduced	%	Tons Reduced	%	Tons Reduced	%	Tons Reduced	%
MISSOURI	1582	46	122	14	66	83	24	36	1794	41
MONTANA	549	52	25	17	15	83	11	37	600	50
NEBRASKA	587	49	43	17	97	84	12	46	739	50
NEVADA	428	39	20	8	9	85	7	40	464	34
NEW HAMPSHIRE	350	44	16	7	10	80	2	17	378	37
NEW JERSEY	928	45	21	2	8	32	7	8	964	31
NEW MEXICO	605	43	40	19	26	84	33	43	704	43
NEW YORK	3018	46	129	6	22	47	112	14	3281	36
NORTH CAROLINA	1536	41	164	14	97	84	39	40	1836	36
NORTH DAKOTA	350	53	24	18	9	85	11	46	394	49
OHIO	2567	49	244	16	142	85	96	46	3049	43
OKLAHOMA	763	39	76	16	45	88	70	46	954	38
OREGON	1587	50	107	18	77	83	55	40	1826	47
PENNSYLVANIA	2302	46	128	9	24	52	70	36	2524	39
RHODE ISLAND	126	46	2	2	1	22	1	8	130	35
SOUTH CAROLINA	812	40	91	14	40	83	20	40	963	36
SOUTH DAKOTA	314	51	21	17	7	84	7	46	349	47
TENNESSEE	1233	43	111	14	59	85	55	46	1458	39
TEXAS	1963	30	400	12	55	53	269	29	2687	25
UTAH	741	50	54	15	27	80	23	37	845	45
VERMONT	286	47	12	11	1	55	1	40	300	42
VIRGINIA	1271	42	58	7	14	47	32	28	1375	35
WASHINGTON	2386	54	161	19	111	82	32	40	2690	50
WEST VIRGINIA	386	49	37	15	29	88	60	40	512	47
WISCONSIN	1802	49	128	14	66	85	24	37	2020	44
WYOMING	344	51	18	17	9	82	11	37	382	49

**Table 2.2.-54.** Impact of proposed controls on total benzene emissions from mobile sources, and the impacts on total benzene emissions from all sources.

	Mobile Source and PFC Tons Reduced	Mobile Source and PFC Tons	% of Mobile Source and PFC Tons Reduced	Total Tons Reduced	Total Mobile and Stationary Tons	% of Mobile and Stationary Tons Reduced
2015						
Fuel Benzene Control	16687	149602	11	18632	269787	7
Vehicle Control	16858	149602	11	16858	269787	6
Fuel, Vehicle and PFC Control	32912	149602	22	34857	269787	13
2020						
Fuel Benzene Control	16790	152618	11	18787	276295	7
Vehicle Control	28104	152618	18	28104	276295	10
Fuel, Vehicle and PFC Control	43245	152618	28	45242	276295	16
2030						
Fuel Benzene Control	20997	174753	12	20997	298430	7
Vehicle Control	47688	174753	27	47688	298430	16
Fuel, Vehicle and PFC Control	65281	174753	37	65281	298430	22

**Table 2.2.-55.** Cumulative impact of proposed controls on total emissions of mobile source air toxics from mobile source and portable fuel containers, as well as the impact on total emissions of mobile source air toxics from both mobile and stationary sources.

	Mobile Source and PFC Tons Reduced	Mobile Source and PFC Tons	% of Mobile and PFC Tons Reduced	Total Tons Reduced	Total Mobile and Stationary Tons	% of Mobile and Stationary Tons Reduced
2015	145436	1260205	12	147381	4164490	4
2020	240032	1229591	20	242029	4362301	6
2030	373658	1369867	27	375655	4502577	8

## 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.<sup>61, 62</sup> 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.<sup>63</sup>

Eastern Research Group, under contract to EPA, recently compared exhaust emissions data from newer technology vehicles to see if the toxic 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.<sup>64</sup> The data from EPA's Office of Research and Development have been published.<sup>65</sup>

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. Initial 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.<sup>66</sup> 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<sub>x</sub> 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.<sup>67,68,69,70,71</sup> 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<sup>72</sup>. 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**

Type	Standard	Fuel	Formaldehyde		Acetaldehyde		Acrolein		Propionaldehyde		Toluene		2,2,4-Trimethylpentane		Xylene	
			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<sup>73,74,75</sup>. 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<sub>2</sub>O and a range of C<sub>1</sub> - C<sub>12</sub> 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 the emission data, EPA will 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 of creating category- and power-specific TAFs for NONROAD. The data will also be used to update NMIM inventories for toxic air compounds.

## **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 70% between 1999 and 2020. 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.

### **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.

#### **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.<sup>B</sup> 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 the Complex Model) were 104.5 mg/mile<sup>C</sup>; 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<sup>76</sup> 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.<sup>D</sup> 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 importers in business during the baseline period had sufficient data to establish an

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<sup>B</sup>See RFG rule for why evaporative emissions are not included in the anti-dumping toxics determination.

<sup>C</sup>Phase II

<sup>D</sup>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).

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**

EPA's gasoline sulfur program<sup>77</sup> requires, beginning in 2006, that sulfur levels in gasoline can be no higher in any one batch than 80 ppm, and must average 30 ppm annually. When 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. 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 6-9 psi, and wintertime RVP ranges from about 9-14 psi, when additional vapor is required for starting in cold temperatures. Gasoline vapors contain a subset of the liquid gasoline components, and thus can contain toxics compounds such as benzene. EPA has controlled summertime gasoline RVP since 1989 primarily as a VOC and ozone precursor control, which also results in some 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.<sup>78</sup> This program contains averaging, banking and trading provisions, as well as other compliance flexibilities. In June 2004, EPA issued rules governing the sulfur content of diesel fuel used in nonroad diesel engines.<sup>79</sup> 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 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. The removal of lead from gasoline has essentially eliminated on-highway mobile source emissions of this highly toxic substance.

#### **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.<sup>80</sup> 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.<sup>81</sup> 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), February 10, 2000	2004 - 2009	✓	✓
	NLEV (National Low-Emitting Vehicle)	1999 - 2003	✓	✓
	Enhanced Evaporative Emissions		✓	
	SFTP (Supplemental FTP) Procedures	2001 (start)	✓	
Heavy-duty trucks	2004 Heavy-duty Rule October 6, 2000	2004 - 2007	✓	✓
	2007 Heavy-duty Rule (including low sulfur fuel), January 18, 2001	2007 - 2010		
Urban Buses	HD Diesel Retrofit	1994 - 1998		✓
Highway motorcycles	December 2003	2006 - 2010	✓	

\* Standards in various forms including HC, NMHC, NMOG, and NO<sub>x</sub>+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	✓	✓
	Tier 3, October 23, 1998	2006-2008	✓	✓
	Tier 4 (w/ low sulfur fuel) June 29, 2004	2008-2014	✓	✓
Locomotives	Tier 0, Tier 1, Tier 2 April 16, 1998	2002 – 2005	✓	✓
Marine	Spark-ignition Gasoline Engine Standards, October 4, 1996	1998 - 2006	✓	
	Diesel Engines, less than 50hp	1999 - 2005		✓
	Recreational Diesel, November 8, 2002	Starting 2006/2009	✓	✓
	Commercial Diesel, February 28, 2003	Starting 2004/2007	✓	✓
Large spark- ignition engines	Tier 1 Standards Tier 2 Standards November 8, 2002	2004 - 2007 2007 - 20XX	✓	
Small spark- ignition engines	Phase 1 Standards,	1997 - 2007	✓	
	Handheld Phase 2 Standards, April 25, 2000	2002 - 2007	✓	
	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	✓	

\* Standards in various forms including HC, NMHC, NMOG, and NO<sub>x</sub>+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, mining equipment and marine engines).<sup>82</sup> These standards are similar in stringency to the 2007 highway diesel engine standards, and are likewise enabled by stringent controls on sulfur levels in 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 fuel controls are scheduled to begin in mid-2007.

#### **2.4.3.2 Small Land-Based SI Engines**

Small land-based spark-ignition (Small SI) engines at or below 25 hp are used primarily in lawn and garden equipment such as lawn mowers, string trimmers, chain saws, lawn and garden tractors, and other similar equipment. Our Phase 1 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.<sup>83</sup> We also have Phase 2 regulations for these engines which, when fully phased-in, are projected to result in additional combined HC and NOx reductions beyond the Phase 1 levels of 60 percent for new non-handheld engines and of 70 percent for new handheld engines.<sup>84</sup> We are currently developing a proposal for Phase 3 standards that would further reduce HC emissions from Small SI engines.

#### **2.4.3.3 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.<sup>85</sup> 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.

#### **2.4.3.4 Recreational Vehicles**

Standards for recreational vehicles, including snowmobiles, off-road motorcycles and “all terrain” vehicles, will begin in 2006. These standards will require significant reductions in HC emissions from new engines, ranging from 50 to 86 percent compared to pre-controlled engines.<sup>86</sup>

#### **2.4.3.5 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. For gasoline-fueled engines, we adopted an initial tier of standards with a phase-in schedule that is complete in the 2006 model year. These standards, which apply to outboard and personal-watercraft engines, have led to a major shift to four-stroke engines and advanced-technology two-stroke engines for an estimated 75 percent reduction in hydrocarbon emissions from uncontrolled levels.<sup>87</sup> We are developing a proposal to adopt new, more stringent standards for these engines that would reduce emissions from these engines by an additional 60 percent or more from the previous tier.

Another kind of gasoline-fueled marine engine, referred to as stern drive and inboard engines, uses an automotive-type engine. 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 gasoline marine engine proposal.<sup>88</sup> These new standards would likely be based on the application of catalyst technology to substantially reduce hydrocarbon and NOx emissions.

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.<sup>89</sup> 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 NO<sub>x</sub> and PM emissions. Finally, we adopted standards to control NO<sub>x</sub> 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 SO<sub>x</sub> 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 SO<sub>x</sub> emissions.

#### **2.4.3.6 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.<sup>90</sup> 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.”<sup>E</sup> 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 NO<sub>x</sub> 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 NO<sub>x</sub> reductions beyond the Tier 0 and Tier 1 regulations. We are currently developing a new tier of more stringent emissions standards for locomotive engines.

#### **2.4.3.7 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) NO<sub>x</sub> and CO emission standards for gas turbine engines. In 2005, we tightened the NO<sub>x</sub> 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.

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<sup>E</sup> “Remanufacture” is an engine rebuild “to new” during four-to-eight year long maintenance cycles.

#### **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 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.

Reducing vehicle idling provides important environmental benefits. As a part of their daily routine, truck drivers often keep their vehicles 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 take advantage of proven systems that provide drivers with basic necessities without using the engine. To date, there are 50 stationary anti-idling projects, and mobile technology has been installed on nearly 20,000 trucks. The SmartWay Transport Partnership also works with the freight industry to reduce fuel use (with a concomitant reduction in emissions) 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<sup>SM</sup> program is working with employers across the country to reverse the trend of longer, single-occupancy vehicle commuting. OTAQ has created a national list of the Best Workplaces for Commuters to formally recognize employers that offer superior commuter benefits such as free transit passes, subsidized vanpools/carpools, and flexi-place, or work-from-home, programs. More than 1,300 employers representing 2.8 million U.S. workers have been designated Best Workplaces for Commuters.

Much of the growth in the Best Workplaces for Commuters program has been through metro area-wide campaigns. Since 2002, EPA has worked with coalitions in 14

major metropolitan areas to increase the penetration of commuter benefits in the marketplace and the visibility of the companies that have received the BWC 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 “District” designation to twenty locations across the country including downtown Denver, Houston, Minneapolis and Tampa.

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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 is 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 has 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.<sup>1</sup> 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.<sup>2</sup> 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. EPA also recently published a draft National Air Toxics Monitoring Strategy to advance this goal.<sup>3</sup>

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).

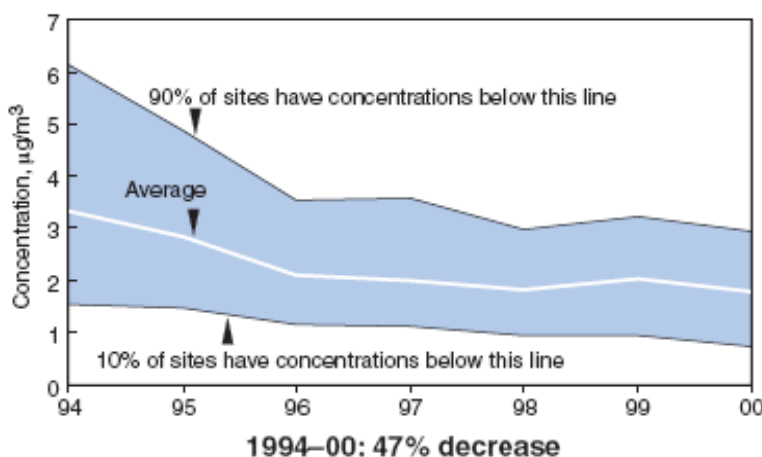
**Figure 3.1-1. Map of Ten Cities in Monitoring Pilot Project**



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 22 national air toxics trends sites (NATTS), and numerous community-scale monitoring studies.<sup>4</sup> 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](http://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.

New York State has a systematic program in place that has been measuring air toxics since the 1990s.<sup>5</sup> 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 of the concentration data. The analysis indicated that ambient concentration levels of benzene decreased by as much as 60% 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.

The downward trend in benzene concentrations reported for New York is consistent with other reported changes in ambient levels of benzene. In California, the Air Resources Board (ARB) maintains an Almanac of Emissions and Air Quality.<sup>6</sup> 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.

**Table 3.1-1. Site Descriptions of the Monitoring Stations Along with Mean Benzene Concentration from 1990-2003 and 2001-2003**

	<b>Lackawanna</b>	<b>Eastern District High School</b>	<b>Troy</b>	<b>Niagara Falls</b>	<b>Whiteface Mountain Base Lodge</b>
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 ( $\mu\text{g}/\text{m}^3$ )	5.09	2.85	2.31	1.80	0.86
Period 2001-2003 Mean Concentration ( $\mu\text{g}/\text{m}^3$ )	2.26	2.05	1.68	1.08	0.54

Another recent evaluation of hazardous air pollutant (HAP) trends was conducted for selected metropolitan areas.<sup>7</sup> 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. Additional reductions are expected with the implementation of additional regulatory measures such as this one.

### **3.1.2 Population-Based (Representative) Exposure Measurements**

In addition to measurements of outdoor and microenvironmental concentrations, an important component of understanding human exposure to air toxics is the body of studies that employ survey techniques to assess 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.<sup>8</sup> 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  $7.52 \mu\text{g}/\text{m}^3$ , with indoor air concentrations averaging  $7.21 \mu\text{g}/\text{m}^3$ . Outdoor air concentrations averaged  $3.61 \mu\text{g}/\text{m}^3$ . Personal air concentrations were significantly associated with indoor air concentrations, as well as blood concentrations.

The results of the NHEXAS study in Arizona, another study area, indicate that median indoor concentrations were  $1.3 \mu\text{g}/\text{m}^3$  during the mid-1990's, while outdoor concentrations were  $1.0 \mu\text{g}/\text{m}^3$ .<sup>9</sup> 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.<sup>10</sup> 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, was also obtained for the study

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

<b>Metropolitan Area</b>	<b>1990 Emissions</b>	<b>2002 Emissions</b>	<b>% Change in Emissions</b>	<b>1990-1994 Average Concentration</b>	<b>2002-2003 Average Concentration</b>	<b>% Change in Concentration</b>
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

area. Overall, outdoor modeled concentrations of benzene and other fuel-related VOCs corresponded well with measured data in the area. Average personal exposure to benzene was  $4.06 \mu\text{g}/\text{m}^3$ , while 95<sup>th</sup> percentile values were  $7.30 \mu\text{g}/\text{m}^3$ . For indoors, the respective values were 3.70 and  $8.34 \mu\text{g}/\text{m}^3$ , while for outdoors the values were 1.84 and  $3.14 \mu\text{g}/\text{m}^3$ . 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 Relationship Between 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.<sup>11</sup> 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  $3.64 \mu\text{g}/\text{m}^3$ , with a 95<sup>th</sup> percentile of  $10.7 \mu\text{g}/\text{m}^3$ . Respective statistics for indoor air were  $3.50 \mu\text{g}/\text{m}^3$  and  $10.0 \mu\text{g}/\text{m}^3$ , while outdoor statistics were 2.15 and  $5.16 \mu\text{g}/\text{m}^3$ . In further EPA-funded analysis of the data from Elizabeth, NJ, concentrations of benzene, toluene, ethylbenzene, and xylene isomers were found to be associated with proximity to both major roadways and gas stations, as was  $\text{PM}_{2.5}$ , EC, and several PAHs.<sup>12,13</sup> Section 3.1.3 provides more detail on concentrations and exposures in these types of mobile-source impacted areas.

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,<sup>14</sup> 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  $4.6 \mu\text{g}/\text{m}^3$ , with the data skewed right. The 95th percentile concentration was  $12.7 \mu\text{g}/\text{m}^3$ . Homes with attached garages had significantly higher concentrations of benzene indoors. 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  $4.8 \mu\text{g}/\text{m}^3$ , with a 95th percentile of  $9.1 \mu\text{g}/\text{m}^3$ . Indoor concentrations in the intensive period averaged  $3.9 \mu\text{g}/\text{m}^3$  and outdoor averaged  $3.3 \mu\text{g}/\text{m}^3$ . Regression analysis indicated that personal exposures generally were higher than the time-weighted average of indoor and outdoor air. Furthermore, living in a home with an attached garage was associated with elevated personal exposures to both benzene and toluene.

In another study, students recruited from an inner-city school in Minneapolis, MN participated in an exposure study called SHIELD.<sup>15</sup> 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  $\mu\text{g}/\text{m}^3$  in spring and 2.1  $\mu\text{g}/\text{m}^3$  in winter.<sup>16</sup>

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.<sup>17</sup> Average winter benzene personal concentrations were 4.70  $\mu\text{g}/\text{m}^3$ , while indoor and outdoor concentrations averaged 5.97 and 2.55  $\mu\text{g}/\text{m}^3$ . Summer values were 3.09, 1.75, and 1.31  $\mu\text{g}/\text{m}^3$ , respectively. The authors noted that VOC concentrations within the city tracked traffic patterns. Generally, indoor concentrations in Los Angeles were of similar magnitude, while personal exposures were not reported as of the time of this proposal. There was no substantial evidence for indoor sources of benzene.<sup>18</sup>

Overall, these studies show that personal and indoor concentrations of benzene and other VOCs are significantly higher than found outdoors. Some of the factors leading to these elevated concentrations are 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<sup>a</sup>**

<b>Location</b>	<b>Year(s)</b>	<b>Includes Smokers</b>	<b>Average (µg/m<sup>3</sup>)</b>	<b>“Upper Bound” (µg/m<sup>3</sup>)</b>	<b>Reference</b>
EPA Region 5	1995-1996	Yes	7.21	13.71 <sup>b</sup>	Clayton et al. (1999)
Baltimore, MD	2000-2001	No	4.06	7.30 <sup>c</sup>	Payne-Sturges et al. (2004)
NJ, TX, CA	1999-2001	No	3.64	10.7 <sup>c</sup>	Weisel et al. (2005)
<i>Minneapolis - St. Paul, MN</i>	<i>1997</i>	<i>Yes<sup>e</sup></i>	<i>4.8</i>	<i>9.1</i>	<i>Adgate et al. (2004a)</i>
<i>Minneapolis, MN</i>	<i>2000</i>	<i>Yes<sup>e</sup></i>	<i>2.1 Winter 1.5 Spring</i>	<i>6.5 Winter<sup>b</sup> 4.2 Spring<sup>b</sup></i>	<i>Adgate et al. (2004b)</i>
<i>New York, NY</i>	<i>1999</i>	<i>No</i>	<i>4.7 Winter 3.1 Summer</i>	<i>11.4 Winter<sup>d</sup> 7.0 Summer<sup>d</sup></i>	<i>Kinney et al. (2002)</i>

<sup>a</sup> Children’s studies in italics

<sup>b</sup> 90<sup>th</sup> percentile

<sup>c</sup> 95<sup>th</sup> percentile

<sup>d</sup> Mean +2 standard deviations

<sup>e</sup> Smoking in homes

### 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.<sup>19</sup>

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

Description	Particle Size, $d_p$ ( $\mu\text{m}$ )
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) <sup>a</sup>	$d_p \leq 0.1$

<sup>a</sup> Nuclei Mode has also been defined as  $d_p \leq 0.05 \mu\text{m}$  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.  $\text{PM}_{10}$  is defined as particulate matter with an aerodynamic diameter of less than or equal to  $10 \mu\text{m}$ .  $\text{PM}_{10}$  is regulated as a specific type of "pollutant" because this size range is considered respirable and can penetrate into the lower respiratory tract.  $\text{PM}_{2.5}$  is particulate matter with an aerodynamic diameter less than or equal to  $2.5 \mu\text{m}$ .  $\text{PM}_{2.5}$  settles quite slowly in the atmosphere relative to coarse and supercoarse particles. Normal weather patterns can keep  $\text{PM}_{2.5}$  airborne for several hours to several days and enable these particles to transport hundreds of miles.  $\text{PM}_{2.5}$  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.<sup>20,21</sup> 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  $0.1 \mu\text{m}$ . On a volume and mass basis, the size distribution of particles emitted from mobile sources has an average particle diameter of approximately  $0.2 \mu\text{m}$ .

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.<sup>22,23</sup> 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.<sup>24,25</sup> 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.<sup>26</sup> 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.<sup>27</sup>

An increase in fine particles near roads could originate from engine deterioration, brake and tire wear, and secondary aerosol formation.<sup>28,29,30,31</sup> Engine deterioration is generally a function of vehicle age and maintenance condition. Brake wear emissions are highly dependent on brake pad materials.<sup>32</sup> 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.<sup>33</sup> Wind direction also affects traffic-related air pollution mass concentrations inside and outside of schools near motorways.<sup>34,35</sup> 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 sources 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.

The NATA National-Scale Assessment estimates average concentrations within a census tract, but it does not differentiate between locations near roadways and those further away. Local-scale modeling can better characterize distributions of concentrations, as observed in assessments done in Houston, TX and Portland, OR. The Houston study calculated the average benzene concentration to be  $2.29 \mu\text{g}/\text{m}^3$ ,<sup>36</sup> using the same emissions inventory as used in the 1996 NATA National-Scale Assessment but with more refined allocation of highway vehicle emissions. In this study, spatially defined inventories placed vehicle emissions at the location of actual roadway links, thus characterizing with greater resolution the spatial distribution of ambient benzene concentrations. As a result, there was better agreement with monitor data ( $2.97 \mu\text{g}/\text{m}^3$ ), than what was obtained by gridding emissions ( $2.09 \mu\text{g}/\text{m}^3$ ). The Portland study modeled concentrations of air toxics at the center of every census block group in the Portland, OR metropolitan area.<sup>37</sup> A subsequent analysis determined average 1,3-butadiene, benzene, and diesel PM concentrations at several distances from major roadways (0-50, 50-200, 200-400, and > 400 m). For benzene, the resulting average concentrations were 1.29, 0.64, 0.40, and 0.12  $\mu\text{g}/\text{m}^3$ , respectively, illustrating the steep concentration gradient around roadways. The overall mean benzene concentration modeled in Portland was  $0.21 \mu\text{g}/\text{m}^3$ .

Air quality monitoring is another means of evaluating pollutant concentrations at locations near sources such as roadways. Several 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.<sup>38,39,40,41,42,43</sup> For example, measurements near a tollbooth in Baltimore observed mean benzene concentrations to vary by time of day from 3 to  $22.3 \mu\text{g}/\text{m}^3$  depending on traffic volume, vehicle type, and meteorology.<sup>44</sup> 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  $\mu\text{g}/\text{m}^3$ .<sup>45</sup> Another study measured the average benzene concentration in a relatively high traffic density (~ 16000 automobiles/day) sampling area at  $9.6 \mu\text{g}/\text{m}^3$  and in rural areas with

hardly any traffic (< 50 automobiles/day) at  $1.3 \mu\text{g}/\text{m}^3$ .<sup>46</sup> 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.

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.<sup>47</sup> 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.

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.<sup>48,49,50,51,52</sup> Researchers have demonstrated exponential decreases in CO, as well as PM number, and black carbon (as measured by an aethalometer), concentration with increasing downwind distance from a freeway in Los Angeles.<sup>53,54</sup> 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).<sup>55</sup> Troopers operated their vehicles in typical patterns, including highway and city driving and refueling. In-vehicle benzene concentrations averaged  $12.8 \mu\text{g}/\text{m}^3$ , while concentrations measured at an “ambient” site located outside a nearby state environmental office averaged  $0.32 \mu\text{g}/\text{m}^3$ . 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.<sup>56</sup> 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 ( $17.5 \mu\text{g}/\text{m}^3$ ), in parking garages above-ground ( $155 \mu\text{g}/\text{m}^3$ ) and below-ground ( $61.7 \mu\text{g}/\text{m}^3$ ), in urban street canyons ( $7.54 \mu\text{g}/\text{m}^3$ ), and during refueling ( $46.0 \mu\text{g}/\text{m}^3$ ). It should be noted that sample sizes in this screening study were small, usually with only one to two samples per microenvironment.

In 1998, the California Air Resources Board published an extensive study of concentrations of in-vehicle air toxics in Los Angeles and Sacramento, CA.<sup>57</sup> The data set is large and included a variety of sampling conditions. On urban freeways, in-vehicle benzene concentrations ranged from 3 to  $15 \mu\text{g}/\text{m}^3$  in Sacramento and 10 to  $22 \mu\text{g}/\text{m}^3$  in Los Angeles. In comparison, ambient benzene concentrations ranged from 1 to  $3 \mu\text{g}/\text{m}^3$  in Sacramento and 3 to  $7 \mu\text{g}/\text{m}^3$  in Los Angeles.

Studies have also been conducted in diesel buses, such as the one recently conducted of LA school buses.<sup>58,59</sup> 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  $9.5 \mu\text{g}/\text{m}^3$ , compared with  $1.6 \mu\text{g}/\text{m}^3$  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.<sup>60</sup> Real-time concentrations of black carbon (BC), particle-bound PAH, nitrogen dioxide ( $\text{NO}_2$ ), particle counts ( $0.3\text{-}0.5 \mu\text{m}$  size range), and  $\text{PM}_{2.5}$  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<sub>2</sub>, Particle Count (PC), and PM<sub>2.5</sub> in Three School Bus Commute Microenvironments and Background Air**

	Mean Concentrations			
	Background	(Un)Loading Zone	Bus Stops	Bus Commutes <sup>a</sup>
BC (µg/m <sup>3</sup> )	2 ± 0.1	2 ± 0.3	4 ± 0.4	3-19 (8)
Particle Bound -PAH (µg/m <sup>3</sup> )	0.027 ± 0.0015	0.015 ± 0.0003	0.044 ± 0.0045	0.064-0.400 (0.134)
NO <sub>2</sub> (ppb)	49 ± 1.0	35 ± 0.2	54 ± 1.9	34-110 (73)
PC (count/cm <sup>3</sup> )	83 ± 3.1	Not collected	62 ± 1.8	77-236 (130)
PM <sub>2.5</sub> (µg/m <sup>3</sup> )	20 ± 2.4	Not collected	25 <sup>b</sup>	21-62 (43)

<sup>a</sup> Ranges are associated with different bus types and window positions. Values in parenthesis are the mean for all runs.

<sup>b</sup> 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.<sup>61</sup> The average in-bus concentration of benzene was 4.5 µg/m<sup>3</sup>, while the average concentrations at three fixed sites taken during the study period ranged from 0.9-2.0 µg/m<sup>3</sup>. 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.<sup>62,63,64,65,66,67</sup>

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.<sup>68,69,70</sup> 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 ( $\mu\text{g}/\text{m}^3$ ) Measured in Vehicles and in Ambient Air**

Study	In-Vehicle		Ambient Air	
	Mean	Max	Mean	Max
Raleigh, NC (1989) <sup>a</sup>	11.6	42.8	1.9	8.5
CA South Coast Air Basin (1989) <sup>b</sup>	42.5	267.1	9.3-16.9	--
Boston, MA (1991) <sup>c</sup>	17.0	64.0	--	--
Los Angeles, CA (1998)	10-22	--	3-7	--
Sacramento, CA (1998)	3-15	--	1-3	--
Detroit, MI (2000) <sup>d</sup>	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

<sup>a</sup> A one-hour measurement was taken for each experimental trip.

<sup>b</sup> The estimated sampling time period was 1.5 hours/round-trip. n=191.

<sup>c</sup> In-vehicle measurement includes both interstate and urban driving, n=40.

<sup>d</sup> 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 majority of what is outdoors can therefore get indoors. A review of the literature determined that approximately 100% of gaseous compounds, such as benzene, and 80% of diesel PM can penetrate indoors.<sup>71,72</sup>

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.<sup>73</sup> 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. Remaining results regarding the variance in traffic pollutant concentrations at schools in relation to proximity to roadways and traffic density will be available in 2006.

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.<sup>74</sup> Concentrations of the traffic pollutants PM<sub>10</sub>, PM<sub>2.5</sub>, black carbon, total NO<sub>x</sub>, and NO<sub>2</sub> 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, NO<sub>x</sub>, NO, and (to a lesser extent) NO<sub>2</sub>, due specifically to roads with heavy traffic within a relatively small geographic area.

An exposure assessment of PM<sub>10</sub> from a major highway interchange in East Los Angeles found that children in nearby schools were exposed to elevated pollutant levels.<sup>75</sup> Each of the four chosen schools was located within 500 m of a major limited-access highway, and three of them were within 150 m of the roadway. Using a computer model to calculate dispersion analysis, researchers predicted that average 24-hour (assuming 10-hour school-based exposure duration to account for time in class and at after-school programs) particle concentrations, which were dominated by road dust, would be 10.45, 14.58, 5.78, and 8.27 µg/m<sup>3</sup>, respectively, for the four schools studied. These results indicate a trend for increased emissions at school locations in closer proximity to the traffic source, with the exception of one school which was 25 m farther. These values reflect the increase in concentration over ambient exposure, not the total ambient exposure.

A study to assess children's exposure to traffic-related air pollution while attending schools near roadways was performed in the Netherlands.<sup>76</sup> Investigators measured PM<sub>2.5</sub>, NO<sub>2</sub> and benzene inside and outside of 24 schools located within 400 m of roadways. The indoor average benzene concentration was 3.2 µg/m<sup>3</sup>, with a range of 0.6-8.1 µg/m<sup>3</sup>. The outdoor average benzene concentration was 2.2 µg/m<sup>3</sup>, with a range of 0.3-5.0 µg/m<sup>3</sup>. 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<sub>10</sub>, and NO<sub>2</sub> in twelve schools between the periods of May and August 1995.<sup>77</sup> The schools were located at varying distances from the motorway (35-645 m). Results indicate that black smoke and NO<sub>2</sub> 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<sub>10</sub> 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.

The TEACH study (Toxic Exposure Assessment – Columbia/Harvard) measured the concentrations of VOCs, PM<sub>2.5</sub>, black carbon, and metals outside the homes of high school students in New York City.<sup>78</sup> 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, analyses of spatial and temporal patterns of MTBE concentrations, used as a tracer for motor vehicle pollution, were consistent with traffic patterns.

The RIOPA study was conducted in three cities (Los Angeles, CA, Houston, TX, and Elizabeth, NJ) during four seasons.<sup>79,80</sup> The study examined 100 non-smoking homes sited in high-emissions environments, including residential areas near freeways, service stations, petroleum industrial estates, and mixed sources. The cities involved were selected to represent different sources: Los Angeles (mobile source dominated), Houston (stationary source dominated), and Elizabeth, NJ (mixture of sources). Of the polycyclic aromatic hydrocarbons (PAHs) analyzed, the presence of 5-7 ring PAHs indoors was attributed to outdoor sources which, in Los Angeles and Elizabeth, NJ, could be attributed to mobile sources.

Average benzene concentrations were determined in a recent evaluation of the exposure of urban inhabitants to atmospheric benzene in Athens, Greece.<sup>81</sup> 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<sup>3</sup>, respectively. Urban levels varied between 15.4 and 27.9 µg/m<sup>3</sup> with an annual mean of 20.4 µg/m<sup>3</sup>. 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<sub>10</sub> 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.<sup>82</sup> Similarly, researchers found that traffic-related pollutant exposure concentrations of car drivers were higher than for cyclists.<sup>83</sup> 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<sub>2</sub> 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.<sup>84</sup> The mean concentration of benzene in the six pedestrian sidewalk samples was 6.8 µg/m<sup>3</sup>. This concentration was lower than the in-vehicle measurement (11.6 µg/m<sup>3</sup>), but higher than the fixed-site measurement (1.9 µg/m<sup>3</sup>) 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.<sup>85</sup> For pedestrians, mean time-weighted concentrations of benzene, toluene, and xylenes of 10.6, 19.8, and 16.7 µg/m<sup>3</sup>, 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<sup>3</sup>, 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.<sup>86</sup> 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<sub>10</sub>, PM<sub>2.5</sub>, and PM<sub>1</sub> were made during walking and in-car journeys on two suburban routes.<sup>87</sup> In-car measurements were highest (43.16, 15.54, and 7.03 µg/m<sup>3</sup> for PM<sub>10</sub>, PM<sub>2.5</sub>, and PM<sub>1</sub>, respectively) followed by walking (38.18, 15.06, and 7.14 µg/m<sup>3</sup>, respectively). Background levels were only available for PM<sub>10</sub> (26.55 µg/m<sup>3</sup>), but were significantly lower than the walking exposure levels. Researchers found similar results for CO exposure levels of schoolchildren commuters.<sup>88</sup> 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.

#### 3.1.3.2.4 Measurement Uncertainties

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 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. Air quality monitoring at these central sites often do not represent actual exposures, especially for populations living near roads.

Air quality 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.<sup>89</sup> 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.

Results from emissions studies suggest that simple methods of estimating the contribution of motor vehicle exhaust to exposure likely do not capture the substantial variability in the chemical and physical characteristics of motor vehicle exhaust. Comprehensive assessments of exposure will be a critical factor in identifying which compounds are impacting the near-road environment.

### **3.1.3.3 Exposure and Concentrations 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.<sup>90</sup> 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. One study from Minnesota examined homes constructed in 1994, 1998, and 2000.<sup>91</sup> 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.<sup>92</sup> 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.<sup>93</sup> 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.<sup>94</sup>

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) was a series of large, probability-based samples of people who underwent study of the air inside and outside their homes and in their personal breathing zones. The study took place in the 1980's, and found that a large fraction of an average nonsmoker's benzene exposure originated from sources in attached garages.<sup>95</sup> Work done as part of the TEAM study also identified stored gasoline as an important source of elevated benzene levels indoors.<sup>96</sup> 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. Gas can emissions, however, are significantly higher than evaporative emissions from lawn and garden equipment, 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. The garage also supplies contaminated air to the home to which it is attached, and emits the rest. One recent study from Michigan found average garage benzene concentrations of  $36.6 \mu\text{g}/\text{m}^3$ , with a standard deviation of  $38.5 \mu\text{g}/\text{m}^3$ , compared to mean and standard deviation concentrations of  $0.4 \mu\text{g}/\text{m}^3$  and  $0.12 \mu\text{g}/\text{m}^3$  in ambient air.<sup>97</sup> In Alaska, where fuel benzene levels tend to be very high and homes built very airtight, garage concentrations have been measured at even higher levels. One study measured average garage benzene concentrations of  $101 \mu\text{g}/\text{m}^3$ , with a standard deviation of  $38 \mu\text{g}/\text{m}^3$ .<sup>98</sup>

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.<sup>99</sup> 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  $3.77 \mu\text{g}/\text{m}^3$ , while during the hot soak, concentrations averaged  $13.4 \mu\text{g}/\text{m}^3$ . In the garage, concentrations averaged  $121 \mu\text{g}/\text{m}^3$  during the cold start. Prior to a cold start, indoor benzene concentrations averaged  $6.98 \mu\text{g}/\text{m}^3$ , while for the two hours following cold start, concentrations averaged  $25.9 \mu\text{g}/\text{m}^3$ . In the garage, concentrations averaged  $422 \mu\text{g}/\text{m}^3$  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.<sup>100</sup> Homes with attached garages had significantly higher concentrations of indoor benzene compared to homes without attached garages (70.8  $\mu\text{g}/\text{m}^3$  vs. 8.6  $\mu\text{g}/\text{m}^3$ ). 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.<sup>101</sup> 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.<sup>102</sup> 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.<sup>103</sup> Homes with attached garages had median toluene levels of 24  $\mu\text{g}/\text{m}^3$ , while homes without garages had median concentrations of 5  $\mu\text{g}/\text{m}^3$ . 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.<sup>104</sup>

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.<sup>105</sup> 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.

EPA undertook an investigation of the effect of attached garages on indoor air under various scenarios.<sup>106</sup> 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. Overall, using in-garage concentration data from Michigan, average indoor concentrations increase by approximately  $4.2 \mu\text{g}/\text{m}^3$ , relative to concentrations estimated without an attached garage term. Using data from Alaska, average indoor concentrations increase by  $11.6 \mu\text{g}/\text{m}^3$ , and using New Jersey data, by  $9.2 \mu\text{g}/\text{m}^3$ . As noted above, the National Human Activity Pattern Survey (NHAPS) estimates that the average person spends 16.68 hours per day indoors in a residence. Taking that into account, overall modeled exposures would be expected to increase by at least  $2.9 \mu\text{g}/\text{m}^3$ , using the Michigan data. These calculations imply that predicted exposures would more than double if attached garages were treated systematically in a national exposure model.

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 Exposure and Concentrations 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 significantly higher than found in outdoor air.

In November 1990, a study of microenvironments, partially funded by the US EPA, evaluated the potential range in concentrations of selected air toxics.<sup>107</sup> 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  $67.1 \mu\text{g}/\text{m}^3$  in the parking garage and  $12.8 \mu\text{g}/\text{m}^3$  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.<sup>108</sup> 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.

A comparative study of indoor air quality in Hong Kong showed that the levels of CO, NO<sub>x</sub>, and nonmethane hydrocarbons (NMHC) detected in a local park garage were the highest among 13 other indoor sampling locations.<sup>109</sup> 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.<sup>110</sup> 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<sub>2</sub>, PM<sub>10</sub>, and PM<sub>2.5</sub>. 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<sub>10</sub> and PM<sub>2.5</sub> 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 µg/m<sup>3</sup> and 43.1 to 175 µg/m<sup>3</sup>, respectively. The mean concentration of NMHC measured in the enclosed garage (1910 µg/m<sup>3</sup>) was about 17 times higher than in the semi-enclosed garage (94.6 µg/m<sup>3</sup>), 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. They 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.<sup>111</sup> 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.<sup>112</sup> Parameters of the parking areas at Liberty Cinema and Natraj Cinema were not specified, but 24-hour geometric means of benzene measured 117.4 and 74.2  $\mu\text{g}/\text{m}^3$  during the summer, 94.5 and 75.4  $\mu\text{g}/\text{m}^3$  during the monsoon, and 148.0 and 703.0  $\mu\text{g}/\text{m}^3$  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  $\mu\text{g}/\text{m}^3$ , 1.9 to 33.5  $\mu\text{g}/\text{m}^3$ , and 4.7 to 18.8  $\mu\text{g}/\text{m}^3$ , 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 NO<sub>x</sub>, CO, CO<sub>2</sub>, BTEX, and PM.<sup>113</sup> 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<sub>2</sub> 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  $\mu\text{g}/\text{m}^3$  and 10 to 350  $\mu\text{g}/\text{m}^3$ , respectively.

In Madrid, Spain, atmospheric pollution produced by vehicles in parking garages was studied.<sup>114</sup> Two parking garages of different design were chosen for measurements of PM<sub>10</sub>, 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  $\mu\text{g}/\text{m}^3$  on the weekdays versus 39  $\mu\text{g}/\text{m}^3$  on the weekend, which was similar to outdoor city average measurement (50  $\mu\text{g}/\text{m}^3$ ). 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 Exposure and Concentrations 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 Total Exposure Assessment Methodology (TEAM) Study was planned in 1979 and completed in 1985.<sup>115</sup> 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. One of the major findings was that pumping gas as well as exposure to auto exhaust was a specific and major source of 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 then exceed  $1000 \mu\text{g}/\text{m}^3$  (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. But since then, implementation of fuel controls 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.<sup>116</sup> 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  $28.8 \mu\text{g}/\text{m}^3$  with the maximum reported value of  $323 \mu\text{g}/\text{m}^3$ . The median benzene concentration in ambient air was significantly lower at  $12.8 \mu\text{g}/\text{m}^3$ .

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.<sup>117</sup> The mean (and maximum) benzene exposure measurements were 96 (927), 160 (1662), and 192 (607)  $\mu\text{g}/\text{m}^3$ , 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.<sup>118</sup> 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.<sup>119</sup> Air samples were collected at service stations in New Jersey, and the mean benzene in-cabin concentration was  $54.3 \mu\text{g}/\text{m}^3$  ( $n=46$ ). The background concentration at the pump island measured  $9.6 \mu\text{g}/\text{m}^3$  ( $n=36$ ). 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.

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.<sup>56</sup> 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  $46.0 \mu\text{g}/\text{m}^3$ .

### 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.<sup>120</sup> The studies reviewed indicate that benzene exposure can range from  $<1$  to more than  $10 \text{ mg/m}^3$ , 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 mobile source benzene emission reductions to reduce their exposures as well. This statement is echoed by researchers in the occupational literature.<sup>121</sup>

Handheld and non-handheld equipment operators are also exposed to elevated concentrations of fuel-related air toxics. 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.<sup>122</sup> Results demonstrated that equipment operators can experience highly variable exposures, with short-term personal concentrations of CO and  $\text{PM}_{2.5}$  ranging over two orders of magnitude. Air toxics data will be available later this year. 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.<sup>123</sup> A study of snowmobile rider exposures in Sweden found benzene concentrations ranging from under  $10 \text{ } \mu\text{g/m}^3$  to  $2.5 \text{ mg/m}^3$ , a range of at least two orders of magnitude. Exposures measured on riders on the back of the vehicle ranged from  $0.7\text{-}0.8 \text{ mg/m}^3$ . 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,  $\text{PM}_{10}$ , and CO.<sup>124</sup> Work shift benzene concentrations at a snowmobile entry gate  $176.7 \text{ } \mu\text{g/m}^3$ , while snowmobile-bound mobile patrol officers' exposure concentrations averaged  $137.20 \text{ } \mu\text{g/m}^3$ . The highest observed work shift concentration in the study was  $514.1 \text{ } \mu\text{g/m}^3$ . At major sites of tourist interest where snowmobiles parked, such as the Old Faithful geyser, concentrations averaged 41.3 to 48.8

$\mu\text{g}/\text{m}^3$ . 15-minute “peak” samples of workers’ personal air ranged from  $46.8 \mu\text{g}/\text{m}^3$  to  $842.8 \mu\text{g}/\text{m}^3$ . 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.<sup>125</sup> 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  $\text{PM}_{2.5}$  concentrations were 1-16 times greater than the average ambient concentrations in each monitoring area. In-cabin exposures to  $\text{PM}_{2.5}$  for operators ranged from  $2 \mu\text{g}/\text{m}^3$  to over  $660 \mu\text{g}/\text{m}^3$ . Additionally, measured concentrations of acetaldehyde, benzene, and formaldehyde were found to be significantly elevated, although concentrations were not presented.

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.

## **3.2 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. It assesses lifetime risks assuming continuous exposure to levels of air toxics estimated for a particular point in time. The most recent National-Scale Air Toxics Assessment was done for the year 1999.<sup>126</sup> It has four steps:

- 1) Compiling 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) Estimating ambient concentrations based on emissions as input to an air dispersion model (the Assessment System for Population Exposure Nationwide, or ASPEN model).<sup>127</sup>
- 3) Estimating 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.<sup>128</sup>
- 4) Characterizing 1999 potential public health risks due to inhalation of air toxics. This includes cancer and noncancer effects, using available information on air toxics health effects, current EPA risk assessment and risk characterization guidelines, and estimated population exposures.<sup>129</sup>

For this rule, we have conducted air quality, exposure and risk modeling for the years 2015, 2020, and 2030, using the same tools and methods as the 1999 National-Scale Air Toxics Assessment. Thus our results are comparable to the 1999 Assessment, other than in the few situations in which risk values were re-computed resulting from stationary source inventory

errors which were determined to impact a tract or county-level risk estimate. For the reference case, which includes all control programs currently planned by EPA in regulations, we modeled all the pollutants in Table 2.2-1. 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. For the fuel benzene control case, we modeled the following pollutants: benzene, 1,3-butadiene, formaldehyde, acetaldehyde, and acrolein. This modeling work is discussed in more detail in an EPA technical report, "National Scale Modeling of Air Toxics for the Mobile Source Air Toxics Rule; Technical Support Document," Report Number EPA-454/R-06-002. EPA has previously done future year projections of the mobile source contribution to air toxics concentrations, exposure, and risk for selected air toxics,<sup>130, 131, 132, 133</sup> but has never done a comprehensive assessment that includes projections for all mobile source air toxics, as well as the stationary source contribution for those pollutants.

The National-Scale Air Toxics Assessment 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 "hot spots," such as areas in immediate proximity to major roads, where the air concentration, exposure and/or risk might be significantly higher within a census tract or county. This limitation may result in underestimates of exposure due to the design of ASPEN. 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 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. The cancer unit risk estimates for many 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.

Another tool which has been used by EPA to assess distributions of concentrations of air toxics at the national scale is the Community Multiscale Air Quality Model (CMAQ).<sup>134</sup> 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.<sup>135</sup> CMAQ underpredicts monitored benzene levels more than ASPEN, although it better calculates the contribution of transport, and more accurately model the effect of benzene decay. 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 effects, such as benzene.<sup>136</sup> Finally, CMAQ 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 significant sources of inhalation exposure, such as benzene emissions from sources in attached garages (such as vehicles, snowblowers, lawnmowers and gas cans). Furthermore, the modeling underestimates the contribution of hydrocarbon and particulate matter emissions at cold temperatures, based on results of recent test data discussed in Chapter 2.

### **3.2.1.1 Air Quality Modeling**

#### **3.2.1.1.1 Methods**

Prior to performing air quality modeling on 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.<sup>137</sup> 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 were processed, they were 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 km away. The model then interpolates concentrations to census tract centroids. For 1999 NATA, meteorological conditions in 1999 and 2000 census tract data were used.

In using ASPEN to estimate concentrations for emissions projected to years 2015, 2020, and 2030, 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 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.<sup>138</sup> 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, a sensitivity analysis was done to evaluate the potential impact of not changing the background concentration (see Section 3.2.1.4).

We estimated the contributions to ambient concentrations for the following source sectors: major, area and other, onroad gasoline, onroad diesel, nonroad gasoline, remaining nonroad (diesel and compressed natural gas), and background.<sup>A</sup>

#### 3.2.1.1.2 Air Quality Trends for Air Toxics

Table 3.2-1 summarizes nationwide mean census tract ambient concentrations 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 60% by 2015, with a decrease in ambient benzene concentration from all sources of over 30%. Summary tables providing data by State, and for reformulated and non-reformulated 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 nonreformulated gasoline areas – about 1.9  $\mu\text{g}/\text{m}^3$  versus 1.1  $\mu\text{g}/\text{m}^3$ . However the percent reduction in average ambient concentration is similar regardless of fuel type – 29% for non-reformulated gasoline counties versus 35% for reformulated gasoline counties.

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<sup>A</sup> 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.

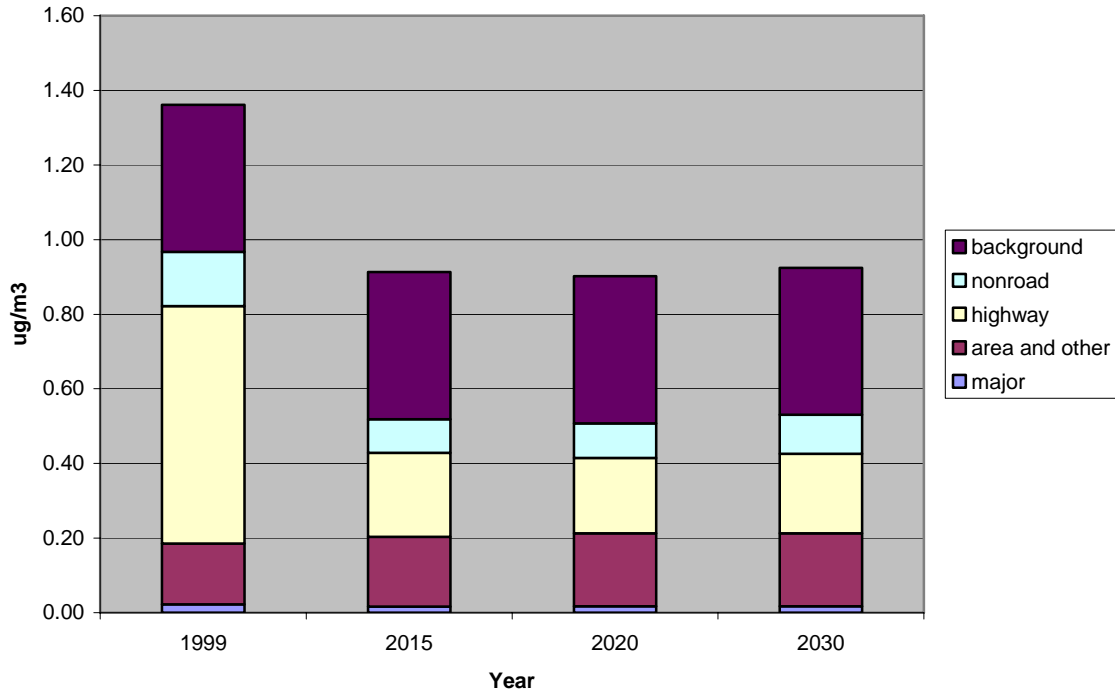
**Table 3.2-1. Mean Ambient Concentrations of Mobile Source Air Toxics in 1999, 2015, 2020, and 2030**

		1999 average concentrations (µg m <sup>-3</sup> )					2015 annual average concentrations (µg m <sup>-3</sup> )				
	background (µg m <sup>-3</sup> )	major	area & other	onroad	nonroad	total (including background)	major	area & other	onroad	nonroad	total (including background)
1,3-Butadiene	5.1017E-02	1.9698E-03	2.0466E-02	5.2667E-02	1.5869E-02	1.4199E-01	2.1691E-03	2.0549E-02	1.4596E-02	9.8082E-03	9.8140E-02
2,2,4-Trimethylpentane	0.0000E+00	2.1480E-02	3.0980E-02	6.4450E-01	1.2691E-01	8.2388E-01	1.0698E-02	3.1161E-02	2.1694E-01	6.8780E-02	3.2757E-01
Acetaldehyde	5.1723E-01	2.9419E-02	5.4907E-02	6.6572E-01	1.6187E-01	1.4291E+00	2.9660E-02	5.7067E-02	2.4887E-01	1.1304E-01	9.6588E-01
Acrolein	0.0000E+00	3.2134E-03	2.9302E-02	5.8653E-02	2.2393E-02	1.1356E-01	3.5272E-03	2.6173E-02	1.6126E-02	1.7986E-02	6.3811E-02
Benzene	3.9388E-01	2.2389E-02	1.6337E-01	6.3574E-01	1.4569E-01	1.3611E+00	1.5952E-02	1.8756E-01	2.2511E-01	9.0530E-02	9.1304E-01
Chromium III	0.0000E+00	8.2203E-04	4.5296E-04	9.4346E-05	6.3356E-05	1.4327E-03	1.0439E-03	6.1614E-04	1.4337E-04	6.8021E-05	1.8714E-03
Chromium VI	0.0000E+00	1.0744E-04	1.9810E-04	2.0710E-05	1.3908E-05	3.4016E-04	1.3561E-04	2.7208E-04	3.1472E-05	1.4930E-05	4.5409E-04
Ethyl Benzene	0.0000E+00	1.8350E-02	8.5479E-02	2.6220E-01	7.9335E-02	4.4537E-01	1.2422E-02	1.1171E-01	8.7494E-02	4.5875E-02	2.5750E-01
Formaldehyde	7.6211E-01	3.9919E-02	8.7655E-02	4.6797E-01	2.4205E-01	1.5997E+00	4.9752E-02	9.8233E-02	1.4065E-01	1.7213E-01	1.2229E+00
Hexane	0.0000E+00	6.6888E-02	4.4754E-01	2.5656E-01	5.1788E-02	8.2277E-01	5.9487E-02	5.3142E-01	1.0304E-01	3.1623E-02	7.2557E-01
Manganese	0.0000E+00	2.7092E-03	2.2154E-03	1.0490E-04	1.5974E-05	5.0455E-03	3.2250E-03	2.9180E-03	1.6633E-04	1.9021E-05	6.3283E-03
MTBE	0.0000E+00	1.1329E-02	6.4319E-02	6.0112E-01	8.9155E-02	7.6592E-01	1.1412E-02	5.8976E-02	9.6267E-02	2.9969E-02	1.9662E-01
Naphthalene	0.0000E+00	4.5711E-03	4.7591E-02	1.4312E-02	4.4408E-03	7.0915E-02	3.9893E-03	5.7526E-02	7.7995E-03	4.5857E-03	7.3901E-02
Nickel	0.0000E+00	7.7621E-04	1.4165E-03	8.2994E-05	1.0799E-04	2.3837E-03	8.8660E-04	1.6165E-03	1.2555E-04	1.2429E-04	2.7530E-03
POM	0.0000E+00	4.9323E-03	1.6349E-02	1.4544E-03	8.6392E-04	2.3600E-02	3.7910E-03	1.8698E-02	6.9925E-04	7.7005E-04	2.3958E-02
Propionaldehyde	0.0000E+00	1.0104E-02	2.3307E-02	1.6625E-01	4.0502E-02	2.4017E-01	9.3087E-03	2.3921E-02	6.5055E-02	2.6944E-02	1.2523E-01
Styrene	0.0000E+00	2.5214E-02	1.4150E-02	2.6736E-02	6.8565E-03	7.2956E-02	3.0020E-02	1.8972E-02	8.2301E-03	4.0461E-03	6.1268E-02
Toluene	0.0000E+00	2.0293E-01	8.0371E-01	1.6809E+00	3.0633E-01	2.9939E+00	1.4319E-01	1.0459E+00	5.4456E-01	1.7942E-01	1.9131E+00
Xylenes	1.7000E-01	9.9861E-02	5.8421E-01	1.0001E+00	3.6587E-01	2.2200E+00	8.2207E-02	7.7990E-01	3.2264E-01	1.9903E-01	1.5538E+00

**Table 3.2-1 (cont'd). Mean Ambient Concentrations of Mobile Source Air Toxics in 1999, 2015, 2020, and 2030**

Pollutant	background (µg m <sup>-3</sup> )	2020 annual average concentrations (µg m <sup>-3</sup> )					2030 annual average concentrations (µg m <sup>-3</sup> )				
		major	area & other	onroad	nonroad	total (including background)	major	area & other	onroad	nonroad	total (including background)
1,3-Butadiene	5.1017E-02	2.3385E-03	2.0502E-02	1.3470E-02	1.0337E-02	9.7664E-02	2.3385E-03	2.0502E-02	1.4505E-02	1.1768E-02	1.0013E-01
2,2,4-Trimethylpentane	0.0000E+00	1.1512E-02	3.2847E-02	1.9217E-01	6.6920E-02	3.0344E-01	1.1512E-02	3.2847E-02	2.0231E-01	7.2355E-02	3.1902E-01
Acetaldehyde	5.1723E-01	3.0983E-02	5.8271E-02	2.1593E-01	1.1333E-01	9.3574E-01	3.0983E-02	5.8271E-02	2.2554E-01	1.2404E-01	9.5606E-01
Acrolein	0.0000E+00	3.9610E-03	2.5356E-02	1.4828E-02	1.8883E-02	6.3028E-02	3.9610E-03	2.5356E-02	1.6000E-02	2.1393E-02	6.6711E-02
Benzene	3.9388E-01	1.7490E-02	1.9521E-01	2.0193E-01	9.3011E-02	9.0152E-01	1.7490E-02	1.9521E-01	2.1345E-01	1.0418E-01	9.2422E-01
Chromium III	0.0000E+00	1.1674E-03	6.9641E-04	1.6085E-04	6.9279E-05	2.0939E-03	1.1674E-03	6.9641E-04	2.0130E-04	7.2035E-05	2.1371E-03
Chromium VI	0.0000E+00	1.5425E-04	3.0719E-04	3.5309E-05	1.5209E-05	5.1196E-04	1.5425E-04	3.0719E-04	4.4188E-05	1.5812E-05	5.2144E-04
Ethyl Benzene	0.0000E+00	1.3878E-02	1.2268E-01	7.7085E-02	4.6255E-02	2.5990E-01	1.3878E-02	1.2268E-01	8.0891E-02	5.1517E-02	2.6897E-01
Formaldehyde	7.6211E-01	5.6500E-02	1.0308E-01	1.2946E-01	1.7331E-01	1.2245E+00	5.6500E-02	1.0308E-01	1.4050E-01	1.9006E-01	1.2523E+00
Hexane	0.0000E+00	6.5428E-02	5.7287E-01	8.5723E-02	3.1921E-02	7.5594E-01	6.5428E-02	5.7287E-01	8.7701E-02	3.5513E-02	7.6151E-01
Manganese	0.0000E+00	3.5898E-03	3.2064E-03	1.8809E-04	2.0348E-05	7.0046E-03	3.5898E-03	3.2064E-03	2.3758E-04	2.3071E-05	7.0568E-03
MTBE	0.0000E+00	1.2800E-02	6.1302E-02	7.3931E-02	3.0828E-02	1.7886E-01	1.2800E-02	6.1302E-02	7.0735E-02	3.4684E-02	1.7952E-01
Naphthalene	0.0000E+00	4.4726E-03	6.1195E-02	7.7568E-03	4.8736E-03	7.8298E-02	4.4726E-03	6.1195E-02	9.0122E-03	5.5601E-03	8.0240E-02
Nickel	0.0000E+00	9.6148E-04	1.7803E-03	1.4075E-04	1.3010E-04	3.0126E-03	9.6148E-04	1.7803E-03	1.7615E-04	1.4243E-04	3.0603E-03
POM	0.0000E+00	4.2071E-03	1.9160E-02	7.1999E-04	7.7679E-04	2.4864E-02	4.2071E-03	1.9160E-02	8.4362E-04	8.6508E-04	2.5076E-02
Propionaldehyde	0.0000E+00	9.3496E-03	2.4509E-02	5.5202E-02	2.6896E-02	1.1596E-01	9.3496E-03	2.4509E-02	5.6897E-02	2.9326E-02	1.2008E-01
Styrene	0.0000E+00	3.4354E-02	2.0977E-02	7.5994E-03	4.2164E-03	6.7147E-02	3.4354E-02	2.0977E-02	8.1455E-03	4.7912E-03	6.8268E-02
Toluene	0.0000E+00	1.5961E-01	1.1471E+00	4.8530E-01	1.7765E-01	1.9697E+00	1.5961E-01	1.1471E+00	5.1189E-01	1.9551E-01	2.0141E+00
Xylenes	1.7000E-01	9.2898E-02	8.5913E-01	2.8630E-01	2.0028E-01	1.6086E+00	9.2898E-02	8.5913E-01	3.0164E-01	2.2249E-01	1.6462E+00

**Figure 3.2-1. Nationwide Average Benzene Concentration, 1999-2030**



#### 3.2.1.1.3 Distributions of Air Toxic Concentrations across the U. S.

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. 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 95<sup>th</sup> percentile 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 95<sup>th</sup> 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 indicate higher than average fuel benzene levels in these areas. 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.

**Table 3.2-2. National Distribution of Census Tract Concentrations for Mobile Source Air Toxics in 2020**

Pollutant	2020 concentration ( $\mu\text{g m}^{-3}$ ) distribution						
	5th percentile	10th percentile	25th percentile	Median	75th percentile	90th percentile	95th percentile
1,3-Butadiene	2.24E-03	4.29E-03	2.70E-02	7.65E-02	1.16E-01	1.71E-01	2.85E-01
2,2,4-Trimethylpentane	2.43E-02	4.30E-02	1.05E-01	2.32E-01	4.02E-01	6.39E-01	8.15E-01
Acetaldehyde	5.33E-01	5.61E-01	6.51E-01	8.31E-01	1.07E+00	1.46E+00	1.78E+00
Acrolein	4.41E-03	7.44E-03	1.64E-02	3.44E-02	7.11E-02	1.55E-01	2.49E-01
Benzene	3.25E-01	3.87E-01	5.67E-01	7.97E-01	1.06E+00	1.48E+00	1.84E+00
Chromium III	7.72E-06	1.99E-05	8.12E-05	3.14E-04	1.03E-03	2.66E-03	5.06E-03
Chromium VI	2.45E-06	6.56E-06	2.97E-05	1.16E-04	3.30E-04	9.80E-04	1.63E-03
Ethyl Benzene	1.50E-02	2.73E-02	7.64E-02	1.78E-01	3.09E-01	5.00E-01	7.17E-01
Formaldehyde	3.99E-01	5.16E-01	7.80E-01	1.10E+00	1.44E+00	2.03E+00	2.53E+00
Hexane	2.75E-02	5.18E-02	1.68E-01	4.29E-01	8.21E-01	1.65E+00	2.81E+00
MTBE	2.16E-03	5.19E-03	1.61E-02	4.96E-02	1.95E-01	5.32E-01	7.62E-01
Manganese	1.54E-05	4.66E-05	2.06E-04	8.72E-04	3.56E-03	1.53E-02	2.26E-02
Naphthalene	2.98E-03	6.06E-03	1.91E-02	4.63E-02	9.19E-02	1.81E-01	2.80E-01
Nickel	1.41E-05	3.91E-05	1.69E-04	6.80E-04	2.11E-03	5.13E-03	8.75E-03
POM	1.72E-03	2.95E-03	5.70E-03	1.19E-02	2.06E-02	3.59E-02	5.76E-02
Propionaldehyde	9.97E-03	1.68E-02	3.73E-02	8.19E-02	1.50E-01	2.65E-01	3.53E-01
Styrene	2.06E-03	3.95E-03	9.58E-03	2.11E-02	4.45E-02	9.45E-02	1.62E-01
Toluene	1.17E-01	2.13E-01	5.64E-01	1.28E+00	2.29E+00	4.11E+00	5.88E+00
Xylenes	2.44E-01	3.04E-01	5.44E-01	1.04E+00	1.74E+00	3.15E+00	4.90E+00

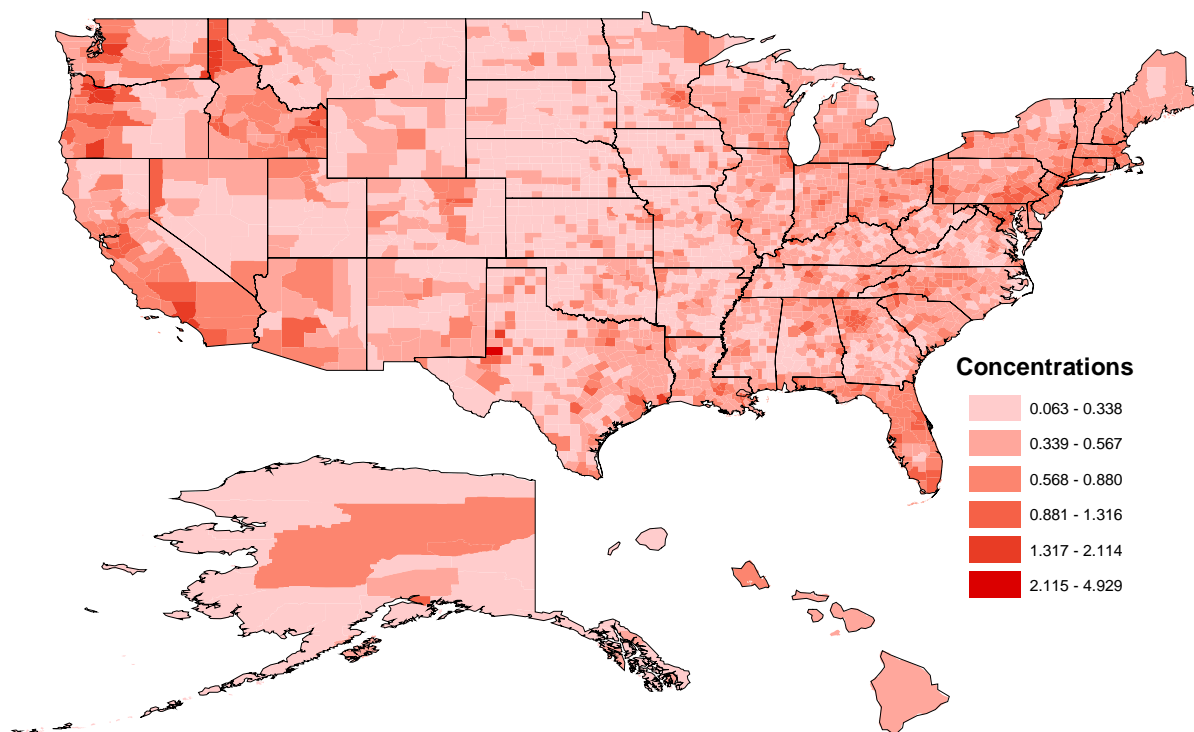
Similar benzene median county concentration maps for 1999, 2015, and 2030 can be found in the docket for this rule, along with maps for other mobile source air toxics and tables of concentration distributions.

#### 3.2.1.1.4 Impacts of Proposed Fuel Benzene Controls on Ambient Concentrations

The fuel benzene standard proposed in this rule will substantially reduce ambient concentrations of benzene across the United States. Table 3.2-3 shows that in 2015, 2020, and 2030, the highway vehicle portion of ambient concentrations will be reduced on average 8 to 9% across the U.S., the nonroad equipment contribution will be reduced about 7%, and the area source contribution about 4%. The reduction for area sources is due to the impacts of fuel benzene control on gasoline distribution emissions. Reductions in non- Federal reformulated gasoline areas (i.e., conventional gasoline areas) are even larger. It should be noted that the estimated total reductions 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. The fuel benzene control proposed does not significantly affect ambient concentrations of other air toxics. Figure 3.2-3 presents the distribution of percent reductions in median ambient benzene concentrations for U. S. counties with the proposed fuel control in 2020. Summary tables providing data by State, as well as maps of benzene concentrations with fuel controls and percent reductions with controls, can be found in the docket for the rule.

Similar data are also available for 1,3-butadiene, formaldehyde and acetaldehyde, even though concentrations were not significantly affected.

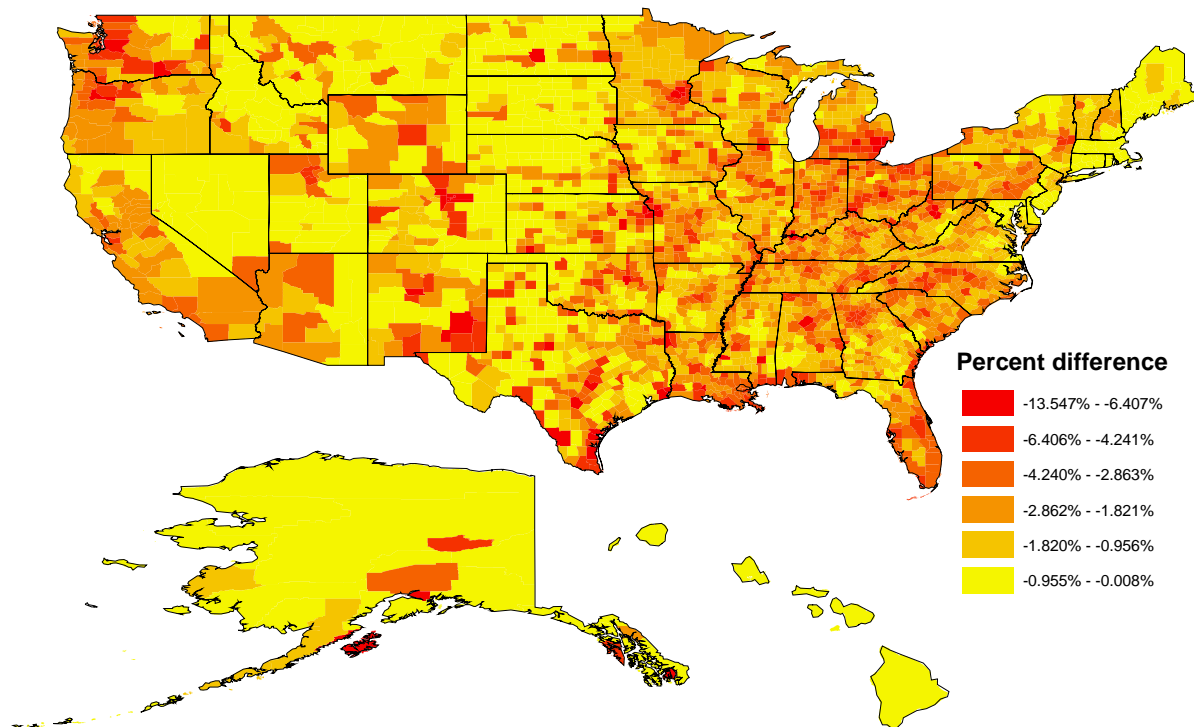
**Figure 3.2-2. Geographic Distribution of County Median Concentrations ( $\mu\text{g}/\text{m}^3$ ) of Benzene in 2020**



**Table 3.2-3. Contributions of Source Sectors to Nationwide Average Census Tract Concentrations of Benzene, with and without Proposed Fuel Benzene Standard, 2015, 2020, and 2030**

	2015 annual average concentrations ( $\mu\text{g m}^{-3}$ )					2020 annual average concentrations ( $\mu\text{g m}^{-3}$ )					2030 annual average concentrations ( $\mu\text{g m}^{-3}$ )				
	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	0.02	0.19	0.23	0.09	0.91	0.02	0.20	0.20	0.09	0.90	0.02	0.20	0.21	0.10	0.92
Control	0.02	0.18	0.20	0.08	0.88	0.02	0.19	0.18	0.09	0.87	0.02	0.19	0.20	0.10	0.89
% Difference	-1	-4	-9	-7	-4	-1	-4	-9	-7	-4	-1	-4	-8	-7	-4
Average Nationwide Difference in Ambient Benzene Concentration -- Non RFG Areas															
Reference	0.01	0.15	0.18	0.06	0.77	0.01	0.16	0.16	0.07	0.76	0.01	0.16	0.16	0.07	0.77
Control	0.01	0.15	0.15	0.06	0.73	0.01	0.15	0.14	0.06	0.72	0.01	0.15	0.14	0.06	0.73
% Difference	-1	-4	-14	-12	-5	-1	-4	-13	-12	-5	-1	-4	-13	-13	-5
Average Nationwide Difference in Ambient Benzene Concentration -- RFG Areas															
Reference	0.02	0.25	0.31	0.14	1.18	0.03	0.26	0.28	0.14	1.16	0.03	0.26	0.31	0.16	1.20
Control	0.02	0.24	0.30	0.13	1.15	0.03	0.25	0.27	0.14	1.14	0.03	0.25	0.29	0.15	1.18
% Difference	-1	-3	-4	-3	-2	-1	-3	-4	-3	-2	-1	-3	-4	-3	-2

**Figure 3.2-3. Distribution of Percent Reductions in Median Ambient Benzene Concentrations, 2020, for U. S. Counties with the Proposed Fuel Control**



### 3.2.1.2 Exposure and Risk Modeling

#### 3.2.1.2.1 Methods

The HAPEM5 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.<sup>139, 140, 141</sup> HAPEM5 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. HAPEM5 uses the general approach of tracking representatives of specified demographic groups as they move among indoor and outdoor microenvironments and among geographic locations. 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.

HAPEM5 uses four primary sources of information: population data from the US Census, population activity data, air quality data, and microenvironmental data. The population data used is obtained from the US 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).<sup>142</sup> The commuting data contained in the HAPEM5 default file were derived from a special 1990 US Census study that specifies the number of residents of each tract that work in that tract and every other US Census tract. The air quality data come from ASPEN (after

background has been added). 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.<sup>143</sup>

HAPEM5 has a number of technical improvements over the previous version of HAPEM. These improvements, along with other details of the model, are described in the HAPEM5 User's Guide.<sup>144</sup> The projection year HAPEM runs used year 2000 census data and 1990 commuting pattern 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 gasoline, onroad diesel, nonroad gasoline, remaining nonroad (diesel and compressed natural gas), and background.

Once HAPEM runs were completed, cancer risk and non-cancer risk calculations were made for each of the mobile source air toxic pollutants. Table 3.2-4 lists the pollutants with their respective Unit Risk Estimates (UREs) for cancer calculations and reference concentrations (RfCs) for non-cancer calculations. These are the same values used in the 1999 National-Scale Air Toxics Assessment, 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 non-cancer calculations. 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 non-cancer effects – used as RfC.
- 3) California Office of Environmental Health Hazard Assessment (OEHHA) values.

**Table 3.2-4. Dose Response Values Use in Risk Modeling (Concentrations in  $\mu\text{g}/\text{m}^3$ )**

HAP	Carcinogen Class	URE (per $\mu\text{g}/\text{m}^3$ )	Source	Organ Systems	RfC (mg/ $\text{m}^3$ )	Source
1,3-Butadiene	A	$3.0 \times 10^{-5}$	IRIS	Reproductive	$2.0 \times 10^{-3}$	
2,2,4-Trimethylpentane	N/A	N/A		N/A	N/A	
Acetaldehyde	B2	$2.2 \times 10^{-6}$	IRIS	Respiratory	$9.0 \times 10^{-3}$	IRIS
Acrolein		0		Respiratory	$2.0 \times 10^{-5}$	IRIS
Benzene	A	$7.8 \times 10^{-6}$ *	IRIS	Immune	$3.0 \times 10^{-2}$	IRIS
Chromium III	N/A	N/A		N/A	N/A	
Chromium VI	A	$1.2 \times 10^{-2}$	IRIS	Respiratory	$1.0 \times 10^{-4}$	IRIS
Ethyl Benzene		0		Developmental	1.0	IRIS
Formaldehyde	B	$5.5 \times 10^{-9}$	CIIT	Respiratory	$9.8 \times 10^{-3}$	ATSDR
Hexane		N/A		Respiratory, Neurological	$2.0 \times 10^{-1}$	IRIS
Manganese		N/A		Neurological	$5.0 \times 10^{-5}$	IRIS
MTBE		N/A		Liver, Kidney, Ocular	3.0	IRIS
Naphthalene	C	$3.4 \times 10^{-5}$	CAL	Respiratory	$3.0 \times 10^{-3}$	IRIS
Nickel	A	$1.6 \times 10^{-4}$	EPA/OAQ PS	Respiratory, Immune	$6.5 \times 10^{-5}$	CAL
Propionaldehyde	N/A	N/A		N/A	N/A	
POM1	B2	$5.5 \times 10^{-5}$	OAQPS		N/A	
POM2	B2	$5.5 \times 10^{-5}$	OAQPS		N/A	
POM3	B2	$1.0 \times 10^{-1}$	OAQPS		N/A	
POM4	B2	$1.0 \times 10^{-2}$	OAQPS		N/A	
POM5	B2	$1.0 \times 10^{-3}$	OAQPS		N/A	
POM6	B2	$1.0 \times 10^{-4}$	OAQPS		N/A	
POM7	B2	$1.0 \times 10^{-5}$	OAQPS		N/A	
POM8	B2	$2.0 \times 10^{-4}$	OAQPS		N/A	
Styrene		N/A		Neurological	1.0	IRIS
Toluene		N/A		Respiratory, Neurological	$4.0 \times 10^{-1}$	IRIS
Xylenes		N/A		Neurological	$1.0 \times 10^{-1}$	IRIS

\*represents upper end of a range of MLE 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.-4 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 2 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 National Scale Assessment and in Appendix H of the 2001 EPA draft report to the Science Advisory Board on the 1996 National-Scale Assessment.<sup>145</sup>

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 National-Scale Assessment, 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. A 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

Table 3.2-5 summarizes nationwide average census tract exposure concentrations of mobile source air toxics in 1999, 2015, 2020, and 2030. It should be noted that all the other non-inventoried sources, as well as the contribution from transport, contribute to background levels. Overall, exposure concentrations tend to be less than ambient concentrations because penetration rates to indoor microenvironments are typically less than one. 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.

Table 3.2-6 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 23 in a million in 1999. This compares to an overall nationwide average population cancer risk from all air toxics in the 1999 National-Scale Assessment of 48 in a million. About twenty-two percent of this risk in the 1999 National Scale Assessment is attributable to benzene.

In all projection years, benzene emissions are by far the largest contributor to cancer risk from mobile sources (see Figure 3.2-4). Furthermore, about 90% of the mobile source risk from all air toxics is due to gasoline vehicles and engines, and about 95% of the benzene risk from mobile sources is from gasoline vehicles and engines. Other significant contributors to cancer risk from mobile source air toxics include 1,3-butadiene, acetaldehyde, naphthalene, and hexavalent chromium.

Despite significant reductions in risk from mobile source air toxics, average inhalation cancer risks for these pollutants, accounting for both mobile and stationary source contributions, remain well above 10 in 1,000,000 (Figure 3.2-5). In addition, average risk from exposure to benzene remains above 5 in 1,000,000.

**Table 3.2-5. Mean Population Exposure Concentrations of Mobile Source Air Toxics in 1999, 2015, 2020, and 2030**

Pollutant	background ( $\mu\text{g m}^{-3}$ )	1999 average concentrations ( $\mu\text{g m}^{-3}$ )					2015 annual average concentrations ( $\mu\text{g m}^{-3}$ )				
		major	area & other	onroad	nonroad	total (including background)	major	area & other	onroad	nonroad	total (including background)
1,3-Butadiene	3.82E-02	1.61E-03	1.72E-02	6.53E-02	1.51E-02	1.37E-01	1.78E-03	1.73E-02	1.84E-02	9.27E-03	8.58E-02
2,2,4-Trimethylpentane	0.00E+00	1.80E-02	2.67E-02	7.57E-01	1.12E-01	9.14E-01	9.01E-03	2.71E-02	2.56E-01	6.04E-02	3.52E-01
Acetaldehyde	3.97E-01	2.51E-02	4.64E-02	7.60E-01	1.41E-01	1.37E+00	2.54E-02	4.86E-02	2.86E-01	9.77E-02	8.58E-01
Acrolein	0.00E+00	2.72E-03	2.48E-02	6.72E-02	1.95E-02	1.14E-01	3.01E-03	2.23E-02	1.86E-02	1.54E-02	5.94E-02
Benzene	2.98E-01	1.88E-02	1.42E-01	7.58E-01	1.33E-01	1.35E+00	1.35E-02	1.64E-01	2.71E-01	8.28E-02	8.33E-01
Chromium III	0.00E+00	3.28E-04	1.86E-04	6.10E-05	2.67E-05	6.01E-04	4.17E-04	2.52E-04	9.27E-05	2.84E-05	7.90E-04
Chromium VI	0.00E+00	4.39E-05	8.19E-05	1.36E-05	5.89E-06	1.45E-04	5.58E-05	1.12E-04	2.07E-05	6.25E-06	1.95E-04
Ethyl Benzene	0.00E+00	1.55E-02	7.52E-02	3.08E-01	7.13E-02	4.70E-01	1.05E-02	9.77E-02	1.03E-01	4.10E-02	2.52E-01
Formaldehyde	5.85E-01	3.47E-02	7.43E-02	5.79E-01	2.14E-01	1.49E+00	4.32E-02	8.43E-02	1.76E-01	1.49E-01	1.04E+00
Hexane	0.00E+00	5.68E-02	3.89E-01	3.03E-01	4.64E-02	7.95E-01	5.04E-02	4.62E-01	1.22E-01	2.82E-02	6.63E-01
MTBE	0.00E+00	9.45E-03	5.38E-02	7.03E-01	7.95E-02	8.45E-01	9.57E-03	4.99E-02	1.14E-01	2.59E-02	2.00E-01
Manganese	0.00E+00	1.07E-03	9.12E-04	7.17E-05	7.60E-06	2.06E-03	1.28E-03	1.20E-03	1.14E-04	8.84E-06	2.60E-03
Naphthalene	0.00E+00	3.94E-03	4.04E-02	1.73E-02	4.01E-03	6.57E-02	3.46E-03	4.90E-02	9.44E-03	4.00E-03	6.59E-02
Nickel	0.00E+00	3.12E-04	5.94E-04	5.48E-05	4.76E-05	1.01E-03	3.58E-04	6.68E-04	8.36E-05	5.19E-05	1.16E-03
POM	0.00E+00	2.89E-03	1.03E-02	1.28E-03	5.69E-04	1.50E-02	2.28E-03	1.17E-02	6.16E-04	5.02E-04	1.51E-02
Propionaldehyde	0.00E+00	8.52E-03	1.95E-02	1.87E-01	3.50E-02	2.50E-01	7.87E-03	2.02E-02	7.36E-02	2.32E-02	1.25E-01
Styrene	0.00E+00	2.11E-02	1.20E-02	3.24E-02	6.32E-03	7.18E-02	2.48E-02	1.61E-02	9.92E-03	3.67E-03	5.45E-02
Toluene	0.00E+00	1.72E-01	6.97E-01	1.98E+00	2.74E-01	3.13E+00	1.22E-01	9.12E-01	6.46E-01	1.60E-01	1.84E+00
Xylenes	1.27E-01	8.53E-02	5.11E-01	1.18E+00	3.30E-01	2.23E+00	7.04E-02	6.82E-01	3.82E-01	1.80E-01	1.44E+00

**Table 3.2-5 (cont'd). Mean Population Exposure Concentrations of Mobile Source Air Toxics in 1999, 2015, 2020, and 2030**

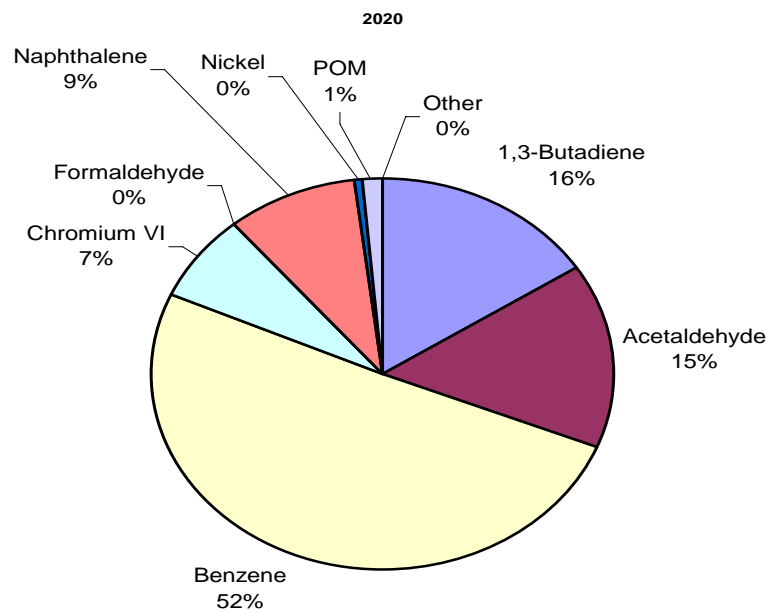
		2020 annual average concentrations ( $\mu\text{g m}^{-3}$ )					2030 annual average concentrations ( $\mu\text{g m}^{-3}$ )				
Pollutant	background ( $\mu\text{g m}^{-3}$ )	major	area & other	onroad	nonroad	total (including background)	major	area & other	onroad	nonroad	total (including background)
1,3-Butadiene	3.82E-02	1.92E-03	1.73E-02	1.70E-02	9.80E-03	8.50E-02	1.91E-03	1.73E-02	1.82E-02	1.12E-02	8.76E-02
2,2,4-Trimethylpentane	0.00E+00	9.70E-03	2.86E-02	2.27E-01	5.93E-02	3.24E-01	9.69E-03	2.86E-02	2.38E-01	6.45E-02	3.41E-01
Acetaldehyde	3.97E-01	2.65E-02	4.97E-02	2.49E-01	9.80E-02	8.24E-01	2.65E-02	4.97E-02	2.60E-01	1.07E-01	8.44E-01
Acrolein	0.00E+00	3.38E-03	2.16E-02	1.71E-02	1.62E-02	5.83E-02	3.38E-03	2.16E-02	1.85E-02	1.83E-02	6.18E-02
Benzene	2.98E-01	1.48E-02	1.71E-01	2.43E-01	8.55E-02	8.16E-01	1.48E-02	1.71E-01	2.57E-01	9.61E-02	8.40E-01
Chromium III	0.00E+00	4.66E-04	2.84E-04	1.04E-04	2.90E-05	8.84E-04	4.66E-04	2.84E-04	1.30E-04	3.03E-05	9.11E-04
Chromium VI	0.00E+00	6.36E-05	1.26E-04	2.33E-05	6.38E-06	2.20E-04	6.36E-05	1.26E-04	2.90E-05	6.67E-06	2.26E-04
Ethyl Benzene	0.00E+00	1.17E-02	1.07E-01	9.05E-02	4.16E-02	2.51E-01	1.17E-02	1.07E-01	9.49E-02	4.65E-02	2.60E-01
Formaldehyde	5.85E-01	4.90E-02	8.86E-02	1.62E-01	1.50E-01	1.04E+00	4.90E-02	8.86E-02	1.75E-01	1.65E-01	1.07E+00
Hexane	0.00E+00	5.54E-02	4.98E-01	1.02E-01	2.86E-02	6.83E-01	5.54E-02	4.98E-01	1.04E-01	3.20E-02	6.89E-01
MTBE	0.00E+00	1.07E-02	5.19E-02	8.78E-02	2.67E-02	1.77E-01	1.07E-02	5.19E-02	8.40E-02	3.02E-02	1.77E-01
Manganese	0.00E+00	1.42E-03	1.32E-03	1.29E-04	9.47E-06	2.88E-03	1.42E-03	1.32E-03	1.63E-04	1.08E-05	2.91E-03
Naphthalene	0.00E+00	3.88E-03	5.22E-02	9.38E-03	4.25E-03	6.97E-02	3.88E-03	5.22E-02	1.09E-02	4.84E-03	7.18E-02
Nickel	0.00E+00	3.89E-04	7.34E-04	9.38E-05	5.43E-05	1.27E-03	3.89E-04	7.34E-04	1.17E-04	5.96E-05	1.30E-03
POM	0.00E+00	2.53E-03	1.20E-02	6.34E-04	5.07E-04	1.57E-02	2.53E-03	1.20E-02	7.41E-04	5.64E-04	1.59E-02
Propionaldehyde	0.00E+00	7.91E-03	2.07E-02	6.26E-02	2.32E-02	1.14E-01	7.91E-03	2.07E-02	6.46E-02	2.52E-02	1.18E-01
Styrene	0.00E+00	2.83E-02	1.78E-02	9.15E-03	3.84E-03	5.91E-02	2.83E-02	1.78E-02	9.81E-03	4.36E-03	6.03E-02
Toluene	0.00E+00	1.36E-01	1.00E+00	5.75E-01	1.60E-01	1.87E+00	1.36E-01	1.00E+00	6.06E-01	1.77E-01	1.92E+00
Xylenes	1.27E-01	7.95E-02	7.51E-01	3.39E-01	1.82E-01	1.48E+00	7.94E-02	7.51E-01	3.56E-01	2.03E-01	1.52E+00

**Table 3.2-6. National Average Cancer Risk Across Census Tracts for 1999, 2015, 2020, and 2030 by Pollutant**

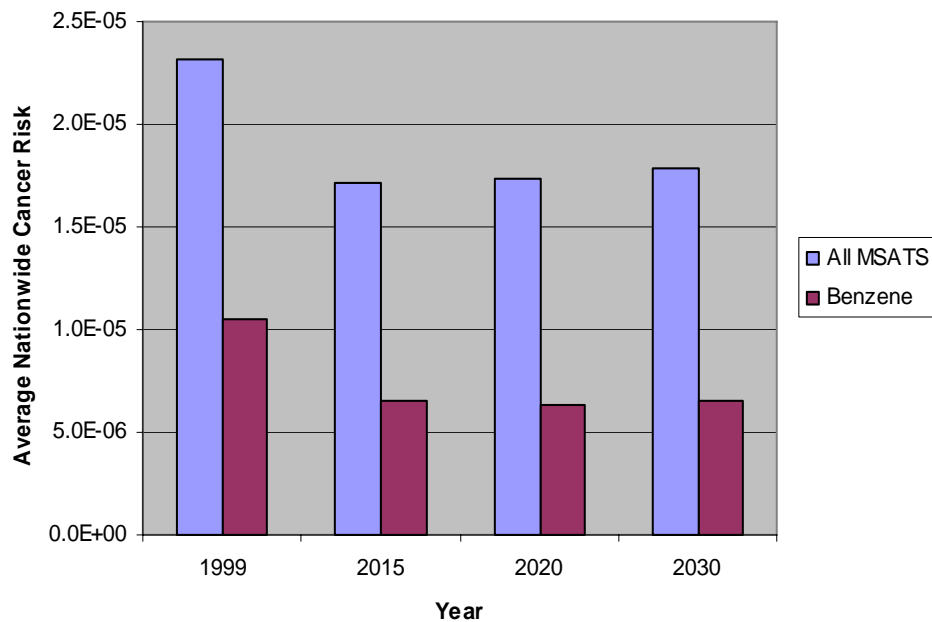
		1999 average cancer risk					2015 annual average cancer risk				
Pollutant	background	major	area & other	onroad	nonroad	total (including background)	major	area & other	onroad	nonroad	total (including background)
Total Risk: All MSATs	4.35E-06	1.14E-06	5.19E-06	1.04E-05	2.05E-06	2.31E-05	1.20E-06	6.19E-06	3.92E-06	1.39E-06	1.71E-05
POM	0.00E+00	1.75E-07	1.01E-06	8.42E-08	3.70E-08	1.31E-06	1.40E-07	1.17E-06	3.97E-08	3.32E-08	1.38E-06
Nickel	0.00E+00	4.99E-08	9.50E-08	8.78E-09	7.61E-09	1.61E-07	5.73E-08	1.07E-07	1.34E-08	8.30E-09	1.86E-07
Naphthalene	0.00E+00	1.34E-07	1.38E-06	5.87E-07	1.36E-07	2.23E-06	1.18E-07	1.67E-06	3.21E-07	1.36E-07	2.24E-06
Formaldehyde	3.22E-09	1.91E-10	4.08E-10	3.18E-09	1.18E-09	8.18E-09	2.37E-10	4.64E-10	9.68E-10	8.22E-10	5.74E-09
Chromium VI	0.00E+00	5.26E-07	9.83E-07	1.63E-07	7.07E-08	1.74E-06	6.70E-07	1.34E-06	2.48E-07	7.50E-08	2.34E-06
Benzene	2.32E-06	1.47E-07	1.11E-06	5.91E-06	1.04E-06	1.05E-05	1.05E-07	1.28E-06	2.12E-06	6.46E-07	6.49E-06
Acetaldehyde	8.74E-07	5.51E-08	1.02E-07	1.67E-06	3.11E-07	3.01E-06	5.59E-08	1.07E-07	6.30E-07	2.15E-07	1.89E-06
1,3-Butadiene	1.15E-06	4.82E-08	5.15E-07	1.96E-06	4.52E-07	4.12E-06	5.33E-08	5.20E-07	5.52E-07	2.78E-07	2.57E-06

		2020 annual average cancer risk					2030 annual average cancer risk				
Pollutant	background	major	area & other	onroad	nonroad	total (including background)	major	area & other	onroad	nonroad	total (including background)
Total Risk: All MSATs	4.35E-06	1.34E-06	6.57E-06	3.61E-06	1.44E-06	1.74E-05	1.34E-06	6.57E-06	3.91E-06	1.61E-06	1.78E-05
POM	0.00E+00	1.54E-07	1.20E-06	4.07E-08	3.37E-08	1.43E-06	1.54E-07	1.20E-06	4.75E-08	3.76E-08	1.44E-06
Nickel	0.00E+00	6.22E-08	1.18E-07	1.50E-08	8.69E-09	2.03E-07	6.22E-08	1.18E-07	1.88E-08	9.53E-09	2.08E-07
Naphthalene	0.00E+00	1.32E-07	1.77E-06	3.19E-07	1.44E-07	2.37E-06	1.32E-07	1.77E-06	3.70E-07	1.65E-07	2.44E-06
Formaldehyde	3.22E-09	2.70E-10	4.87E-10	8.90E-10	8.27E-10	5.73E-09	2.70E-10	4.87E-10	9.65E-10	9.06E-10	5.88E-09
Chromium VI	0.00E+00	7.63E-07	1.52E-06	2.79E-07	7.66E-08	2.64E-06	7.63E-07	1.52E-06	3.49E-07	8.00E-08	2.71E-06
Benzene	2.32E-06	1.15E-07	1.33E-06	1.90E-06	6.67E-07	6.36E-06	1.15E-07	1.33E-06	2.00E-06	7.49E-07	6.55E-06
Acetaldehyde	8.74E-07	5.84E-08	1.09E-07	5.48E-07	2.16E-07	1.81E-06	5.84E-08	1.09E-07	5.73E-07	2.36E-07	1.86E-06
1,3-Butadiene	1.15E-06	5.75E-08	5.19E-07	5.09E-07	2.94E-07	2.55E-06	5.74E-08	5.18E-07	5.47E-07	3.35E-07	2.63E-06

**Figure 3.2-4. Contributions to Inhalation Cancer Risk from Air Toxics Emitted by Mobile Sources, 2020 (Not Including Diesel PM and Diesel Exhaust Organic Gases)**

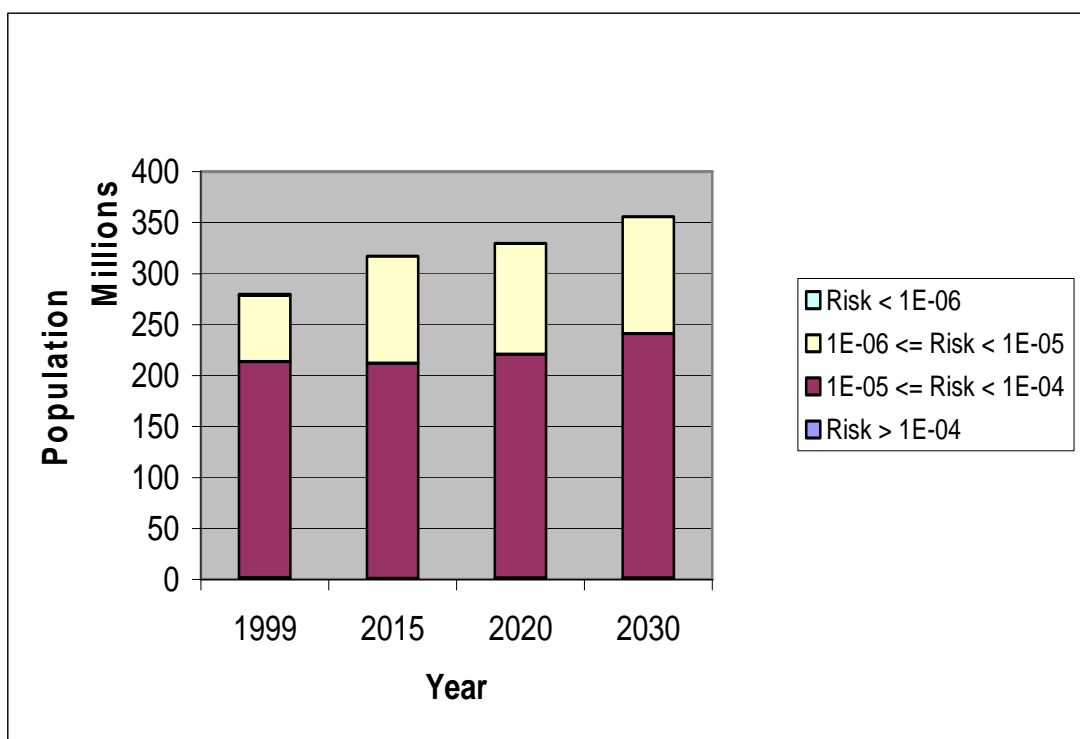


**Figure 3.2-5. Average Nationwide Cancer Risk from Emissions of Mobile Source Air Toxics from both Mobile and Stationary Sources across Census Tracts, 1999 to 2030 (Not Including Diesel PM and Diesel Exhaust Organic Gases)**



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 is 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).<sup>146</sup>). These statistics do not include populations in Alaska and Hawaii. More details on the methodology used to project the U. S. population above various cancer risk benchmarks are provided in the document "National-Scale Modeling of Mobile Source Air Toxic Emissions, Air Quality, Exposure and Risk for the Mobile Source Air Toxics Rule." From this figure it can be seen that, based on average census tract risks, the vast majority of the population experiences risks between one in a million ( $1 \times 10^{-6}$ ) and one in ten thousand ( $1 \times 10^{-4}$ ). However, the number of people experiencing risks above one in a hundred thousand ( $1 \times 10^{-5}$ ) increases from 214 million in 1999 to 240 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**



Tables 3.2-7 and 3.2-8 summarize national average population hazard quotient 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 50% between 1999 and 2030 (Figure 3.2-7), it is still over 3 in 2030, indicating a potential for adverse health effects. In addition, about 95% 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) is 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 will increase the number of Americans with a respiratory hazard index for mobile source air toxics above one, from 250 million in 1999 to 273 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.

Table 3.2-9 gives the distribution of nationwide average cancer risks for mobile source air toxics in 2020. 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 95<sup>th</sup> percentile benzene concentration is about twice the median value, the 95<sup>th</sup> percentile cancer risk is roughly six 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, 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.

Table 3.2-10 gives the distribution of nationwide average census tract 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 95<sup>th</sup> percentile is almost 40 times that at the 5<sup>th</sup> percentile, and about six times the median. Thus, some populations are experiencing much higher hazard indices than others. Figure 3.2-13 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.

**Table 3.2-7. National Average Population Hazard Quotient for Chronic Non-Cancer Effects across Census Tracts**

			1999 average Hazard Quotient					2015 average Hazard Quotient				
Pollutant	Target System	background	major	area & other	onroad	Nonroad	total (including background)	major	area & other	onroad	nonroad	total (including background)
1,3-Butadiene	Reproductive	1.91E-02	8.04E-04	8.58E-03	3.27E-02	7.54E-03	6.87E-02	8.88E-04	8.66E-03	9.19E-03	4.63E-03	4.29E-02
Acetaldehyde	Respiratory	4.41E-02	2.78E-03	5.15E-03	8.44E-02	1.57E-02	1.52E-01	2.82E-03	5.40E-03	3.18E-02	1.09E-02	9.54E-02
Acrolein	Respiratory	0.00E+00	1.36E-01	1.24E+00	3.36E+00	9.77E-01	5.72E+00	1.50E-01	1.12E+00	9.32E-01	7.71E-01	2.97E+00
Benzene	Immunological	9.93E-03	6.27E-04	4.72E-03	2.53E-02	4.42E-03	4.50E-02	4.49E-04	5.47E-03	9.04E-03	2.76E-03	2.78E-02
Chromium VI	Respiratory	0.00E+00	4.39E-04	8.19E-04	1.36E-04	5.89E-05	1.45E-03	5.58E-04	1.12E-03	2.07E-04	6.25E-05	1.95E-03
Ethyl Benzene	Developmental	0.00E+00	1.55E-05	7.52E-05	3.08E-04	7.13E-05	4.70E-04	1.05E-05	9.77E-05	1.03E-04	4.10E-05	2.52E-04
Formaldehyde	Respiratory	5.97E-02	3.55E-03	7.58E-03	5.91E-02	2.19E-02	1.52E-01	4.41E-03	8.60E-03	1.80E-02	1.52E-02	1.07E-01
Hexane	Neurological, Respiratory	0.00E+00	2.84E-04	1.94E-03	1.52E-03	2.32E-04	3.98E-03	2.52E-04	2.31E-03	6.11E-04	1.41E-04	3.31E-03
MTBE	Liver, Kidney, Ocular	0.00E+00	3.15E-06	1.79E-05	2.34E-04	2.65E-05	2.82E-04	3.19E-06	1.66E-05	3.80E-05	8.62E-06	6.65E-05
Manganese	Neurological	0.00E+00	2.14E-02	1.82E-02	1.43E-03	1.52E-04	4.13E-02	2.55E-02	2.40E-02	2.28E-03	1.77E-04	5.20E-02
Naphthalene	Respiratory	0.00E+00	1.31E-03	1.35E-02	5.76E-03	1.34E-03	2.19E-02	1.15E-03	1.63E-02	3.15E-03	1.33E-03	2.20E-02
Nickel	Respiratory, Immunological	0.00E+00	4.79E-03	9.14E-03	8.44E-04	7.32E-04	1.55E-02	5.50E-03	1.03E-02	1.29E-03	7.98E-04	1.79E-02
Styrene	Neurological	0.00E+00	2.11E-05	1.20E-05	3.24E-05	6.32E-06	7.18E-05	2.48E-05	1.61E-05	9.92E-06	3.67E-06	5.45E-05
Toluene	Respiratory, Neurological	0.00E+00	4.29E-04	1.74E-03	4.96E-03	6.85E-04	7.81E-03	3.05E-04	2.28E-03	1.61E-03	4.00E-04	4.60E-03
Xylenes	Neurological	1.27E-03	8.53E-04	5.11E-03	1.18E-02	3.30E-03	2.23E-02	7.04E-04	6.82E-03	3.82E-03	1.80E-03	1.44E-02

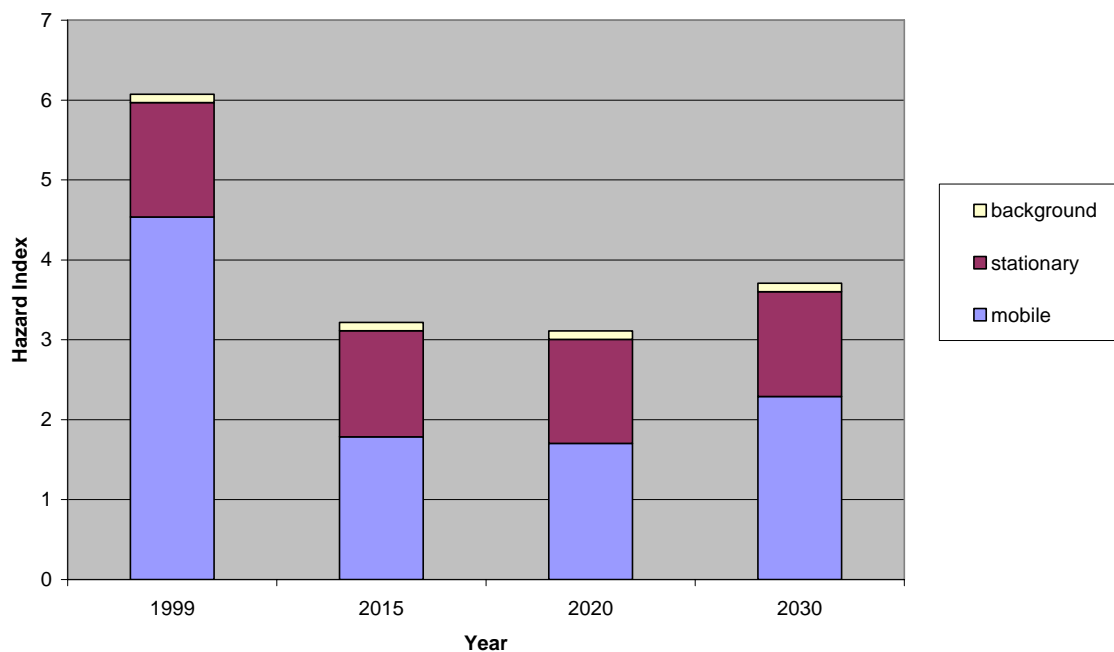
**Table 3.2-7 (cont'd). National Average Population Hazard Quotient for Chronic Non-Cancer Effects across Census Tracts**

			2020 average Hazard Quotient					2030 average Hazard Quotient				
Pollutant	Target System	background	major	area & other	onroad	Nonroad	total (including background)	major	area & other	onroad	nonroad	total (including background)
1,3-Butadiene	Reproductive	1.91E-02	9.58E-04	8.64E-03	8.48E-03	4.90E-03	4.25E-02	9.57E-04	8.64E-03	9.12E-03	5.59E-03	4.38E-02
Acetaldehyde	Respiratory	4.41E-02	2.95E-03	5.52E-03	2.77E-02	1.09E-02	9.15E-02	2.95E-03	5.52E-03	2.89E-02	1.19E-02	9.38E-02
Acrolein	Respiratory	0.00E+00	1.69E-01	1.08E+00	8.57E-01	8.09E-01	2.91E+00	1.69E-01	1.08E+00	9.25E-01	9.16E-01	3.09E+00
Benzene	Immunological	9.93E-03	4.93E-04	5.70E-03	8.12E-03	2.85E-03	2.72E-02	4.93E-04	5.69E-03	8.57E-03	3.20E-03	2.80E-02
Chromium VI	Respiratory	0.00E+00	6.36E-04	1.26E-03	2.33E-04	6.38E-05	2.20E-03	6.36E-04	1.26E-03	2.90E-04	6.67E-05	2.26E-03
Ethyl Benzene	Developmental	0.00E+00	1.17E-05	1.07E-04	9.05E-05	4.16E-05	2.51E-04	1.17E-05	1.07E-04	9.49E-05	4.65E-05	2.60E-04
Formaldehyde	Respiratory	5.97E-02	5.00E-03	9.04E-03	1.65E-02	1.53E-02	1.06E-01	5.00E-03	9.04E-03	1.79E-02	1.68E-02	1.09E-01
Hexane	Neurological, Respiratory	0.00E+00	2.77E-04	2.49E-03	5.08E-04	1.43E-04	3.42E-03	2.77E-04	2.49E-03	5.20E-04	1.60E-04	3.44E-03
MTBE	Liver, Kidney, Ocular	0.00E+00	3.58E-06	1.73E-05	2.93E-05	8.91E-06	5.91E-05	3.58E-06	1.73E-05	2.80E-05	1.01E-05	5.89E-05
Manganese	Neurological	0.00E+00	2.84E-02	2.63E-02	2.58E-03	1.89E-04	5.75E-02	2.84E-02	2.63E-02	3.26E-03	2.15E-04	5.82E-02
Naphthalene	Respiratory	0.00E+00	1.29E-03	1.74E-02	3.13E-03	1.42E-03	2.32E-02	1.29E-03	1.74E-02	3.63E-03	1.61E-03	2.39E-02
Nickel	Respiratory, Immunological	0.00E+00	5.98E-03	1.13E-02	1.44E-03	8.36E-04	1.96E-02	5.98E-03	1.13E-02	1.80E-03	9.17E-04	2.00E-02
Styrene	Neurological	0.00E+00	2.83E-05	1.78E-05	9.15E-06	3.84E-06	5.91E-05	2.83E-05	1.78E-05	9.81E-06	4.36E-06	6.03E-05
Toluene	Respiratory, Neurological	0.00E+00	3.40E-04	2.50E-03	1.44E-03	4.00E-04	4.68E-03	3.40E-04	2.50E-03	1.52E-03	4.42E-04	4.80E-03
Xylenes	Neurological	1.27E-03	7.95E-04	7.51E-03	3.39E-03	1.82E-03	1.48E-02	7.94E-04	7.51E-03	3.56E-03	2.03E-03	1.52E-02

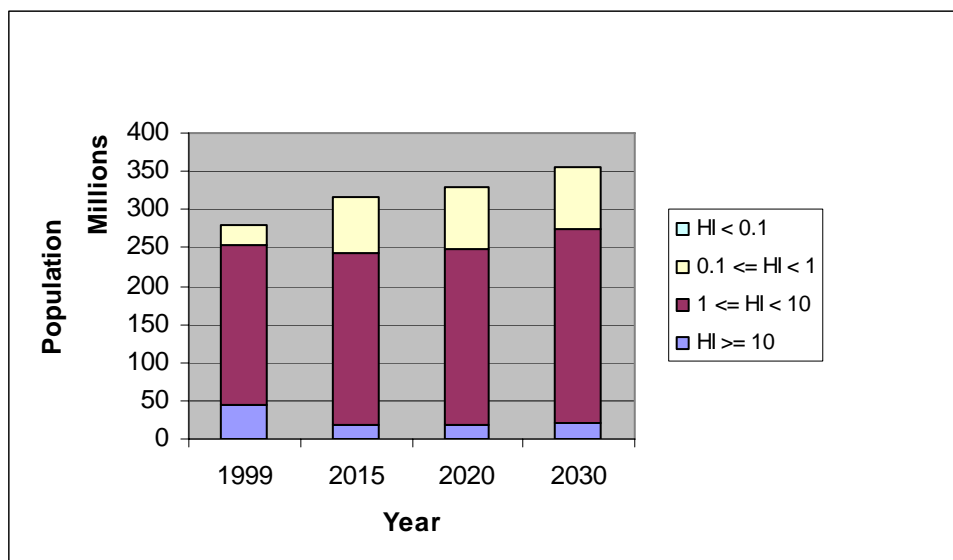
**Table 3.2-8. National Respiratory Hazard Index for Chronic Non-Cancer Effects across Census Tracts**

Respiratory System Average Hazard Index						
Year	background	major	area & other	onroad	nonroad	total (including background)
1999	1.04E-01	1.49E-01	1.28E+00	3.52E+00	1.02E+00	6.07E+00
2015	1.04E-01	1.65E-01	1.16E+00	9.88E-01	7.99E-01	3.22E+00
2020	1.04E-01	1.85E-01	1.13E+00	9.08E-01	8.38E-01	3.17E+00
2030	1.04E-01	1.85E-01	1.13E+00	9.79E-01	9.48E-01	3.35E+00

**Figure 3.2-7. Average Respiratory Hazard Index for U.S. Population (Aggregate of Hazard Quotients for Individual Pollutants)**



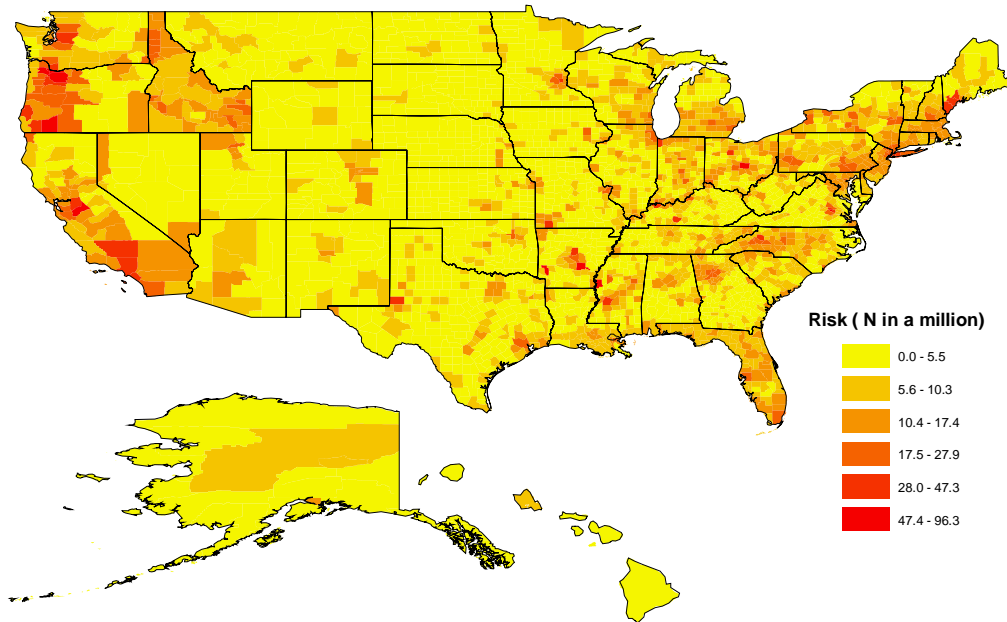
**Figure 3.2-8. U. S. Population at Various Non-Cancer Hazard Benchmarks due to Exposure to Mobile Source Air Toxics, 1999 – 2030**



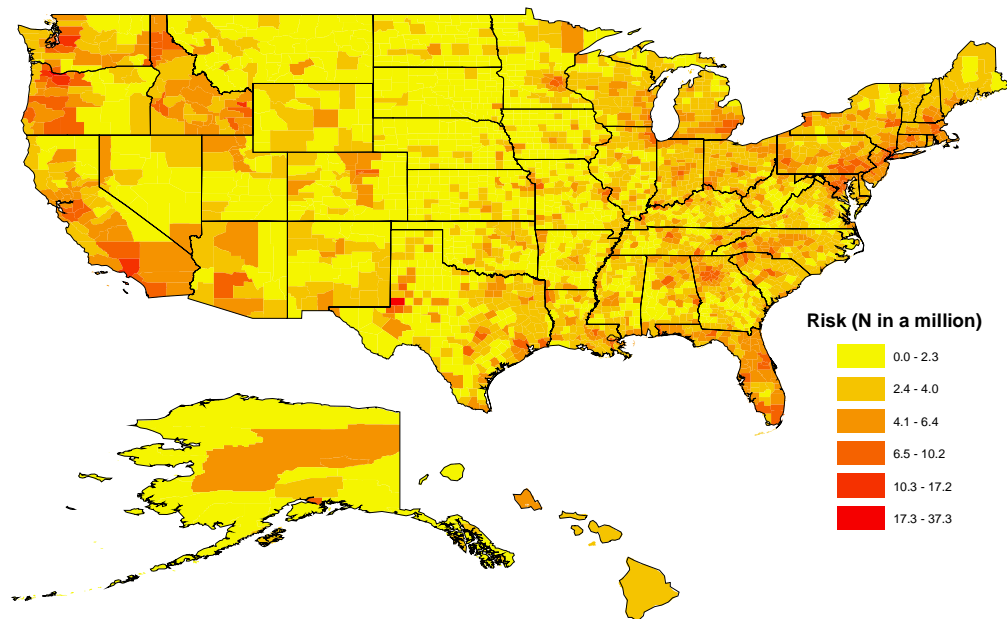
**Table 3.2-9. Distribution of Average Census Tract Cancer Risks for Mobile Source Air Toxics in 2020**

Pollutant	2020 risk distribution						
	5th percentile	10th percentile	25th percentile	Median	75th percentile	90th percentile	95th percentile
Total Risk: All HAPs	3.59E-06	4.61E-06	8.04E-06	1.34E-05	2.02E-05	3.34E-05	4.39E-05
POM	7.48E-08	1.40E-07	7.38E-07	1.99E-06	3.05E-06	4.48E-06	7.47E-06
Nickel	9.32E-07	9.98E-07	1.20E-06	1.60E-06	2.13E-06	2.94E-06	3.64E-06
Naphthalene	2.08E-06	2.54E-06	3.87E-06	5.61E-06	7.63E-06	1.07E-05	1.35E-05
Formaldehyde	1.65E-08	4.33E-08	1.82E-07	6.73E-07	1.83E-06	5.32E-06	8.58E-06
Chromium VI	1.75E-09	2.29E-09	3.53E-09	5.12E-09	6.80E-09	9.63E-09	1.23E-08
Benzene	1.02E-07	2.09E-07	6.20E-07	1.44E-06	2.79E-06	5.38E-06	8.47E-06
Acetaldehyde	1.27E-09	3.38E-09	1.35E-08	5.04E-08	1.53E-07	3.62E-07	6.15E-07
1,3-Butadiene	9.64E-08	1.71E-07	3.32E-07	6.81E-07	1.15E-06	1.93E-06	3.11E-06

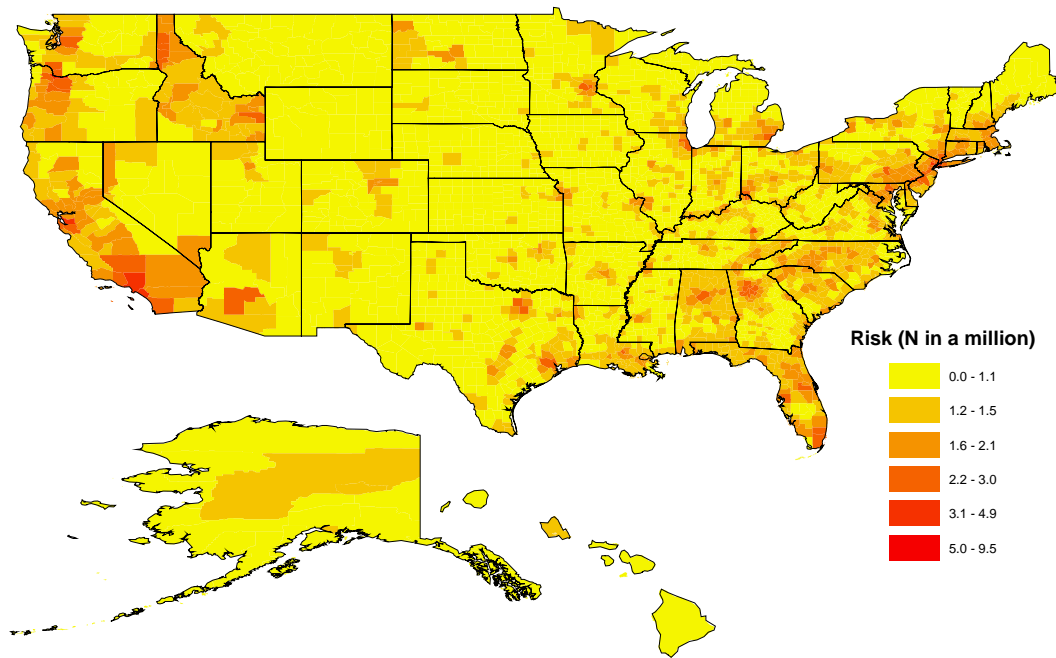
**Figure 3.2-9. 2020 County Median Cancer Risk for All Mobile Source Air Toxics**



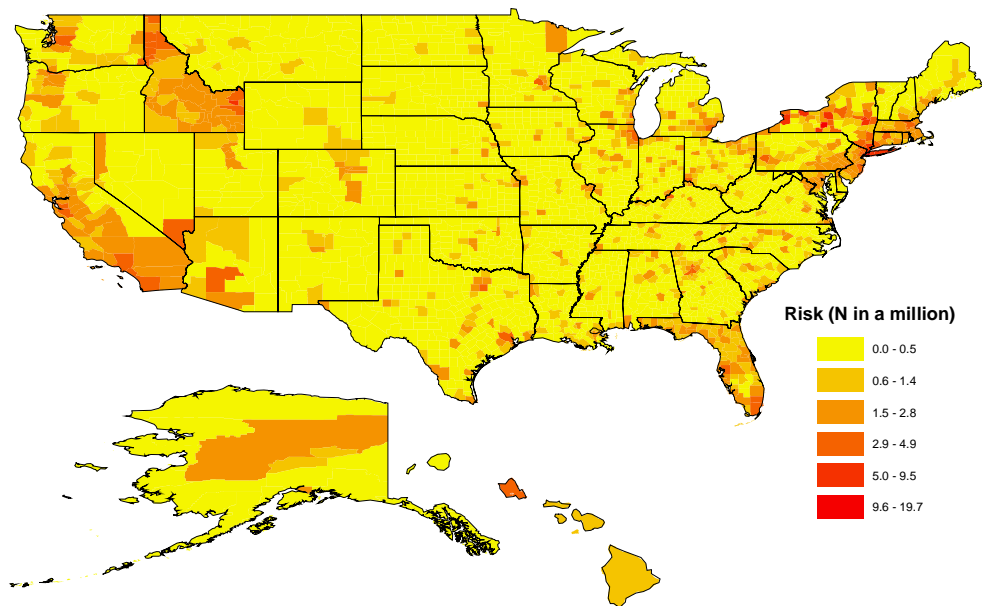
**Figure 3.2-10. 2020 County Median Cancer Risk for Benzene**



**Figure 3.2-11. 2020 County Median Cancer Risk for Acetaldehyde**



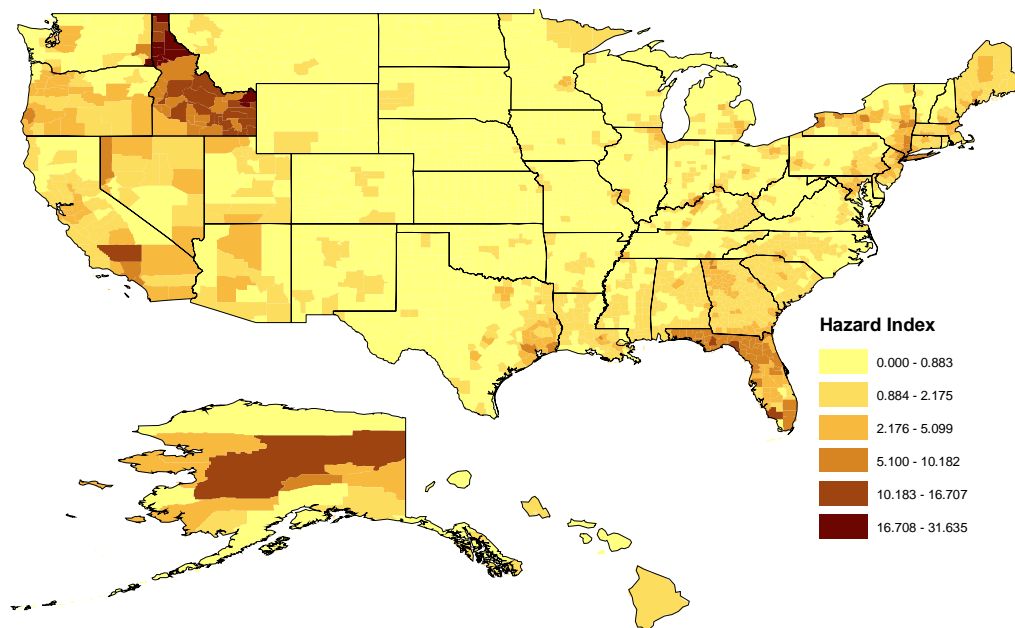
**Figure 3.2-12. 2020 County Median Cancer Risk for 1,3-Butadiene**



**Table 3.2-10. Distribution of Average Census Tract Hazard Quotients/Hazard Indices for Mobile Source Air Toxics (from both Mobile and Stationary Sources) in 2020**

Pollutant	2020 average Hazard Quotient or Hazard Index						95th percentile
	5th percentile	10th percentile	25th percentile	Median	75th percentile	90th percentile	
Acrolein	2.13E-01	3.65E-01	8.08E-01	1.69E+00	3.36E+00	6.99E+00	1.11E+01
Respiratory System	3.06E-01	4.79E-01	9.61E-01	1.91E+00	3.67E+00	7.39E+00	1.17E+01

**Figure 3.2-13. 2020 County Median Non-Cancer Hazard Index Respiratory Mobile Source Air Toxics**



#### 3.2.1.2.4 Impacts of Proposed Fuel Benzene Controls on Average Inhalation Cancer Risk

The fuel benzene standard proposed in this rule will substantially reduce inhalation cancer risk from exposure to benzene emitted by mobile sources across the United States. Table 3.2-11 shows that in 2015, 2020, and 2030, the highway vehicle contribution to benzene cancer risk will be reduced on average 8 to 9 percent across the U.S., the nonroad equipment contribution will be reduced about 7 percent, and the area source contribution about 4 percent. Reductions in conventional gasoline areas (i.e., areas not subject to reformulated gasoline) are almost 13 percent. In States with high fuel benzene levels, such as Minnesota and Washington, the risk reduction exceeds 17 percent (Table 3.2-12). Figure 3.2-14 depicts the impact on the mobile source contribution to nationwide average population cancer risk from benzene in 2020. Figure 3.2-15 presents the distribution of percent reductions in average benzene cancer risk for U. S. counties with the proposed control in 2020. Patterns are similar for other years. Summary tables providing exposure and risk data by State, as well as maps of benzene cancer risks with fuel controls and percent reductions with controls, can be found in the docket for the rule. Similar data are also available for 1,3-butadiene, formaldehyde and acetaldehyde, even though cancer risks were not significantly affected. Data are also available for noncancer risks, which are also not significantly affected.

It should be noted that the estimated total 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.

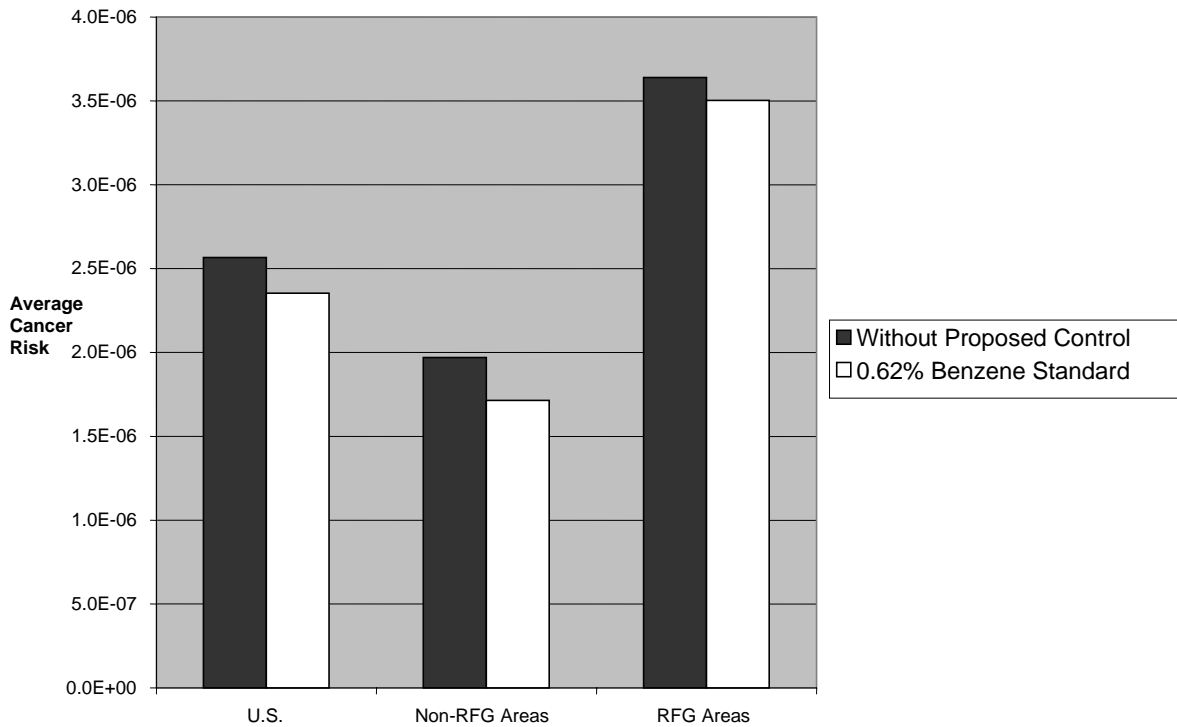
**Table 3.2-11. Contributions of Source Sectors to Nationwide Average Benzene Cancer Risk, with and without Proposed Fuel Benzene Standard, 2015, 2020, and 2030**

	2015 Average Risks					2020 Average Risks					2030 Average Risks				
	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	1.05E-07	1.28E-06	2.12E-06	6.46E-07	6.49E-06	1.15E-07	1.33E-06	1.90E-06	6.67E-07	6.36E-06	1.15E-07	1.33E-06	2.00E-06	7.49E-07	6.55E-06
Control	1.04E-07	1.23E-06	1.92E-06	6.00E-07	6.21E-06	1.14E-07	1.28E-06	1.73E-06	6.19E-07	6.10E-06	1.14E-07	1.28E-06	1.84E-06	6.95E-07	6.28E-06
% Difference	0.8	3.6	9.0	7.0	4.3	0.8	3.7	8.7	7.1	4.1	0.8	3.7	8.3	7.2	4.1
Average Nationwide Difference in Risk -- Non RFG Areas															
Reference	7.24E-08	1.05E-06	1.66E-06	4.57E-07	5.40E-06	8.06E-08	1.08E-06	1.49E-06	4.74E-07	5.29E-06	8.05E-08	1.08E-06	1.54E-06	5.35E-07	5.40E-06
Control	7.19E-08	1.00E-06	1.44E-06	4.02E-07	5.08E-06	7.99E-08	1.04E-06	1.30E-06	4.15E-07	5.00E-06	7.99E-08	1.03E-06	1.34E-06	4.68E-07	5.09E-06
% Difference	0.8	4.2	13.6	12.2	6.0	0.8	4.2	13.1	12.4	5.6	0.8	4.2	12.9	12.5	5.7
Average Nationwide Difference in Risk -- RFG Areas															
Reference	1.64E-07	1.70E-06	2.93E-06	9.84E-07	8.46E-06	1.78E-07	1.79E-06	2.63E-06	1.01E-06	8.28E-06	1.78E-07	1.79E-06	2.84E-06	1.13E-06	8.62E-06
Control	1.63E-07	1.65E-06	2.80E-06	9.57E-07	8.25E-06	1.77E-07	1.73E-06	2.52E-06	9.85E-07	8.09E-06	1.76E-07	1.73E-06	2.73E-06	1.10E-06	8.42E-06
% Difference	0.7	3.0	4.4	2.7	2.4	0.8	3.1	4.1	2.8	2.3	0.8	3.1	3.9	2.8	2.3

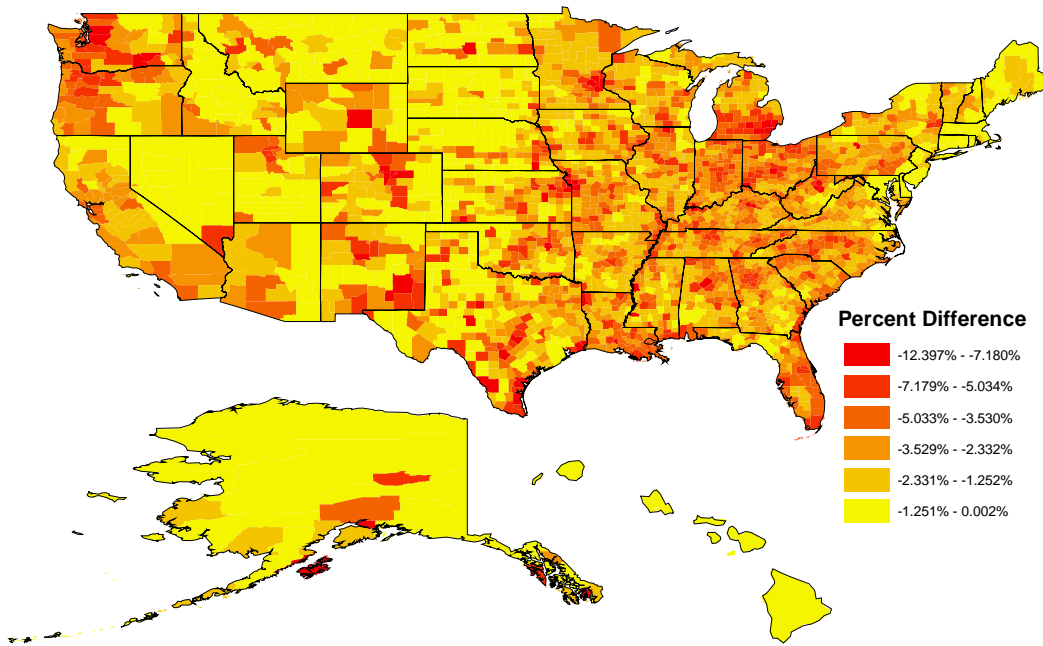
**Table 3.2-12. States with Highest Reductions in Average Benzene Cancer Risk Resulting from Mobile Source Emissions, 2020**

State	Average Risk – Reference Case	Average Risk – 0.62% Benzene Standard	Percent Difference
Alaska	$1.22 \times 10^{-6}$	$8.36 \times 10^{-7}$	-31%
Washington	$3.21 \times 10^{-6}$	$2.64 \times 10^{-6}$	-18%
Minnesota	$2.60 \times 10^{-6}$	$2.14 \times 10^{-6}$	-18%
New Mexico	$1.45 \times 10^{-6}$	$1.19 \times 10^{-6}$	-18%
Oregon	$2.97 \times 10^{-6}$	$2.47 \times 10^{-6}$	-17%

**Figure 3.2-14. Contribution to Nationwide Average Population Cancer Risk in 2020 Resulting from Proposed Fuel Benzene Controls**



**Figure 3.2-15. Distribution of Percent Reductions in Median Benzene Cancer Risk, 2020, for U.S. Counties with the Proposed Control**



As a result of the proposed fuel benzene control, 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 3 million in 2020 and by about 3.5 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 over 4 million in 2020 and 5 million in 2030 (Table 3.2-13).

**Table 3.2-13. 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 Proposed Fuel Benzene Control**

Year	Benzene	All Mobile Source Air Toxics
2015	4,976,000	3,226,000
2020	4,150,000	3,077,000
2030	5,253,000	3,477,000

The proposed standard will have little impact on the number of people above various respiratory hazard index levels, since this potential non-cancer risk is dominated by exposure to acrolein. Population statistics on number of individuals above various cancer and non-cancer benchmarks, by source sector, with fuel benzene control are available in the docket for this rule.

### 3.2.1.3 Impacts of Near Roadway Microenvironment on Modeled Exposures to Benzene

#### 3.2.1.3.1 Assessment Methods

In HAPEM5, if only a single outdoor concentration is provided for each census tract, as is typical, this concentration is assumed to uniformly apply to the entire census tract. EPA has recently developed a new version of the model, HAPEM6, which refines the model to account for the spatial variability of outdoor concentrations within a tract due to higher outdoor concentrations of onroad mobile source pollutants at locations near major roadways.<sup>B</sup> The new version of HAPEM more accurately reflects the average and range of exposure concentrations within each census tract by accounting for some of the spatial variability in the outdoor concentrations within the tract, and by extension some of the spatial variability in indoor concentrations within the tract. At this time, HAPEM6 only accounts for near-roadway effects for benzene.

The new version of HAPEM was developed using the following three steps.

1) *Estimating the fraction of the population living near major roadways in each census tract by demographic group.*

First, the “zone of influence” of transportation facilities needed to be determined – that is, the width of the area around major roads within which concentrations of benzene are elevated. Second, population data of sufficient geographic specificity was needed. Using geographic information systems, we conducted a study of the populations in three states, Colorado, Georgia, and New York<sup>147</sup> 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%.

This was done by overlaying extracts from the ESRI StreetMap US roadway geographic database on a geographic database of US Census blocks.

2) *Estimating the increase near major roadways of air toxic pollutant concentrations from onroad motor vehicle emissions relative to concentrations at other outdoor locations.*

In this step, data on spatial gradients of pollutants near roads from several sources were analyzed.<sup>148, 149, 150, 151, 152, 153, 154</sup> Data were analyzed for their suitability to estimate concentration distributions within 75 meters of a major roadway, or between 75 meters and 200 meters from such a road. All the data sources analyzed were from monitoring studies, except for one, which was a modeling study in Portland using the CALPUFF dispersion model to estimate concentrations at receptors located at census block centroids (Cohen et al., 2005). The monitoring data were consistent with the spatial gradients characterized using CALPUFF, but had limitations which precluded their use in quantifying concentration distributions. Among the limitations were that measured concentrations did not span various distances near the road

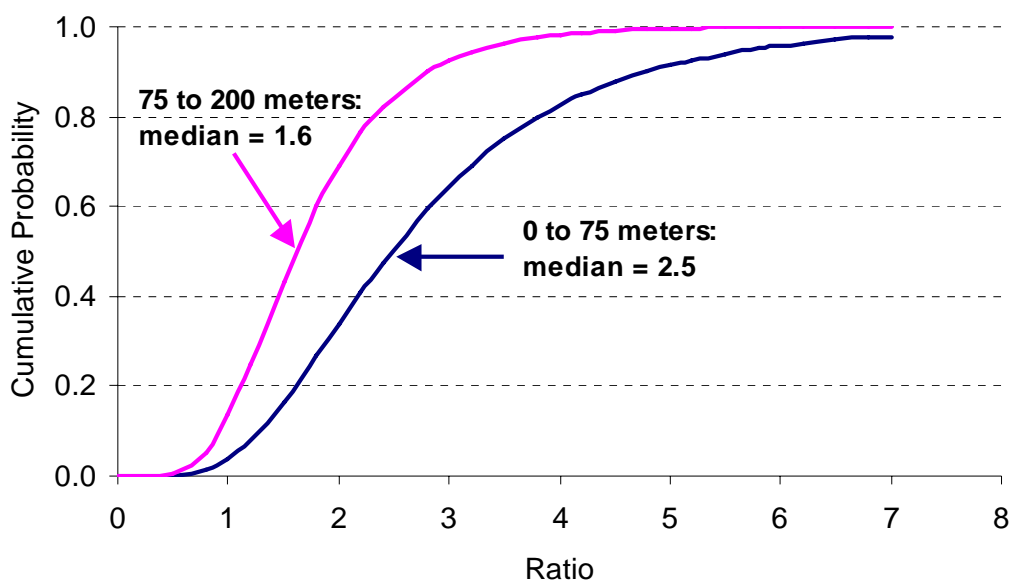
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<sup>B</sup> The term “major roadway” will be used to describe a “Limited Access Highway”, “Highway”, “Major Road” or “Ramp”, as defined by the Census Feature Class Codes (CFCC).

needed to develop a model, monitors were all downwind, or measurements were taken at limited times of year, making it difficult to extrapolate to annual averages. Modeling output from Portland included receptor locations at many distances from major roadways and calculated annual averages of benzene concentration in ambient air at those receptors. Thus the Portland modeling data was used to develop concentration ratios via regression analysis.

One way of comparing the concentrations for near-road and other locations is to examine the distribution of ratios between concentrations at multiple distances from a major road. Figure 3.2-16 presents a distribution of the concentration ratios between locations “near” a major roadway (within 75 meters) and locations “far” from a roadway (>200 meters distant). Also shown is a distribution of concentration ratios between locations at “intermediate” locations (between 75 meters and 200 meters) and those “far” from a roadway. These data were derived from the Portland modeling.

**Figure 3.2-16. Distribution of Ratios of Near Roadway to Remote Concentrations**



### 3) Modification of the HAPEM model

HAPEM6 models exposure for a simulated, demographically representative population within each census tract. For each simulated individual, HAPEM6 randomly selects for each home tract indoor microenvironment whether it is within D1 (75) meters of a major roadway, from D1 to D2 (75 to 200) meters from a major roadway, or greater than D2 meters from a major roadway, according to the database developed in the first step described above.

If the simulated person is a commuter, HAPEM6 randomly selects for each work tract indoor microenvironment whether it is within D1 meters of a major roadway, from D1 to D2 meters from a major roadway, or greater than D2 meters from a major roadway, according to the fractions of the populations living near major roadways in Step 1.

For each microenvironment, HAPEM6 selects a near-roadway ratio multiplier distribution for the proper distance according to the probabilities specified in the Step 2; and selects a ratio multiplier from that distribution.

HAPEM6 calculates the ambient concentration for locations more than D2 meters from a major roadway according to the equation:

$$A_{\text{far}} * C_{\text{far}} + A_{\text{D1-D2}} * C_{\text{D1-D2}} = C_{\text{ASPEN}} \quad \text{or}$$

$$A_{\text{far}} * C_{\text{far}} + A_{\text{D1-D2}} * R_{\text{D1-D2}} * C_{\text{far}} = C_{\text{ASPEN}} \quad \text{or}$$

$$C_{\text{far}} = C_{\text{ASPEN}} / (A_{\text{far}} + A_{\text{D1-D2}} * R_{\text{D1-D2}})$$

Where:

$C_{\text{ASPEN}}$  is the ASPEN concentration prediction for the tract

$C_{\text{D1-D2}}$  is the ambient concentration in the area between D1 and D2 meters from a major roadway (i.e., ASPEN concentration estimate x mean of the ratio multiplier distribution)

$C_{\text{far}}$  is ambient concentration in the area more than D2 meters from a major roadway

$A_{\text{D1-D2}}$  is the fraction of the tract area that is between D1 and D2 meters from a major roadway,

$A_{\text{far}}$  is the fraction of the tract area that is more than D2 meters from a major roadway, and

$R_{\text{D1-D2}}$  is the near roadway ratio multiplier selected for the D1 meters to D2 meters distance range.

The implicit assumption for this step is that the ASPEN estimate for the average census tract concentration represents the spatial average over the tract excluding the area within D1 meters of a major roadway. This is a reasonable assumption given the way that the ASPEN concentration estimate is generated.

The ASPEN estimate for the census tract average concentration is an aggregate of the contributions from all sources within 50 km of the tract. For sources located outside of the tract the concentration contribution is estimated at the geographic centroid of the tract and assumed to be uniform throughout the tract. For sources within the tract, which we expect to be the dominant contributors, the concentration contribution is calculated as a weighted average of the concentrations at all the modeling receptors that fall within the tract.

HAPEM6 calculates the "ambient" concentrations in at different distances from major roads by applying the relevant ambient concentration ratio. If located within 75 meters of a major road, the concentration ratio for that area is applied to the  $C_{\text{far}}$  concentration, shown above. Indoor microenvironmental concentrations are calculated based on this ambient concentration. Likewise if located between 75 and 200 meters of a major road, the concentration ratio for that area is used to calculate ambient and indoor concentrations at that point. If located more that 200 meters away from a major road, the  $C_{\text{far}}$  concentration is used for ambient air and for calculating indoor microenvironmental concentrations.

### 3.2.1.3.2 Results

The revised model was run for three geographic areas representing different parts of the

country. For these initial runs, benzene was the only pollutant modeled. ASPEN output for calendar year 1999 were used as inputs. We studied the states of Colorado, Georgia, and New York. These areas are intended to represent different geographies, development patterns, and housing densities.

Within a given census tract, the HAPEM model predicts 30 lifetime exposure concentrations depicting the variation in potential individual exposures within the tract. Such variation can result from differences in human activity patterns and as is the case for the simulation with HAPEM6, proximity of populations to roadways. Table 3.2-14 depicts the results of a comparison between HAPEM5 (does not include near roadway residents) and HAPEM6 (includes near roadway residents). The Table shows the distribution of individual exposure concentrations both within a given tract as well as in tracts across the state. When applied to each of these states, the greatest change in exposures resulting from the use of HAPEM6 occurred for the individuals at the upper end of the exposure distribution within each tract. Further, this effect was most pronounced at the tracts with the highest exposures within a state. In summary, the models show that including the effects of residence locations can result in exposures to some individuals that are up to 50% higher than those predicted by HAPEM5 (as was applied in the 1999 NATA).

**Table 3.2-14. Comparison Predicted Exposure Concentrations from HAPEM5 and HAPEM6 Results for Georgia, Colorado, and New York**

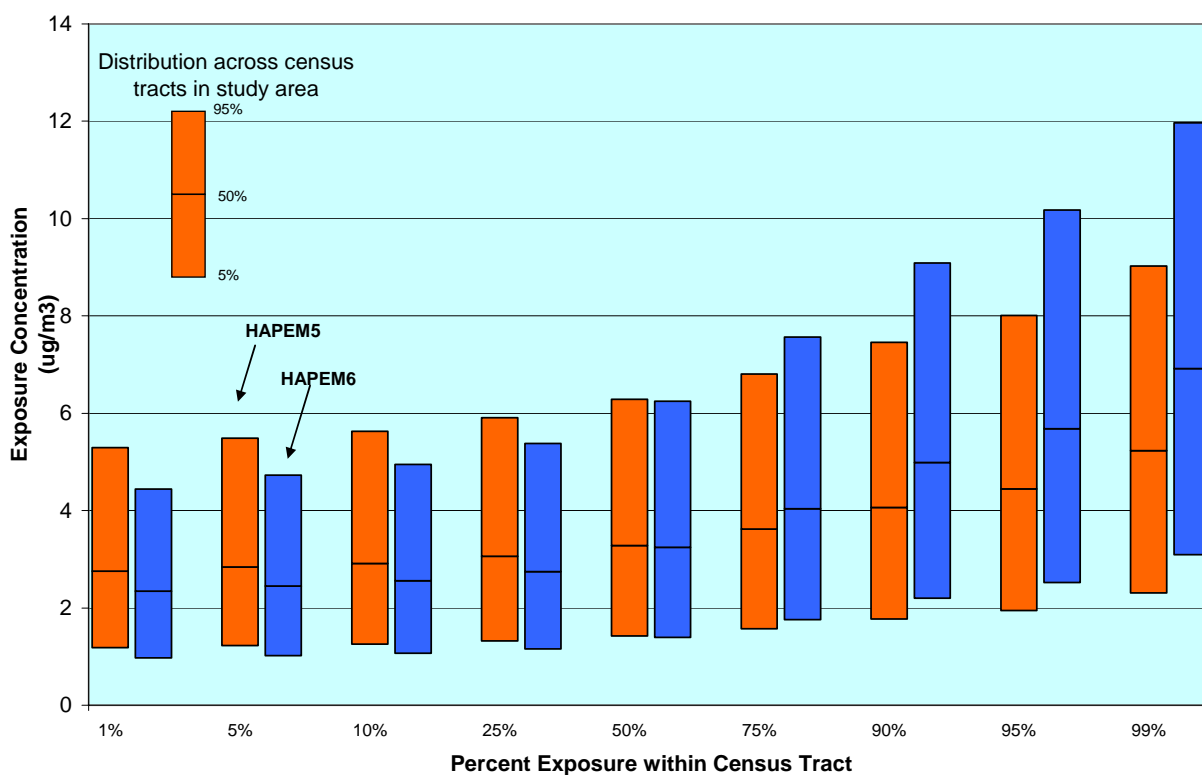
Modeled State	Model Version	Percentile of Tracts Across State	Percentile of Exposure within Census Tract (ug/m3)								
			1%	5%	10%	25%	50%	75%	90%	95%	99%
Georgia	HAPEM6	5% tract	0.54	0.57	0.60	0.64	0.73	0.92	1.15	1.31	1.55
		50% tract	0.83	0.87	0.89	0.95	1.06	1.28	1.57	1.76	2.07
		95% tract	1.29	1.34	1.39	1.53	1.86	2.45	3.11	3.59	4.43
	HAPEM5	5% tract	0.63	0.66	0.68	0.71	0.77	0.85	0.95	1.00	1.11
		50% tract	0.91	0.94	0.96	1.01	1.08	1.19	1.32	1.40	1.57
		95% tract	1.65	1.70	1.75	1.84	2.01	2.19	2.40	2.59	2.76
Colorado	HAPEM6	5% tract	0.49	0.52	0.53	0.58	0.67	0.80	1.01	1.10	1.27
		50% tract	0.71	0.74	0.76	0.81	0.92	1.08	1.30	1.42	1.61
		95% tract	0.66	0.71	0.76	0.84	0.99	1.24	1.50	1.70	2.18
	HAPEM5	5% tract	0.56	0.58	0.59	0.63	0.69	0.77	0.87	0.92	1.04
		50% tract	0.76	0.78	0.81	0.85	0.92	1.02	1.13	1.20	1.34
		95% tract	0.89	0.93	0.96	1.01	1.09	1.17	1.24	1.29	1.40
New York	HAPEM6	5% tract	0.97	1.02	1.07	1.16	1.39	1.76	2.20	2.52	3.09
		50% tract	1.37	1.43	1.49	1.59	1.85	2.27	2.79	3.16	3.82
		95% tract	2.10	2.28	2.39	2.63	3.00	3.53	4.10	4.49	5.05
	HAPEM5	5% tract	1.19	1.22	1.26	1.32	1.42	1.57	1.77	1.95	2.31
		50% tract	1.57	1.62	1.66	1.74	1.86	2.05	2.29	2.50	2.92
		95% tract	2.54	2.65	2.71	2.85	3.00	3.18	3.39	3.56	3.79

The results indicate that by accounting for within-tract variability in concentrations, HAPEM6 substantially increases overall variability in exposure to benzene. Demonstrating

these trends, the results of this modeling exercise for the state of New York are shown in Figure 3.2-17. In the graph, the horizontal axis shows percentiles of exposure within census tracts, while the range of each bar represents the 50<sup>th</sup>, 5<sup>th</sup>, and 95<sup>th</sup> percentiles of exposure concentration across census tracts within the state.

Overall, these study results indicate that proximity to major roads can significantly increase personal exposure for populations living near major roads. These models will be extended to a national scale for the final rulemaking.

**Figure 3.2-17. Changes in Predicted Benzene Exposure Patterns between HAPEM5 (no near-roadway adjustment) and HAPEM6 (with near-roadway adjustment) for New York**



### 3.2.1.4 Strengths and Limitations

Air quality, exposure, and risk were assessed using the best available suite of tools for national-scale analysis of air toxics. In addition, the modeling done to support this rule was consistent with NATA for 1999, making direct comparisons of results possible. The first NATA, done for calendar year 1996, 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.<sup>155</sup>
- 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.

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 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 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. The modeling also has certain key limitations: results are most accurate for large geographic areas and cannot be used to identify “hot spots,” such as the near road microenvironment, 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.<sup>156</sup> 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 3.2-15).

More detailed discussion of modeling limitations and uncertainties can be found on the 1999 NATA website.

**Table 3.2-15. 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. A key limitation is using 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. 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 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 3.2-16 compares national average total concentrations using 1999 versus scaled backgrounds. More details are provided in the technical document previously referenced.

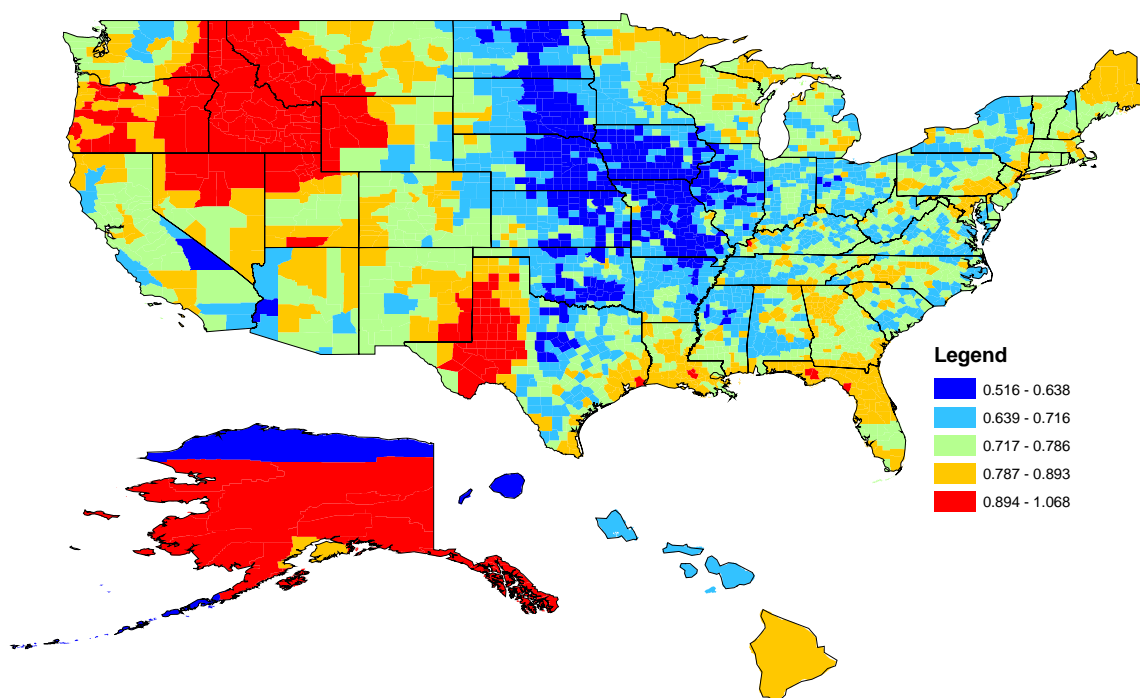
**Table 3.2-16. National Average Total Concentrations (All Sources and Background) for 2015, 2020, and 2030 using both the 1999 Background and the Scaled Backgrounds**

HAP	Total Concentrations ( $\mu\text{g m}^{-3}$ ) using 1999 Background			Total Concentrations ( $\mu\text{g m}^{-3}$ ) using Scaled Concentrations		
	2015	2020	2030	2015	2020	2030
1,3-Butadiene	$9.81 \times 10^{-2}$	$9.77 \times 10^{-2}$	$1.00 \times 10^{-1}$	$7.57 \times 10^{-2}$	$7.50 \times 10^{-2}$	$7.86 \times 10^{-2}$
Acetaldehyde	$9.66 \times 10^{-1}$	$9.36 \times 10^{-1}$	$9.56 \times 10^{-1}$	$7.77 \times 10^{-1}$	$7.47 \times 10^{-1}$	$7.78 \times 10^{-1}$
Benzene	$9.13 \times 10^{-1}$	$9.02 \times 10^{-1}$	$9.24 \times 10^{-1}$	$7.57 \times 10^{-1}$	$7.40 \times 10^{-1}$	$7.71 \times 10^{-1}$
Formaldehyde	1.22	1.22	1.25	$9.56 \times 10^{-1}$	$9.68 \times 10^{-1}$	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 3.2-18, 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: (1) near road impacts; (2) impacts of emissions from vehicles, equipment and fuels in attached garages; (3) increased risks from early lifetime exposures; and (4) properly estimated cold start emissions, estimated risks and risk reductions from fuel benzene control would be larger.

**Figure 3.2-18. Ratios of Benzene Concentrations with and without an Adjusted Background, 2020**



### 3.2.1.5. 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.<sup>157</sup> 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.”<sup>158</sup> 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. The following equation is used to develop this estimate.

$$\text{Excess Cancer Cases} = (\text{Average Individual Cancer Risk}) \times (\text{Population})$$

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. Also, a proper calculation would require characterization of the full distribution of exposure and risks. However, the modeling in this chapter estimates average nationwide risk based on average census tract risks; thus, the full distribution has not been characterized. Also, since census tracts vary in population, the average risk is not a population-weighted average.

In 2030, the cumulative excess average individual cancer risk from outdoor emissions of mobile source air toxics is estimated at  $1.7 \times 10^{-5}$ . If the entire U. S. population (projected to be about 364 million)<sup>159</sup> were exposed to this level of risk over a 70-year lifetime, it would result in about 6300 cancer cases, which translates into 90 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. 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. As discussed in Chapter 1, the current unit risk estimate for benzene may underestimate risk from acute nonlymphocytic 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.

In 2030, the national average inhalation individual cancer risk from outdoor mobile and stationary sources of benzene, in the absence of the proposed benzene standard, is estimated at approximately  $6.6 \times 10^{-6}$ , 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 34 excess cancer cases per year (Equation 1).

$$\begin{aligned} (1) \text{ Excess Cancer Cases at 2030 Exposure Level} &= \\ &(\text{Average Individual Cancer Risk}) \times (\text{2030 Population}) \\ &= 6.6 \times 10^{-6} \times 3.64 \times 10^8 = 2402 \\ \text{Annual Cancer Cases} &= 2402 / 70 = 34 \end{aligned}$$

However, this estimate does not include the higher estimates of benzene emissions from light-duty vehicles at cold temperatures, higher gasoline distribution emissions, or portable fuel container emissions developed for this rule. These revisions increase the total benzene inventory from about 228,000 tons to 298,000 tons. Assuming risks increase proportionally to the change in the inventory, the estimated number of excess cases would be approximately 44 per year, assuming continuous exposure to 2030 levels (equation 2).

$$\begin{aligned} (2) \text{ Adj. Excess Cancer Cases in 2030} &= \\ \text{Unadjusted Cancer Cases} &\times \frac{\text{Adjusted Inventory}}{\text{Unadjusted Inventory}} \\ = 34 \times \frac{298,000 \text{ tons}}{228,000 \text{ tons}} &= 44 \end{aligned}$$

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, average individual exposures to benzene could increase by roughly 1 to 3  $\mu\text{g}/\text{m}^3$ .<sup>160</sup> This could result in about another 40 to 120 excess cancer cases (equation 3).

$$\begin{aligned} (3) \text{ Attached Garage Excess Cancer Cases} &= \\ (\text{Average Exposure}) \times (\text{Benzene URE}) \times (\text{Population}) & \\ = (1 - 3 \mu\text{g} / \text{m}^3) \times (7.8 \times 10^{-6} / \mu\text{g} / \text{m}^3) \times (3.64 \times 10^8) &= 2839 - 8518 \\ \text{Annual Cancer Cases} &= 41 - 122 \end{aligned}$$

Thus, including attached garages would increase the number of benzene-related excess cancer cases to somewhere between 85 and 166 annually, assuming continuous exposure to 2030 levels. This estimate would still not include higher exposure levels from near-road impacts, 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.

The controls proposed in this rule reduce nationwide benzene emissions from all sources in 2030 by about 22%, from 298,000 tons to 233,000 tons. That would reduce excess leukemia cases due to benzene exposure, not including attached garage exposures, by 10, from about 44 per year to 34 per year, assuming cancer risk decreases proportionally to emissions. This

assumption likely understates the distribution of benzene exposure reductions, as populations with significant fractions of their daily activity on or near roadways are more likely to inhale vehicle-related pollutants than a person living downwind.<sup>161,162</sup> A roughly 40% reduction in fuel benzene will reduce attached garage exposures by about 40% as well, reducing excess cancer cases from this source of exposure by another 16 to 49 excess cancer cases. Thus, this rule would prevent roughly 26 to 59 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 near-road exposure, 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:

- Geographically heterogeneous percentage emissions reductions do not translate directly into changes in ambient levels, exposure, and risk.
- High and low end exposures are not fully characterized.
- The U.S. population would have experienced higher average exposures in previous years, but this is not accounted for.
- 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.
- The current unit risk estimate may underestimate risk from acute nonlymphocytic leukemia, because recent epidemiology data, discussed in Chapter 1 of the Regulatory Impact Analysis, suggest a supralinear rather than linear dose-response at low doses. As noted earlier, these data have not yet been formally evaluated by EPA as part of the IRIS review process.

### **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.

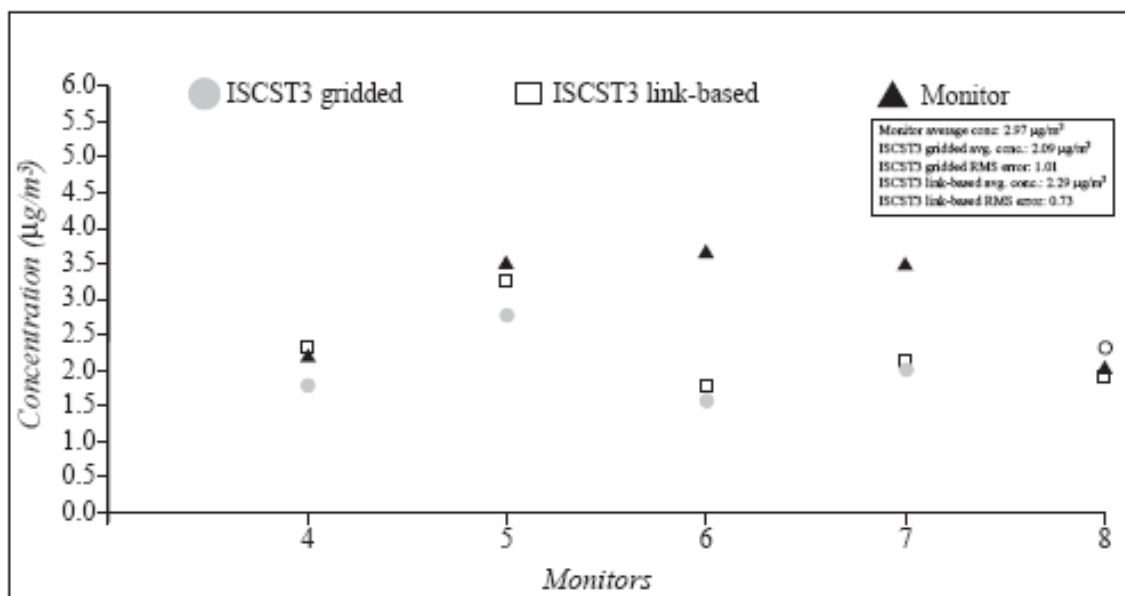
Local-scale modeling is typically done using steady-state plume dispersion models, such as the Integrated Source Complex (ISC) Model, the newly promulgated AERMOD (AMS/EPA Regulatory Model), or non-steady-state puff models such as CALPUFF. These models have a limited ability to simulate chemical reactions 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.<sup>163</sup> A case study of diesel exhaust particulate matter in Wilmington, CA was recently conducted employing some of these advances.<sup>164</sup> 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.<sup>165</sup> 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.<sup>166</sup> 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 3.2-18. 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.

**Figure 3.2-19. Model to Monitor Comparisons of Houston Benzene Concentrations**



Recent air quality modeling in Portland, OR using the CALPUFF dispersion model assigned emissions to specific roadway links.<sup>167</sup> 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 µg/m³, 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 µg/m³, with concentrations increasing to 1.29 µg/m³ 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.

A recent review of local-scale modeling studies concluded that:<sup>168</sup>

- 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.<sup>169</sup> 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 Philadelphia differed significantly between the top-down and the bottom-up methodologies as shown in Table 3.2-17.

**Table 3.2-17. 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, using local registration distribution data resulted in significantly lower air toxics emission factors and resultant emissions.

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 proposed 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, the main ingredient in smog, is formed by the reaction of VOCs and

nitrogen oxides (NO<sub>x</sub>) 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. VOCs can also be emitted by natural sources such as vegetation.

The science of ozone formation, transport, and accumulation is complex.<sup>170</sup> 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. Further complicating matters, 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<sub>x</sub> emissions. As a result, spatial and temporal differences in VOC and NO<sub>x</sub> emissions and weather patterns contribute to daily, seasonal, and yearly differences in ozone concentrations across different locations.

The highest levels of ozone are produced when both VOC and NO<sub>x</sub> emissions are present in significant quantities on clear summer days. Relatively small amounts of NO<sub>x</sub> enable ozone to form rapidly when VOC levels are relatively high, but ozone production is quickly limited by removal of the NO<sub>x</sub>. Under these conditions NO<sub>x</sub> reductions are highly effective in reducing ozone while VOC reductions have little effect. Such conditions are called “NO<sub>x</sub> -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<sub>x</sub> -limited.

When NO<sub>x</sub> levels are relatively high and VOC levels relatively low, NO<sub>x</sub> 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<sub>x</sub> reductions can actually increase local ozone under certain circumstances. Even in VOC-limited urban areas, NO<sub>x</sub> reductions are not expected to increase ozone levels if the NO<sub>x</sub> reductions are sufficiently large.

Rural areas are usually NO<sub>x</sub> -limited, due to the relatively large amounts of biogenic VOC emissions in many rural areas. Urban areas can be either VOC- or NO<sub>x</sub> -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<sub>2</sub>); as the air moves downwind and the cycle continues, the NO<sub>2</sub> forms additional ozone. The importance of this reaction depends, in part, on the relative concentrations of NO<sub>x</sub>, 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 4<sup>th</sup> 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. We are relying on the data and conclusions in the 1996 ozone criteria document (CD) and ozone staff paper, which reflect EPA's analysis of policy-relevant science from the ozone CD, regarding the health effects associated with ozone.<sup>171,172</sup> In August 2005, the EPA released the second external review draft of a new ozone CD which is scheduled to be released in final form in February 2006.<sup>173</sup> The new ozone criteria document summarizes the findings of the 1996 ozone CD and critically assesses relevant new scientific information that has emerged in the past decade. In all, the new epidemiological studies that have become available since the 1996 ozone CD continue to demonstrate the harmful effects of ozone on public health, and the need to attain and maintain the ozone NAAQS.

Ozone-related health effects include lung function decrements, respiratory symptoms, aggravation of asthma, increased hospital and emergency room visits, increased medication usage, inflammation of lung tissues, as well as a variety of other respiratory effects. People who are particularly at risk for high ozone exposures include healthy children and adults who are active outdoors. Susceptible subgroups include children, people with respiratory disease, such as asthma, and people with unusual sensitivity to ozone.<sup>174,175,176,177,178</sup>

Based on a large number of scientific studies, EPA has identified several key health effects associated with human 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.<sup>179,180,181,182,183,184,185,186,187,188,189,190,191,192</sup> Repeated exposure to ozone can make people more susceptible to lung inflammation and can aggravate preexisting respiratory diseases, such as asthma.<sup>193,194,195,196,197,198,199,200,201</sup> Repeated exposure to ozone can also cause inflammation of the lung, impairment of lung defense mechanisms, and possibly irreversible changes in lung structure.<sup>202,203,204,205,206,207</sup>

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.<sup>208,209,210,211,212</sup> Specifically, children and outdoor workers are most at risk from ozone exposure because they typically are active outside, working, playing and exercising, during the summer when ozone levels are highest.<sup>213,214,215,216</sup> 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 pain on deep inspiration and cough, when exposed to relatively low ozone levels during prolonged periods of moderate exertion.<sup>217</sup> For example, summer camp studies in the Eastern United States and Southeastern Canada have reported significant reductions in lung function in children who are active outdoors.<sup>218,219,220,221,222,223,224,225,226</sup> Further, children are more at risk of experiencing health

effects from ozone exposure than adults because their respiratory systems are still developing.

There has been new research that suggests additional serious health effects beyond those that had been known when the 1996 ozone CD was published. Since then, over 1,700 new ozone-related health and welfare studies have been published in peer-reviewed journals.<sup>227</sup> Many of these studies have investigated the impact of ozone exposure on such health effects as changes in lung structure and biochemistry, inflammation of the lungs, exacerbation and causation of asthma, respiratory illness-related school absence, hospital and emergency room visits for asthma and other respiratory causes, and premature mortality. EPA is currently in the process of evaluating these and other studies as part of the ongoing review of the criteria document and NAAQS for ozone. Key new health information falls into four general areas: development of new-onset asthma, hospital admissions for young children, school absence rate, and premature mortality. Examples of new studies in these areas are briefly discussed below.

Aggravation of existing asthma resulting from short-term ambient ozone exposure was reported prior to the 1997 ozone NAAQS revision and has been observed in studies published since then.<sup>228,229,230,231,232</sup> More recent studies now suggest the potential for a relationship between long-term ambient ozone concentrations and the incidence of new-onset asthma. In particular, such a relationship in adult males (but not in females) was reported by McDonnell et al. (1999).<sup>233</sup> Subsequently, McConnell et al. (2002) reported that incidence of new diagnoses of asthma in children is associated with heavy exercise in communities with high ambient ozone concentrations (i.e., mean 8-hour concentration of 59.6 ppb or greater of ozone).<sup>234</sup> This relationship was documented in children who played 3 or more sports and thus spent more time outdoors. It was not documented for those children who played one or two sports.<sup>C</sup> The larger effect of high activity sports than low activity sports and an independent effect of time spent outdoors also in the higher ozone communities strengthens the inference that exposure to ozone may modify the effect of sports on the development of asthma in some children.

Previous studies have shown relationships between ozone and hospital admissions in the general population. More recently there have been studies that report the effects of ozone on unscheduled respiratory hospital admissions of children.<sup>235,236,237,238</sup> A study in Toronto reported a significant relationship between 1-hour maximum ozone concentrations and respiratory hospital admissions in children under the age of two.<sup>239</sup> Given the relative vulnerability of children in this age category, there is particular concern about these findings from the literature on ozone and hospital admissions.

Increased rates of illness-related school absenteeism have been associated with 1-hour daily maximum<sup>240</sup> and 8-hour average ozone concentrations.<sup>241,242</sup> In a study by Chen and colleagues (2000), daily school absenteeism was examined in 27,793 students (kindergarten to sixth grade) from 57 elementary schools in Washoe County, NV over a two-year period.<sup>243</sup> In models adjusting for PM<sub>10</sub> and CO, ambient ozone levels were found to be associated with school absenteeism. Ozone-related school absences were also examined in a study of 1,933 fourth grade students from 12 southern California communities participating in the Children's Health Study.<sup>244</sup> Due to the comprehensive characterization of health outcomes, this study is

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<sup>C</sup> In communities with mean 8-hour ozone concentration of 59.6 ppb, the relative risk of developing asthma in children playing three or more sports was 3.3 (95% CI 1.9 - 5.8) compared with children playing no sports.

valuable in assessing the effect of ozone on illness-related school absenteeism in children. The study spanned the months of January through June 1996, which captured a wide range of exposures while staying mostly below the highest levels observed in the summer season. Larger ozone effects were seen for respiratory causes than for nonrespiratory causes. Park et al. (2002) examined the association between air pollution and school absenteeism in 1,264 students, first to sixth grade, attending school in Seoul, Korea.<sup>245</sup> The study period extended from March 1996 to December 1999, with 8-hour average ozone concentrations ranging from 3.13 ppb to 69.15 ppb (mean 22.86 ppb). Same day ozone concentrations were positively associated with illness-related absences, but inversely associated with non-illness-related absences. These studies reported that ambient ozone concentrations, on the same day as well as accumulated over two to four weeks, are associated with school absenteeism, particularly illness-related absences.

The air pollutant most clearly associated with premature mortality is PM, with many studies reporting such an association. However, recent studies have reported statistically significant associations between ozone exposure and premature mortality. Key findings are available from a multi-city time-series study that reports associations between ozone and mortality based on analyses using data from the 90 U.S. cities in the original National Mortality, Morbidity and Air Pollution (NMMAPS) study<sup>246,247</sup> and from 95 U.S. cities in an extension to the NMMAPS analyses<sup>248</sup>, and further analyses using a subset of 19 U.S. cities and focusing on cause-specific mortality associations<sup>249</sup>. An additional study used case-crossover design and data from 14 U.S. cities, to further investigate the influence of adjustment for weather variables in the ozone-mortality relationship.<sup>250</sup> Finally, results are available from a European study, Air Pollution and Health: a European Approach (APHEA), an analysis using data from 23 cities and 4 cities.<sup>251,252</sup>

In addition, several meta-analyses have been conducted on the relationship between O<sub>3</sub> and mortality. These analyses reported fairly consistent and positive combined effect estimates for an increase in mortality for a standardized change in O<sub>3</sub>. Three recent meta-analyses evaluated potential sources of heterogeneity in ozone-mortality associations.<sup>253,254,255</sup> Common findings were observed across all three analyses, in that all reported that effect estimates were larger in warm season analyses, reanalysis of results using default GAM criteria did not change the effect estimates, and there was no strong evidence of confounding by PM. Bell et al. (2005) and Ito et al. (2005) both provided suggestive evidence of publication bias, but ozone-mortality associations remained after accounting for that potential bias. These studies “provide strong evidence that ozone is associated with mortality.” This discussion is drawn from the second draft of the ozone criteria document. EPA is in the process of finalizing the ozone criteria document and the discussion in the final rule will reflect the final ozone criteria document.

There is a substantial amount of recent experimental evidence that links ozone exposure with respiratory effects in laboratory animals and humans. These include structural changes in the bronchiolar-alveolar transition (centriacinar) region of the lung, biochemical evidence of acute cellular/tissue injury, inflammation, increased frequency and severity of experimental bacterial infection, and temporary reductions in mechanical lung function. The data linking ozone exposure with respiratory effects have been observed with exposure to ozone at ambient or near-ambient concentrations. Thus, many of the reported epidemiologic associations of ambient ozone with respiratory health effects have considerable biological credibility. Accordingly, the

new epidemiologic studies of ambient ozone discussed here are best considered in combination with information on ambient ozone concentration and exposure, and toxicological effects of ozone in animals and humans. This discussion is drawn from the second draft of the ozone criteria document. EPA is in the process of finalizing the ozone criteria document and the discussion in the final rule will reflect the final ozone criteria document.

### **3.3.3 Current 8-Hour Ozone Levels**

The proposed gas can emission reductions would 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.

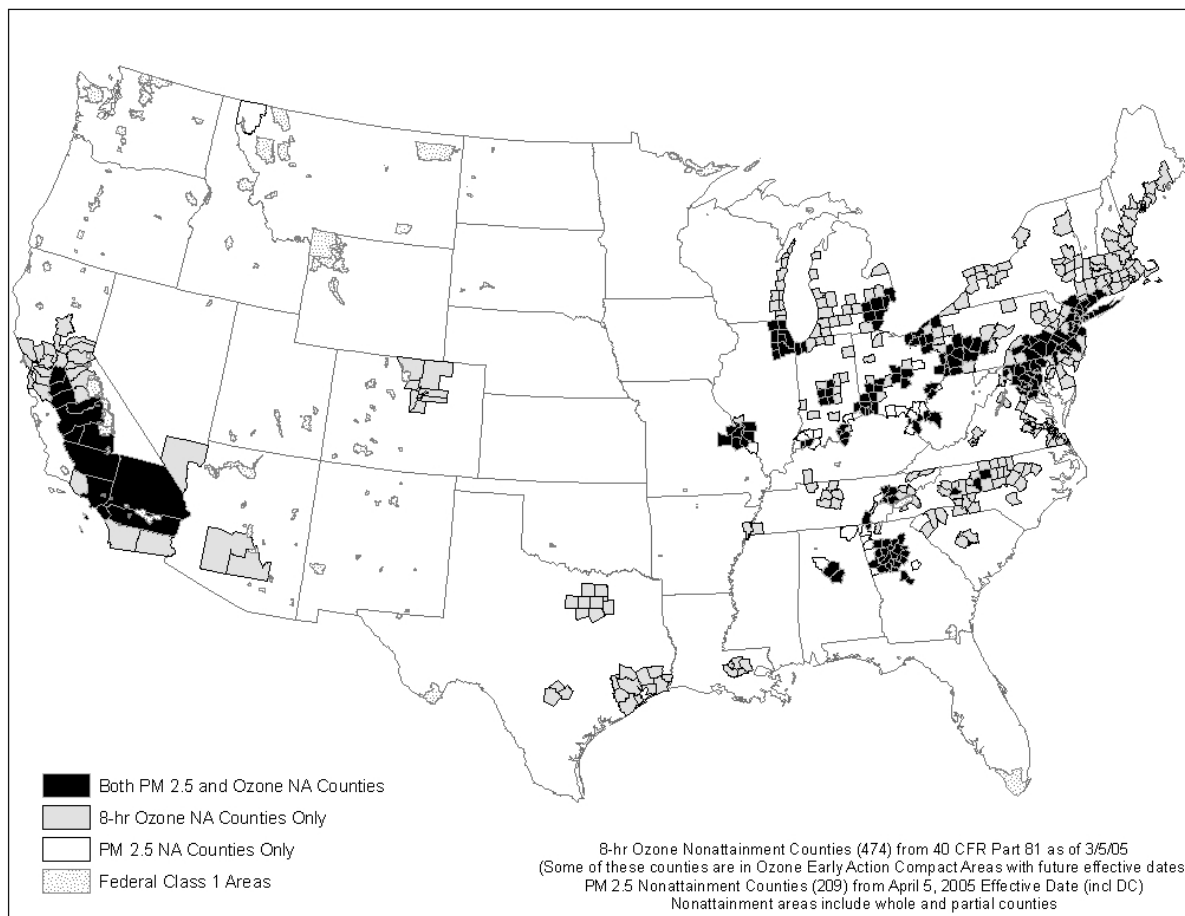
A nonattainment area is defined in the CAA as an area that is violating a NAAQS or is contributing to a nearby area that is violating the NAAQS. EPA designated nonattainment areas for the 8-hour ozone NAAQS in June 2004. The final rule on Air Quality Designations and Classifications for the 8-hour Ozone 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.<sup>D</sup>

According to EPA's designations, as of September 29, 2005, approximately 159 million people live in the 126 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 474 full or partial counties that make up the 126 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<sub>2.5</sub> nonattainment areas and the Mandatory Class I Federal Areas. The 8-hour ozone nonattainment areas, nonattainment counties and populations are listed in Appendix 3A to this RIA.

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<sup>D</sup> An ozone design value is the concentration that determines whether a monitoring site meets the NAAQS for ozone. Because of the way they are defined, design values are 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. The full details of these determinations (including accounting for missing values and other complexities) are given in Appendices H and I of 40 CFR Part 50. Due to the precision with which the standards are expressed (0.08 parts per million (ppm) for the 8-hour), a violation of the 8-hour standard is defined as a design value greater than or equal to 0.085 ppm or 85 parts per billion (ppb). For a county, the design value is the highest design value from among all the monitors with valid design values within that county. If a county does not contain an ozone monitor, it does not have a design value. Thus, our analysis may underestimate the number of counties with design values above the level of NAAQS.

**Figure 3.3.-1. 8-Hour Ozone and PM<sub>2.5</sub> Nonattainment Areas and Mandatory Class I Federal Areas**



Counties designated as 8-hour ozone nonattainment were classified, on the basis of their one-hour ozone design value, as Subpart 1 or Subpart 2 (69 FR 23951, April 30, 2004). Areas classified 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 3A-1 presents the 8-hour ozone nonattainment areas, their 8-hour design values, their category or classification and their maximum attainment date. States with 8-hour ozone nonattainment areas are required to take action to bring those areas into compliance in the future. 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 2014 time frame and then be required to maintain the 8-hour ozone NAAQS thereafter.<sup>E</sup> The gas can emission standards being proposed in this action would become effective in 2009. Thus, the expected ozone precursor emission inventory reductions from the standards proposed in this

<sup>E</sup> The Los Angeles Southcoast Air Basin 8-hour ozone nonattainment area will have to attain before June 15, 2021.

action would be useful to States in attaining and/or maintaining the 8-hour ozone NAAQS.

### **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 proposed 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 proposed rule.<sup>256</sup>

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.<sup>F</sup> 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 proposed rule may help ensure that these counties continue to maintain their attainment status and the emission reductions from this proposed rule would be included by the states in their baseline inventory modeling for their ozone maintenance plans.

**Table 3.3-1. Eastern Counties with 2010 projected 8-hour Ozone Concentrations  
Above and within 10% of the 8-hour Ozone Standard**

<b>State</b>	<b>County</b>	<b>2010 Projected 8-hour Ozone Concentration (ppb)<sup>a</sup></b>	<b>2000 pop<sup>b</sup></b>	<b>2010 pop<sup>c</sup></b>
Arkansas	Crittenden Co	80.8	50,866	52,889
Connecticut	Fairfield Co	<b>92.2</b>	882,567	891,694
Connecticut	Hartford Co	80.1	857,183	859,080
Connecticut	Middlesex Co	<b>90.6</b>	155,071	164,202
Connecticut	New Haven Co	<b>91.3</b>	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	<b>85.0</b>	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	<b>85.1</b>	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

State	County	2010 Projected	2000 pop <sup>b</sup>	2010 pop <sup>c</sup>
		8-hour Ozone Concentration (ppb) <sup>a</sup>		
Maine	Hancock Co	80.5	51,791	53,886
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

State	County	2010 Projected	2000 pop <sup>b</sup>	2010 pop <sup>c</sup>
		8-hour Ozone Concentration (ppb) <sup>a</sup>		
New Jersey	Mercer Co	95.2	350,761	359,912
New Jersey	Middlesex Co	92.1	750,162	805,537
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

State	County	2010 Projected	2000 pop <sup>b</sup>	2010 pop <sup>c</sup>
		8-hour Ozone Concentration (ppb) <sup>a</sup>		
Pennsylvania	Beaver Co	79.6	181,412	183,693
Pennsylvania	Berks Co	81.7	373,637	388,194
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

State	County	2010 Projected 8-hour Ozone Concentration (ppb) <sup>a</sup>	2000 pop <sup>b</sup>	2010 pop <sup>c</sup>
Wisconsin	Door Co	82.1	27,961	30,508
Wisconsin	Kenosha Co	<b>91.0</b>	149,577	166,359
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	<b>85.8</b>	82,317	95,549
Wisconsin	Racine Co	83.9	188,831	199,178
Wisconsin	Sheboygan Co	<b>87.7</b>	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 proposal.<sup>257</sup>

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.<sup>258</sup> 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.<sup>259</sup> This inventory does not include the gas can emissions that are being controlled in this proposed action. 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. 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 proposal.<sup>260</sup>

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.<sup>261</sup> 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 proposed gas can controls. Section 2.1.1.2 also details the states that have their own gas can control programs and how the controls proposed 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 proposed 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 (NO<sub>x</sub> 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 140 runs (a base case plus 139 control 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 proposed 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 proposed 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 proposed 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 proposed 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.<sup>G</sup> 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-

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<sup>G</sup> Appendix I of 40 CFR Part 50.

hour ozone design values due to the proposed gas can controls, when weighted by population. The AQMTSD, contained in the docket for this proposal, 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.<sup>262</sup> 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 Air Quality Criteria Document for Ozone and related Photochemical Oxidants notes that “ozone affects vegetation throughout the United States, impairing crops, native vegetation, and ecosystems more than any other air pollutant.”<sup>263</sup> Like carbon dioxide (CO<sub>2</sub>) 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.<sup>264</sup> Once ozone, a highly reactive substance, reaches the interior of plant cells, it inhibits or damages 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.<sup>265,266</sup> 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.<sup>267</sup> 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 (e.g., increasing CO<sub>2</sub> concentrations). Furthermore, there is considerable 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.<sup>268</sup>

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<sub>3</sub> uptake through closure of stomata).<sup>269,270,271</sup> 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.<sup>272</sup> 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 toxic for all plants. However, in general, the science suggests that ozone concentrations of 100 ppb or

greater can be phytotoxic to a large number of plant species, and can produce acute foliar injury responses, crop yield loss and reduced biomass production. Ozone concentrations below 100 ppb (50 to 99 ppb) can produce these effects in more sensitive plant species, and have the potential over a longer duration of creating chronic stress on vegetation that can lead to effects of concern associated with reduced carbohydrate production and decreased plant vigor. 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.<sup>273,274</sup> In terms of forest productivity and ecosystem diversity, ozone may be the pollutant with the greatest potential for regional-scale forest impacts.<sup>275</sup> Studies have demonstrated repeatedly that ozone concentrations commonly observed in polluted areas can have substantial impacts on plant function.<sup>276,277</sup>

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 damages 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.<sup>278</sup> In most instances, responses to chronic or recurrent exposure are subtle and not observable for many years. These injuries can cause stand-level forest decline in sensitive ecosystems.<sup>279,280,281</sup> It is not yet possible to predict ecosystem responses to ozone with much certainty; however, considerable knowledge of potential ecosystem responses has been acquired through long-term observations in highly damaged forests in the United States.

Laboratory and field experiments have also shown reductions in yields for agronomic crops exposed to ozone, including vegetables (e.g., lettuce) and field crops (e.g., cotton and wheat). The most extensive field experiments, conducted under the National Crop Loss Assessment Network (NCLAN) examined 15 species and numerous cultivars. The NCLAN results show that “several economically important crop species are sensitive to ozone levels typical of those found in the United States.”<sup>282</sup> In addition, economic studies have shown a relationship between observed ozone levels and crop yields.<sup>283,284,285</sup>

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. 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. 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.<sup>286</sup> This is therefore a potentially costly environmental effect. However, 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 proposed 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 described based on its size fractions. PM<sub>10</sub> refers to particles with an aerodynamic diameter less than or equal to a nominal 10 micrometers. PM<sub>2.5</sub> refers to fine particles, those particles with an aerodynamic diameter less than or equal to a nominal 2.5 micrometers. Coarse fraction particles refer to those particles with an aerodynamic diameter less than or equal to a nominal 10 micrometers. Inhalable coarse fraction particles refer to those particles with an aerodynamic diameter greater than 2.5 micrometers, but less than or equal to a nominal 10 micrometers. Ultrafine PM refers to particles with diameters of less than 100 nanometers (0.1 micrometers). Larger particles (greater than 10 micrometers) tend to be removed by the respiratory clearance mechanisms whereas smaller particles (PM<sub>10</sub>) are deposited deeper in the lungs. Ambient fine particles are a complex mixture including sulfates, nitrates, chlorides, ammonium compounds, organic carbon, elemental carbon, geological material, and metals. Fine particles can remain in the atmosphere for days to weeks and travel through the atmosphere hundreds to thousands of kilometers, while coarse particles generally tend to deposit to the earth within minutes to hours and within tens of kilometers from the emission source.

The vehicles that would be covered by the proposed 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<sub>2.5</sub>, namely organic carbonaceous PM<sub>2.5</sub>. The gas cans that would be covered by the proposed standards also emit VOC which contribute to secondary PM<sub>2.5</sub>. Both types of directly and indirectly formed particles from vehicles and gas cans are found principally in the fine fraction.

EPA has National Ambient Air Quality Standards (NAAQS) for both PM<sub>2.5</sub> and PM<sub>10</sub>. The PM NAAQS consist of a short-term (24-hour) and a long-term (annual) standard. The short-term PM<sub>2.5</sub> NAAQS is set at a level of 65  $\mu\text{g}/\text{m}^3$  based on the 98<sup>th</sup> percentile concentration averaged over three years. The long-term PM<sub>2.5</sub> NAAQS specifies an expected annual arithmetic mean not to exceed 15  $\mu\text{g}/\text{m}^3$  averaged over three years. The short-term (24-hour) PM<sub>10</sub> NAAQS is set at a level of 150  $\mu\text{g}/\text{m}^3$  not to be exceeded more than once per year. The long-term PM<sub>10</sub> NAAQS specifies an expected annual arithmetic mean not to exceed 50  $\mu\text{g}/\text{m}^3$ .

EPA has recently proposed to amend the PM NAAQS.<sup>H</sup> The proposal includes lowering the level of the primary 24-hour fine particle standard from the current level of 65 micrograms per cubic meter ( $\mu\text{g}/\text{m}^3$ ) to 35  $\mu\text{g}/\text{m}^3$ , retaining the level of the annual fine standard at 15 $\mu\text{g}/\text{m}^3$ , and setting a new primary 24-hour standard for certain inhalable coarse particles (the indicator is qualified so as to include any ambient mix of  $\text{PM}_{10-2.5}$  that is dominated by sources typically found in urban environments, such as resuspended dust from high-density traffic on paved roads and PM generated by industrial and construction sources, and excludes any ambient mix of  $\text{PM}_{10-2.5}$  dominated by rural windblown dust and soils and PM generated by agricultural and mining sources) at 70 $\mu\text{g}/\text{m}^3$ . The Agency is also requesting comment on various other standards for fine and inhalable coarse PM (71 FR 2620, Jan. 17, 2006).

### **3.4.2 Health Effects of Particulate Matter**

As stated in the EPA Air Quality Criteria Document for PM (PM Criteria Document), available scientific findings “demonstrate well that human health outcomes are associated with ambient PM.”<sup>287</sup> We are relying primarily on the data and conclusions in the PM Criteria Document and PM staff paper, which reflects EPA’s analysis of policy-relevant science from the PM Criteria Document, regarding the health effects associated with particulate matter.<sup>288</sup> We also present additional recent studies published after the cut-off date for the PM criteria document. Taken together this information supports the conclusion that PM-related emissions from the gasoline vehicles and gas cans being controlled in this action are associated with adverse health effects. Information on PM-related mortality is presented first, followed by information on PM-related morbidity and near-roadway PM exposure.

#### **3.4.2.1 Short-Term Exposure Mortality and Morbidity Studies**

As discussed in the PM Criteria Document (CD), short-term exposure to  $\text{PM}_{2.5}$  is associated with premature mortality from cardiopulmonary diseases (CD, p. 8-305), hospitalization and emergency department visits for cardiopulmonary diseases (CD, p. 9-93), increased respiratory symptoms (CD, p. 9-46), decreased lung function (CD Table 8-34) and physiological changes or biomarkers for cardiac changes (CD, Section 8.3.1.3.4). In addition, the CD 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. (CD, Section 8.3.4).

Among the studies of effects from short-term exposure to  $\text{PM}_{2.5}$ , several studies specifically address the contribution of mobile sources to short-term  $\text{PM}_{2.5}$  effects on daily mortality. These studies indicate that there are statistically significant associations between mortality and PM related to mobile source emissions (CD, 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  $\text{PM}_{2.5}$  and mortality.<sup>289,290</sup> Another recent study in 14 U.S. cities examined the effect of  $\text{PM}_{10}$  exposures on daily hospital admissions for

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<sup>H</sup> US EPA, National Ambient Air Quality Standards for Particulate Matter (71 FR 2620, Jan. 17, 2006). This document is also available on the web at: <http://www.epa.gov/air/particlepollution/actions.html>.

cardiovascular disease. They found that the effect of PM<sub>10</sub> was significantly greater in areas with a larger proportion of PM<sub>10</sub> coming from motor vehicles, indicating that PM<sub>10</sub> from these sources may have a greater effect on the toxicity of ambient PM<sub>10</sub> when compared with other sources.<sup>291</sup> 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**

Short-term exposure studies provide one way of examining the effect of short-term variations in air quality on morbidity and mortality. However, they do not allow for an evaluation of the effect of long-term exposure to air pollution on human mortality and morbidity.<sup>292</sup> Longitudinal cohort studies allow for analysis of such effects.

Long-term exposure to elevated ambient PM<sub>2.5</sub> is associated with mortality from cardiopulmonary diseases and lung cancer (CD, p. 8-307), and effects on the respiratory system such as decreased lung function or the development of chronic respiratory disease (CD, pp. 8-313, 8-314). Of specific importance to this proposal, the PM Criteria Document also notes that the PM components of gasoline and diesel engine exhaust are likely to be major contributors to the observed increases in lung cancer mortality associated with ambient PM<sub>2.5</sub> (CD, p. 8-318).

The PM Criteria Document emphasizes the results of two long-term studies, the Six Cities and American Cancer Society (ACS) prospective cohort studies, based on several factors – the large study population in the ACS study, the large air quality data set in the Six Cities study, the generally representative study population used in the Six Cities study, and the fact that these studies have undergone extensive reanalysis (CD, p. 8-306).<sup>293,294,295</sup> One analysis of a subset of the ACS cohort data, which was published after the PM criteria document was finalized, found a larger association than had previously been reported between long-term PM<sub>2.5</sub> exposure and mortality in the Los Angeles area using a new exposure estimation method that accounted for variations in concentration within the city.<sup>296</sup> These studies provide strong evidence of a link between PM<sub>2.5</sub> and mortality, including all-cause, cardiorespiratory, and lung cancer mortality (CD, p. 8-307).

As discussed in the PM Criteria Document, the newer 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<sub>2.5</sub> and/or PM<sub>10</sub> on reduced lung function growth (CD, Section 8.3.3.2.3). In another recent publication, investigators in southern California reported the results of a cross-sectional study of outdoor PM<sub>2.5</sub> and measures of atherosclerosis in the Los Angeles basin.<sup>297</sup> The study found significant associations between ambient residential PM<sub>2.5</sub> and carotid intima-media thickness (CMT), an indicator of subclinical atherosclerosis, an underlying factor in cardiovascular disease.

### **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<sub>2.5</sub> health effects is a study that was done in North Carolina looking at concentrations of PM<sub>2.5</sub> 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<sub>2.5</sub> inside police cars on North Carolina state highways.<sup>298</sup> 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 proposed rule would 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<sub>2.5</sub> 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. EPA has recently designated nonattainment areas for the 1997 PM<sub>2.5</sub> NAAQS by calculating air quality design values (using 2001-2003 or 2002-2004 measurements) and considering other factors.<sup>1</sup> The Air Quality Designations and Classifications for the Fine Particles (PM<sub>2.5</sub>) NAAQS rule lays out the factors that EPA considered in making the nonattainment designations (70 FR 943, Jan. 5, 2005). According to EPA's recent designations, approximately 88 million people live in the 39 PM<sub>2.5</sub> areas designated as nonattainment for either failing to meet the 1997 PM<sub>2.5</sub> NAAQS or for contributing to poor air quality in a nearby area. There are 208 full or partial counties that make up the PM<sub>2.5</sub> nonattainment areas, as shown in Figure 3.3-1. The PM<sub>2.5</sub> nonattainment counties, areas and populations, as of September 2005, are listed in Appendix 3B to this RIA.

States with PM<sub>2.5</sub> nonattainment areas will be required to take action to bring those areas into compliance in the future. Most PM<sub>2.5</sub> nonattainment areas will be required to attain the 1997 PM<sub>2.5</sub> NAAQS in the 2009 to 2014 time frame and then be required to maintain the PM<sub>2.5</sub> NAAQS thereafter.<sup>2</sup> The emission standards being proposed in this action would become effective between 2009 and 2015. The expected PM<sub>2.5</sub> and PM<sub>2.5</sub> precursor inventory reductions

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<sup>1</sup> The full details involved in calculating a PM<sub>2.5</sub> design value are given in Appendix N of 40 CFR Part 50.

<sup>2</sup> While the final implementation process for bringing the nation's air into attainment with the PM<sub>2.5</sub> NAAQS is still being completed in a separate rulemaking action, the basic framework is well defined by the statute. The EPA finalized PM<sub>2.5</sub> attainment and nonattainment areas in April 2005. Following designation, Section 172(b) of the Clean Air Act allows states up to 3 years to submit a revision to their state implementation plan (SIP) that provides for the attainment of the PM<sub>2.5</sub> standard. Based on this provision, states could submit these SIPs until April 2008. Section 172(a)(2) of the Clean Air Act requires that these SIP revisions demonstrate that the nonattainment areas will attain the PM<sub>2.5</sub> standard as expeditiously as practicable but no later than 5 years from the date that the area was designated nonattainment. However, based on the severity of the air quality problem and the availability and feasibility of control measures, the Administrator may extend the attainment date "for a period of no greater than 10 years from the date of designation as nonattainment." Based on section 172(a) provisions in the Act, we expect that areas will need to attain the PM<sub>2.5</sub> NAAQS in the 2010 (based on 2007 - 2009 air quality data) to 2015 (based on 2012 to 2014 air quality data) time frame, and then be required to maintain the NAAQS thereafter.

from the standards proposed in this action would be useful to states in attaining or maintaining the 1997 PM<sub>2.5</sub> NAAQS.

### 3.4.3.2 Current PM<sub>10</sub> Levels

EPA designated PM<sub>10</sub> nonattainment areas in 1990.<sup>K</sup> As of September 2005, approximately 29 million people live in the 55 areas that are designated as PM<sub>10</sub> nonattainment, for either failing to meet the PM<sub>10</sub> NAAQS or for contributing to poor air quality in a nearby area. There are 54 full or partial counties that make up the PM<sub>10</sub> nonattainment areas. The PM<sub>10</sub> nonattainment areas and populations are listed in Appendix 3B to this RIA.

The attainment date for the initial moderate PM<sub>10</sub> nonattainment areas, designated by law on November 15, 1990, was December 31, 1994. Several additional moderate PM<sub>10</sub> nonattainment areas were designated in January of 1994, and the attainment date for these areas was December 31, 2000. The initial serious PM<sub>10</sub> nonattainment areas had an attainment date set by the Act of December 31, 2001. The Act provides that EPA may grant extensions of the serious area attainment dates of up to 5 years, provided that the area requesting the extension meets the requirements of section 188(e) of the Act. Four serious PM<sub>10</sub> nonattainment areas (Phoenix, Arizona; Clark County (Las Vegas), NV; Coachella Valley, and South Coast (Los Angeles), CA) have received extensions of the December 31, 2001 attainment date and thus have new attainment dates of December 31, 2006. We expect that most PM<sub>10</sub> nonattainment areas will attain the PM<sub>10</sub> standard in the 2006 time frame, depending on an area's classification and other factors, and then be required to maintain the PM<sub>10</sub> NAAQS thereafter. The projected reductions in emissions from the proposed controls would be useful to states to maintain the PM<sub>10</sub> NAAQS.<sup>L</sup>

### 3.4.3.3 Projected PM<sub>2.5</sub> 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 Clean Air Interstate Rule (CAIR), which was promulgated by EPA in 2005. 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 CAIR air quality assessment. The CAIR analysis

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<sup>K</sup> A PM<sub>10</sub> design value is the concentration that determines whether a monitoring site meets the NAAQS for PM<sub>10</sub>. The full details involved in calculating a PM<sub>10</sub> design value are given in Appendices H and I of 40 CFR Part 50.

<sup>L</sup> As mentioned above, the EPA has recently proposed to amend the PM NAAQS, by establishing a new indicator for certain inhalable coarse particles, and a new primary 24-hour standard for coarse particles described by that indicator. EPA also proposed to revoke the current 24-hour PM<sub>10</sub> standard in all areas of the country except in those areas with a population of at least 100,000 people and which contain at least one monitor violating the 24-hour PM<sub>10</sub> standard, based on the most recent 3 years of air quality data. In addition, EPA proposed to revoke upon promulgation of this rule the current annual PM<sub>10</sub> standard if EPA finalizes the proposed primary standard for PM<sub>10.2.5</sub> (71 FR 2620, Jan. 17, 2006).

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 proposed rule.<sup>299</sup>

### 3.4.3.3.2 Areas at Risk of Future PM<sub>2.5</sub> Violations

Air quality modeling performed for CAIR indicates that in the absence of additional local, regional or national controls, counties with annual average PM<sub>2.5</sub> levels above 15 µg/m<sup>3</sup> are likely to persist in the future. The CAIR analysis provided estimates of future PM<sub>2.5</sub> levels across the country. For example, in 2010 based on emission controls currently adopted or expected to be in place<sup>M</sup>, we project that 19 million people will live in 28 Eastern counties with average PM<sub>2.5</sub> levels at and above 15 µg/m<sup>3</sup>, see Table 3.4-1. The proposed rule would assist these counties in attaining the PM<sub>2.5</sub> NAAQS. Table 3.4-1 also lists the 56 Eastern counties, where 24 million people are projected to live, with 2010 projected design values that do not violate the annual PM<sub>2.5</sub> NAAQS but are within ten percent of it. These are counties that are not projected to violate the standard, but to be close to it. The proposed rule may help ensure that these counties continue to maintain their attainment status and the emission reductions from this proposed rule would be included by the states in their baseline inventory modeling for their PM<sub>2.5</sub> maintenance plans.

**Table 3.4-1. Eastern Counties with 2010 Projected Annual PM<sub>2.5</sub> Design Values Above and within 10% of the Annual PM<sub>2.5</sub> Standard**

State	County	2010 Projected PM <sub>2.5</sub> Concentration (µg/m <sup>3</sup> ) <sup>a,b</sup>	2000 pop <sup>c</sup>	2010 pop <sup>d</sup>
Alabama	DeKalb Co	13.97	64,452	70,826
Alabama	Jefferson Co	<b>17.46</b>	662,046	667,602
Alabama	Montgomery Co	14.10	223,509	240,104
Alabama	Morgan Co	14.11	111,064	121,931
Alabama	Russell Co	<b>15.15</b>	49,756	52,706
Alabama	Shelby Co	13.83	143,293	202,915
Alabama	Talladega Co	14.00	80,321	84,163
Delaware	New Castle Co	14.84	500,264	534,631
District of Columbia	District of Columbia	13.68	572,058	554,474
Georgia	Bibb Co	<b>15.17</b>	153,887	158,291
Georgia	Chatham Co	14.02	232,047	242,134
Georgia	Clarke Co	14.96	101,488	106,187
Georgia	Clayton Co	<b>16.29</b>	236,516	265,407
Georgia	Cobb Co	<b>15.35</b>	607,750	744,488
Georgia	DeKalb Co	<b>15.70</b>	665,864	698,335
Georgia	Dougherty Co	13.85	96,065	99,323
Georgia	Floyd Co	<b>15.87</b>	90,565	95,238
Georgia	Fulton Co	<b>16.98</b>	816,005	855,826

<sup>M</sup> 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 PM standards by their statutory date.

State	County	2010 Projected PM <sub>2.5</sub> Concentration ( $\mu\text{g}/\text{m}^3$ ) <sup>a,b</sup>	2000 pop <sup>c</sup>	2010 pop <sup>d</sup>
Georgia	Gwinnett Co	14.02	588,447	743,813
Georgia	Hall Co	14.28	139,276	156,939
Georgia	Muscogee Co	14.57	186,290	193,867
Georgia	Richmond Co	14.64	199,774	207,977
Georgia	Walker Co	14.22	61,053	64,140
Georgia	Washington Co	14.22	21,176	22,220
Georgia	Wilkinson Co	<b>15.22</b>	10,220	10,958
Illinois	Cook Co	<b>16.88</b>	5,376,739	5,363,464
Illinois	DuPage Co	13.81	904,160	1,019,575
Illinois	Madison Co	<b>15.96</b>	258,940	267,328
Illinois	St. Clair Co	<b>15.54</b>	256,081	253,343
Illinois	Will Co	14.30	502,265	588,797
Indiana	Clark Co	<b>15.15</b>	96,472	107,096
Indiana	Dubois Co	14.37	39,674	41,394
Indiana	Elkhart Co	13.93	182,790	195,982
Indiana	Lake Co	<b>16.48</b>	484,563	489,220
Indiana	Marion Co	<b>15.54</b>	860,453	879,932
Indiana	Vanderburgh Co	14.26	171,922	175,307
Kentucky	Bullitt Co	13.67	61,236	71,957
Kentucky	Fayette Co	14.17	260,511	292,752
Kentucky	Jefferson Co	<b>15.44</b>	693,603	704,891
Kentucky	Kenton Co	13.72	151,464	160,582
Maryland	Baltimore city	14.88	651,153	616,324
Michigan	Kalamazoo Co	13.66	238,602	251,616
Michigan	Monroe Co	14.03	145,945	153,348
Michigan	Oakland Co	13.70	1,194,155	1,299,592
Michigan	Wayne Co	<b>18.23</b>	2,061,161	1,964,209
Mississippi	Jones Co	14.21	64,958	68,915
Missouri	St. Louis City	14.40	348,188	324,156
New Jersey	Union Co	13.60	522,540	523,568
New York	Bronx Co	13.62	1,332,649	1,298,206
New York	New York Co	14.95	1,537,194	1,539,917
North Carolina	Catawba Co	14.07	141,685	155,349
North Carolina	Davidson Co	14.36	147,246	164,790
North Carolina	Mecklenburg Co	13.92	695,453	814,088
Ohio	Butler Co	15.03	332,806	384,410
Ohio	Cuyahoga Co	<b>17.11</b>	1,393,977	1,348,313
Ohio	Franklin Co	<b>15.13</b>	1,068,977	1,142,894
Ohio	Hamilton Co	<b>16.61</b>	845,302	843,226
Ohio	Jefferson Co	<b>15.64</b>	73,894	70,731
Ohio	Lawrence Co	14.11	62,319	63,014
Ohio	Lucas Co	13.76	455,053	447,302
Ohio	Montgomery Co	13.83	559,061	552,901
Ohio	Scioto Co	<b>15.98</b>	79,195	80,248
Ohio	Stark Co	<b>15.08</b>	378,097	382,563
Ohio	Summit Co	14.69	542,898	552,567

State	County	2010 Projected PM <sub>2.5</sub> Concentration ( $\mu\text{g}/\text{m}^3$ ) <sup>a,b</sup>	2000 pop <sup>c</sup>	2010 pop <sup>d</sup>
Pennsylvania	Allegheny Co	<b>18.01</b>	1,281,665	1,259,040
Pennsylvania	Beaver Co	13.61	181,412	183,693
Pennsylvania	Berks Co	13.56	373,637	388,194
Pennsylvania	Delaware Co	13.94	550,863	543,169
Pennsylvania	Lancaster Co	14.09	470,657	513,684
Pennsylvania	Philadelphia Co	14.98	1,517,549	1,420,803
Pennsylvania	York Co	14.20	381,750	404,807
Tennessee	Davidson Co	14.26	569,890	589,133
Tennessee	Hamilton Co	<b>15.57</b>	307,895	327,337
Tennessee	Knox Co	<b>16.16</b>	382,031	426,545
Tennessee	McMinn Co	13.64	49,015	51,072
Tennessee	Roane Co	13.58	51,910	54,744
Tennessee	Shelby Co	13.77	897,471	958,501
Tennessee	Sullivan Co	14.01	153,048	159,873
Texas	Harris Co	13.78	3,400,577	3,770,129
West Virginia	Brooke Co	14.42	25,447	24,753
West Virginia	Cabell Co	<b>15.08</b>	96,784	93,421
West Virginia	Hancock Co	14.89	32,667	31,374
West Virginia	Kanawha Co	<b>15.27</b>	200,072	197,381
West Virginia	Wood Co	14.14	87,986	87,994
Number of Violating Counties		28		
Population of Violating Counties			19,488,510	19,750,033
Number of Counties within 10%		56		
Population of Counties within 10%			23,310,383	24,583,976

a) Bolded concentrations indicate levels above the annual PM<sub>2.5</sub> standard.

b) Concentrations are calculated for counties with Federal Reference Method PM<sub>2.5</sub> monitoring data.

c) Populations are based on 2000 census data.

d) 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 Degradation

Visibility is important because it directly affects people's enjoyment of daily activities in all parts of the country. Individuals value good visibility for the well-being it provides them directly, both in 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, because of the special emphasis given to protecting these lands now and for future generations.

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<sub>2.5</sub> standards in 1997

which would work in conjunction with the establishment of a regional haze program. The secondary (welfare-based) PM<sub>2.5</sub> NAAQS was established as equal to the suite of primary (health-based) NAAQS (62 FR 38652, July 18, 1997). Furthermore, Section 169 of the Act provides additional authorities to remedy existing visibility impairment and prevent future visibility impairment in the 156 national parks, forests and wilderness areas labeled as Mandatory Class I Federal Areas (62 FR 38652, July 18, 1997).<sup>N</sup> In July 1999 the regional haze rule (64 FR 35714) was put in place to protect the visibility in Mandatory Class I Federal Areas. A list of the Mandatory Class I Federal Areas is included in Appendix 3C.<sup>O</sup>

Data showing PM<sub>2.5</sub> nonattainment areas and visibility levels above background at the Mandatory Class I Federal Areas demonstrate that unacceptable 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<sub>2.5</sub> is widespread. Currently, high ambient PM<sub>2.5</sub> 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.<sup>300</sup>

As mentioned above the secondary PM<sub>2.5</sub> standards were set as equal to the suite of primary PM<sub>2.5</sub> standards. Recently designated PM<sub>2.5</sub> nonattainment areas indicate that almost 90 million people live in 208 counties that are in nonattainment for the 1997 PM<sub>2.5</sub> NAAQS, see Appendix 3.4-A. 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.<sup>301,302</sup> 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.<sup>303</sup>

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

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<sup>N</sup> 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.

<sup>O</sup> As mentioned above, the EPA has recently proposed to amend the PM NAAQS (71 FR 2620, Jan. 17, 2006). The proposal would set the secondary NAAQS equal to the primary standards for both PM<sub>2.5</sub> and PM<sub>10-2.5</sub>. EPA also is taking comment on whether to set a separate PM<sub>2.5</sub> standard, designed to address visibility (principally in urban areas), on potential levels for that standard within a range of 20 to 30 µg/m<sup>3</sup>, and on averaging times for the standard within a range of four to eight daylight hours.

ensure no degradation occurs on the cleanest days (20% least impaired days). Although there have been 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.<sup>304</sup>

#### 3.4.4.1.3 Future Visibility Impairment

Recent modeling for the CAIR was used to project PM<sub>2.5</sub> levels in the U.S. in 2010. The results suggest that PM<sub>2.5</sub> levels above the 1997 NAAQS will persist in the future. We predicted that in 2010, there will be 28 Eastern counties with a population of 19 million where annual PM<sub>2.5</sub> levels are above 15 µg/m<sup>3</sup>, 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<sub>2.5</sub> levels above the annual 1997 PM<sub>2.5</sub> NAAQS. Thus, the emissions from these sources contribute to the current and anticipated visibility impairment and the proposed emission reductions may help improve future visibility impairment.

#### 3.4.4.1.4 Future Visibility Impairment at Mandatory Class I Federal Areas

Achieving the annual 1997 PM<sub>2.5</sub> 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<sub>2.5</sub> concentrations above 15 µg/m<sup>3</sup> 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 annual 1997 PM<sub>2.5</sub> 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 the Clean Air Interstate Rule (CAIR) was also used to project visibility conditions in mandatory Federal class I areas across the country in 2015. The results for the mandatory Federal class I 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 3C it is projected that there will continue to be Mandatory Class I Federal Areas with visibility levels above background in 2015.<sup>305</sup> Additional emission reductions will be needed from the broad set of sources that contribute, including the vehicles

and gas cans subject to this proposed rule. The reductions proposed 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.<sup>306</sup>

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 adverse effects to human health and welfare through 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.<sup>307,308,309,310,311</sup>

Adverse impacts on soil chemistry and plant life have been observed for areas heavily impacted by atmospheric deposition of metals and acid species, resulting in 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 (CD, p. 4-87).<sup>312</sup> 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 (CD, 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 (CD, p. 4-76).<sup>313</sup> Contamination of plant leaves by heavy metals can lead to elevated soil levels. Trace metals absorbed into the plant frequently bind to the leaf tissue, and then are lost when the leaf drops (CD, p. 4-75). As the fallen leaves decompose, the heavy metals are transferred into the soil.<sup>314,315</sup>

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 it is ingested by people and other animals. Mercury is unusual compared with other metals in that it largely partitions into the gas phase (in elemental form), and therefore has a longer residence time in the atmosphere than a metal found predominantly in the particle phase. This property enables mercury to travel far from the primary source before being deposited and accumulating in the aquatic ecosystem. The major source of mercury in the Great Lakes is from atmospheric deposition, accounting for approximately eighty percent of the mercury in Lake Michigan.<sup>316,317</sup> Over fifty percent of the mercury in the Chesapeake Bay has been attributed to atmospheric deposition.<sup>318</sup> Overall, the National Science and Technology Council (NSTC, 1999) identifies atmospheric deposition as the primary source of mercury to aquatic systems. Thirty-seven 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.<sup>319,320</sup> 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.<sup>321</sup> 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.<sup>322</sup> Polycyclic aromatic hydrocarbons (PAHs) are a class of POM that contain 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  $\mu\text{m}$  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.<sup>323</sup>

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.<sup>324,325</sup> Analyses of PAH deposition to Chesapeake and

Galveston Bay indicate that dry deposition and gas exchange from the atmosphere to the surface water predominate.<sup>326,327</sup> 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.<sup>328</sup> 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.<sup>329</sup> 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.<sup>330</sup> 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.<sup>331</sup>

Cousins et al. (1999) estimates that greater than ninety percent of semi-volatile organic compound (SVOC) emissions in the United Kingdom deposit on soil.<sup>332</sup> An analysis of polycyclic aromatic hydrocarbon (PAH) concentrations near a Czechoslovakian roadway indicated that concentrations were thirty times greater than background.<sup>333</sup>

#### **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.<sup>334</sup> 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.

The concentration changes that occur near major roadways are not fully captured in our current air quality models used to assess the public health impacts of the proposed standards. The studies discussed in this section address exposures and health effects that are at least partially captured by our modeling, but there are additional exposures and health effects associated with pollutants that are not explicitly quantified.

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 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**

In addition to studies that have documented the relationship between 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 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 two cohort studies have examined premature mortality in relation to residence near traffic, 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 two recent cohort studies for all-cause and cardiopulmonary mortality from the Netherlands and from Ontario, Canada.<sup>335,336,337</sup> 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.<sup>338</sup> 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. 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.

One cohort study conducted in the United Kingdom examined cardiocerebral (stroke) mortality in relation to living near traffic.<sup>339</sup> 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.<sup>340</sup> 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<sub>2.5</sub> 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.<sup>341</sup> 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.<sup>342</sup> 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.<sup>343</sup> 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.<sup>344</sup> Overall, children hospitalized for asthma were more likely to live within 200 meters of roads above the 90<sup>th</sup> 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.<sup>345</sup> 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.<sup>346</sup> 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 proposal. Taken together, these studies provide substantial 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.<sup>347</sup> Overall, the review concluded that there is some limited evidence of an association between traffic-generated pollutants and asthma incidence. 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 mechanism whereby PM<sub>2.5</sub> may be leading to premature mortality. Non-fatal acute myocardial infarction and cardiovascular hospital admissions are also PM-related cardiovascular effects. The studies described in Section 3.5.1 found higher relative risks for cardiopulmonary causes of death.

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.<sup>348</sup> 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<sub>2.5</sub>, VOCs, and metals.<sup>349</sup> In-vehicle PM<sub>2.5</sub> 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.<sup>350</sup> In the study, ambient PM<sub>2.5</sub> 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.<sup>351</sup> 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**

Studies examining birth outcomes in populations living near major traffic sources have generally 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.<sup>352</sup> 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.<sup>353</sup> In another study, preterm birth was associated with ambient PM<sub>10</sub> and CO.<sup>354</sup> 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.<sup>355</sup> 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.<sup>356</sup>

Overall, although the number of studies examining perinatal exposures is relatively 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 to account for early life exposures in the Supplemental Guidance for Assessing Susceptibility from Early-Life Exposure to Carcinogens.<sup>357</sup>

Furthermore, 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.<sup>358</sup>

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.<sup>359</sup> The study was reanalyzed using an approach to combine traffic volume with residential distance from major roads to assess "distance-weighted traffic volume."<sup>360</sup> The study found that the significant, monotonically increasing risks associated with increased distance-weighted traffic volume.

NO<sub>2</sub> has been used as an indicator of traffic emissions in some studies; however, it is important to note that NO<sub>2</sub> is not implicated as causing cancer. For instance, a study used a dispersion model of NO<sub>2</sub> from traffic to conduct a case-control study of childhood cancer in Sweden.<sup>361</sup> 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.<sup>362</sup> A large study of nearly 2,000 Danish children with cancer found no association between modeled concentrations of benzene and NO<sub>2</sub> at home and the risk of leukemia, central nervous system tumors, or total cancers.<sup>363</sup> 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.<sup>364</sup> 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.<sup>365</sup>

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.<sup>366</sup> 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<sub>x</sub>, PM<sub>10</sub>, 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 proposed standards will reduce a broad range of pollutants present in higher concentrations near roadways. The extent to which these health effects are attributable to PM versus other components of the complex mixture is unclear.

### **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. As noted earlier, we conducted a study in three states, Colorado, Georgia, and New York. Geographic information systems were used in the analysis. 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%.

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.<sup>367</sup> 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.<sup>368</sup> 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.<sup>369</sup> 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 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.<sup>370</sup> 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.<sup>371</sup> 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: 8-Hour Ozone Nonattainment

**Table 3A-1. 8-Hour Ozone Nonattainment Areas and Populations (Data is Current through April 2005 and Population Numbers are from 2000 Census Data)**

<b>8-hour Ozone Nonattainment Areas</b>	<b>Population</b>	<b>2001-2003 8-hr Design Value (ppb)</b>	<b>Category / Classification<sup>a,c,d</sup></b>	<b>Maximum Attainment Date<sup>b</sup></b>
Albany-Schenectady-Troy, NY	923,778	87	Subpart 1	Jun. 15, 2009
Allegan Co, MI	105,665	97	Subpart 1	Jun. 15, 2009
Allentown-Bethlehem-Easton, PA	637,958	91	Subpart 1	Jun. 15, 2009
Altoona, PA	129,144	85	Subpart 1	Jun. 15, 2009
Amador and Calaveras Cos (Central Mtn), CA	75,654	91	Subpart 1	Jun. 15, 2009
Atlanta, GA	4,228,492	91	Marginal	Jun. 15, 2007
Baltimore, MD	2,512,431	103	Moderate	Jun. 15, 2010
Baton Rouge, LA	636,214	86	Marginal	Jun. 15, 2007
Beaumont-Port Arthur, TX	385,090	91	Marginal	Jun. 15, 2007
Benton Harbor, MI	162,453	91	Subpart 1	Jun. 15, 2009
Benzie Co, MI	15,998	88	Subpart 1	Jun. 15, 2009
Berkeley and Jefferson Counties, WV	118,095	86	Subpart 1 EAC	Dec. 31, 2007
Birmingham, AL	805,340	87	Subpart 1	Jun. 15, 2009
Boston-Lawrence-Worcester (E. MA), MA	5,534,130	95	Moderate	Jun. 15, 2010
Boston-Manchester-Portsmouth(SE),NH	696,713	95	Moderate	Jun. 15, 2010
Buffalo-Niagara Falls, NY	1,170,111	99	Subpart 1	Jun. 15, 2009
Canton-Massillon, OH	378,098	90	Subpart 1	Jun. 15, 2009
Cass Co, MI	51,104	93	Marginal	Jun. 15, 2007
Charleston, WV	251,662	86	Subpart 1	Jun. 15, 2009
Charlotte-Gastonia-Rock Hill, NC-SC	1,476,564	100	Moderate	Jun. 15, 2010
Chattanooga, TN-GA	372,264	88	Subpart 1 EAC	Dec. 31, 2007
Chicago-Gary-Lake County, IL-IN	8,757,808	101	Moderate	Jun. 15, 2010
Chico, CA	203,171	89	Subpart 1	Jun. 15, 2009
Cincinnati-Hamilton, OH-KY-IN	1,891,518	96	Subpart 1	Jun. 15, 2009
Clarksville-Hopkinsville, TN-KY	207,033	85	Subpart 1	Jun. 15, 2009
Clearfield and Indiana Cos, PA	172,987	90	Subpart 1	Jun. 15, 2009
Cleveland-Akron-Lorain, OH	2,945,831	103	Moderate	Jun. 15, 2010
Columbia, SC	494,518	89	Subpart 1 EAC	Dec. 31, 2007
Columbus, OH	1,541,930	95	Subpart 1	Jun. 15, 2009

<b>8-hour Ozone Nonattainment Areas</b>	<b>Population</b>	<b>2001-2003 8-hr Design Value (ppb)</b>	<b>Category / Classification<sup>a,c,d</sup></b>	<b>Maximum Attainment Date<sup>b</sup></b>
Dallas-Fort Worth, TX	5,030,828	100	Moderate	Jun. 15, 2010
Dayton-Springfield, OH	950,558	90	Subpart 1	Jun. 15, 2009
Denver-Boulder- Greeley-Ft Collins-Love., CO	2,811,580	87	Subpart 1 EAC	Dec. 31, 2007
Detroit-Ann Arbor, MI	4,932,383	97	Marginal	Jun. 15, 2007
Door Co, WI	27,961	94	Subpart 1	Jun. 15, 2009
Erie, PA	280,843	92	Subpart 1	Jun. 15, 2009
Essex Co (Whiteface Mtn), NY	1,000	91	Subpart 1	Jun. 15, 2009
Evansville, IN	224,305	85	Subpart 1	Jun. 15, 2009
Fayetteville, NC	302,963	87	Subpart 1 EAC	Dec. 31, 2007
Flint, MI	524,045	90	Subpart 1	Jun. 15, 2009
Fort Wayne, IN	331,849	88	Subpart 1	Jun. 15, 2009
Franklin Co, PA	129,313	93	Subpart 1	Jun. 15, 2009
Frederick Co, VA	82,794	85	Subpart 1 EAC	Dec. 31, 2007
Fredericksburg, VA	202,120	99	Moderate	Jun. 15, 2010
Grand Rapids, MI	812,649	89	Subpart 1	Jun. 15, 2009
Greater Connecticut, CT	1,543,919	95	Moderate	Jun. 15, 2010
Greene Co, IN	33,157	88	Subpart 1	Jun. 15, 2009
Greene Co, PA	40,672	89	Subpart 1	Jun. 15, 2009
Greensboro-Winston Salem-High Point, NC	1,285,879	93	Marginal EAC	Dec. 31, 2007
Greenville-Spartanburg- Anderson, SC	799,147	87	Subpart 1 EAC	Dec. 31, 2007
Hancock, Knox, Lincoln & Waldo Cos, ME	92,476	94	Subpart 1	Jun. 15, 2009
Harrisburg-Lebanon- Carlisle, PA	629,401	88	Subpart 1	Jun. 15, 2009
Haywood and Swain Cos (Great Smoky NP), NC	288	85	Subpart 1	Jun. 15, 2009
Hickory-Morganton- Lenoir, NC	309,512	88	Subpart 1 EAC	Dec. 31, 2007
Houston-Galveston- Brazoria, TX	4,669,571	102	Moderate	Jun. 15, 2010
Huntington-Ashland, WV-KY	189,439	91	Subpart 1	Jun. 15, 2009
Huron Co, MI	36,079	87	Subpart 1	Jun. 15, 2009
Imperial Co, CA	142,361	87	Marginal	Jun. 15, 2007
Indianapolis, IN	1,607,486	96	Subpart 1	Jun. 15, 2009
Jackson Co, IN	41,335	85	Subpart 1	Jun. 15, 2009
Jamestown, NY	139,750	94	Subpart 1	Jun. 15, 2009
Jefferson Co, NY	111,738	97	Moderate	Jun. 15, 2010
Johnson City-Kingsport- Bristol, TN	206,611	86	Subpart 1 EAC	Dec. 31, 2007
Johnstown, PA	152,598	87	Subpart 1	Jun. 15, 2009
Kalamazoo-Battle Creek, MI	452,851	86	Subpart 1	Jun. 15, 2009

<b>8-hour Ozone Nonattainment Areas</b>	<b>Population</b>	<b>2001-2003 8-hr Design Value (ppb)</b>	<b>Category / Classification<sup>a,c,d</sup></b>	<b>Maximum Attainment Date<sup>b</sup></b>
Kent and Queen Anne's Cos, MD	59,760	95	Marginal	Jun. 15, 2007
Kern Co (Eastern Kern), CA	99,251	98	Subpart 1	Jun. 15, 2009
Kewaunee Co, WI	20,187	93	Subpart 1	Jun. 15, 2009
Knoxville, TN	713,755	92	Subpart 1	Jun. 15, 2009
La Porte, IN	110,106	93	Marginal	Jun. 15, 2007
Lancaster, PA	470,658	92	Marginal	Jun. 15, 2007
Lansing-East Lansing, MI	447,728	86	Subpart 1	Jun. 15, 2009
Las Vegas, NV	1,348,864	86	Subpart 1	Jun. 15, 2009
Lima, OH	108,473	89	Subpart 1	Jun. 15, 2009
Los Angeles South Coast Air Basin, CA	14,593,587	131	Severe 17	Jun. 15, 2021
Los Angeles-San Bernardino Cos(W Mojave),CA	656,408	106	Moderate	Jun. 15, 2010
Louisville, KY-IN	968,313	92	Subpart 1	Jun. 15, 2009
Macon, GA	153,937	86	Subpart 1	Jun. 15, 2009
Madison and Page Cos (Shenandoah NP), VA	2	87	Subpart 1	Jun. 15, 2009
Manitowoc Co, WI	82,887	90	Subpart 1	Jun. 15, 2009
Mariposa and Tuolumne Cos (Southern Mtn),CA	71,631	91	Subpart 1	Jun. 15, 2009
Mason Co, MI	28,274	89	Subpart 1	Jun. 15, 2009
Memphis, TN-AR	948,338	92	Marginal	Jun. 15, 2007
Milwaukee-Racine, WI	1,839,149	101	Moderate	Jun. 15, 2010
Muncie, IN	118,769	88	Subpart 1	Jun. 15, 2009
Murray Co (Chattahoochee Nat Forest), GA	1,000	85	Subpart 1	Jun. 15, 2009
Muskegon, MI	170,200	95	Marginal	Jun. 15, 2007
Nashville, TN	1,097,810	86	Subpart 1 EAC	Dec. 31, 2007
Nevada Co. (Western Part), CA	77,735	98	Subpart 1	Jun. 15, 2009
New York-N. New Jersey-Long Island,NY- NJ-CT	19,634,122	102	Moderate	Jun. 15, 2010
Norfolk-Virginia Beach- Newport News (HR),VA	1,542,144	90	Marginal	Jun. 15, 2007
Parkersburg-Marietta, WV-OH	151,237	87	Subpart 1	Jun. 15, 2009
Philadelphia-Wilmin- Atlantic Ci,PA-NJ-MD- DE	7,333,475	106	Moderate	Jun. 15, 2010
Phoenix-Mesa, AZ	3,086,045	87	Subpart 1	Jun. 15, 2009
Pittsburgh-Beaver Valley, PA	2,431,087	94	Subpart 1	Jun. 15, 2009
Portland, ME	456,508	91	Marginal	Jun. 15, 2007

8-hour Ozone Nonattainment Areas	Population	2001-2003 8-hr Design Value (ppb)	Category / Classification <sup>a,c,d</sup>	Maximum Attainment Date <sup>b</sup>
Poughkeepsie, NY	717,262	94	Moderate	Jun. 15, 2010
Providence (All RI), RI	1,048,319	95	Moderate	Jun. 15, 2010
Raleigh-Durham-Chapel Hill, NC	1,244,053	94	Subpart 1	Jun. 15, 2009
Reading, PA	373,638	91	Subpart 1	Jun. 15, 2009
Richmond-Petersburg, VA	919,277	94	Marginal	Jun. 15, 2007
Riverside Co, (Coachella Valley), CA	324,750	108	Serious	Jun. 15, 2013
Roanoke, VA	235,932	85	Subpart 1 EAC	Dec. 31, 2007
Rochester, NY	1,098,201	88	Subpart 1	Jun. 15, 2009
Rocky Mount, NC	143,026	89	Subpart 1	Jun. 15, 2009
Sacramento Metro, CA	1,978,348	107	Serious	Jun. 15, 2013
San Antonio, TX	1,559,975	89	Subpart 1 EAC	Dec. 31, 2007
San Diego, CA	2,813,431	93	Subpart 1	Jun. 15, 2009
San Francisco Bay Area, CA	6,541,828	86	Marginal	Jun. 15, 2007
San Joaquin Valley, CA	3,191,367	115	Serious	Jun. 15, 2013
Scranton-Wilkes-Barre, PA	699,312	86	Subpart 1	Jun. 15, 2009
Sheboygan, WI	112,646	100	Moderate	Jun. 15, 2010
South Bend-Elkhart, IN	448,350	93	Subpart 1	Jun. 15, 2009
Springfield (Western MA), MA	814,967	94	Moderate	Jun. 15, 2010
St Louis, MO-IL	2,504,603	92	Moderate	Jun. 15, 2010
State College, PA	135,758	88	Subpart 1	Jun. 15, 2009
Steubenville-Weirton, OH-WV	132,008	86	Subpart 1	Jun. 15, 2009
Sutter Co (Sutter Buttes), CA	1	88	Subpart 1	Jun. 15, 2009
Terre Haute, IN	105,848	87	Subpart 1	Jun. 15, 2009
Tioga Co, PA	41,373	86	Subpart 1	Jun. 15, 2009
Toledo, OH	576,119	93	Subpart 1	Jun. 15, 2009
Ventura Co, CA	753,197	95	Moderate	Jun. 15, 2010
Washington Co (Hagerstown), MD	131,923	86	Subpart 1 EAC	Dec. 31, 2007
Washington, DC-MD-VA	4,452,498	99	Moderate	Jun. 15, 2010
Wheeling, WV-OH	153,172	87	Subpart 1	Jun. 15, 2009
York, PA	473,043	89	Subpart 1	Jun. 15, 2009
Youngstown-Warren- Sharon, OH-PA	715,039	95	Subpart 1	Jun. 15, 2009
<b>Total</b>	<b>159,271,919</b>			

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 have 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) The nonattainment areas covered under subpart 1 will be required to attain the standard no later than 5 years after designation and, in limited circumstances; they may apply for an additional extension of up to 5 years (e.g., 2009 to 2014). The areas classified under subpart 2 have attainment dates ranging from up to 3 years for marginal areas (2007) to up to 20 years for extreme areas (2024).

c) Boston-Manchester-Portsmouth (SE), NH has the same classification as Boston-Lawrence- Worcester (E. MA), MA.

d) Fredericksburg, VA has the same classification as Washington, DC-MD-VA.

**Table 3A-2. 8-Hour Ozone Nonattainment Counties and Populations (Data is Current through April 13, 2005 and Population Numbers are from 2000 Census Data)**

State	8-hour Ozone Nonattainment County	Whole (W) or Partial (P) County?	Population
AL	Jefferson Co	W	662,047
AL	Shelby Co	W	143,293
AZ	Maricopa Co	P	3,054,504
AZ	Pinal Co	P	31,541
AR	Crittenden Co	W	50,866
CA	Alameda Co	W	1,443,741
CA	Amador Co	W	35,100
CA	Butte Co	W	203,171
CA	Calaveras Co	W	40,554
CA	Contra Costa Co	W	948,816
CA	El Dorado Co	P	124,164
CA	Fresno Co	W	799,407
CA	Imperial Co	W	142,361
CA	Kern Co	P	649,471
CA	Kings Co	W	129,461
CA	Los Angeles Co	P	9,519,338
CA	Madera Co	W	123,109
CA	Marin Co	W	247,289
CA	Mariposa Co	W	17,130
CA	Merced Co	W	210,554
CA	Napa Co	W	124,279
CA	Nevada Co	P	77,735
CA	Orange Co	W	2,846,289
CA	Placer Co	P	239,978
CA	Riverside Co	P	1,519,609
CA	Sacramento Co	W	1,223,499
CA	San Bernardino Co	P	1,689,509
CA	San Diego Co	P	2,813,431
CA	San Francisco Co	W	776,733
CA	San Joaquin Co	W	563,598
CA	San Mateo Co	W	707,161
CA	Santa Clara Co	W	1,682,585
CA	Solano Co	P	394,542
CA	Sonoma Co	P	413,716
CA	Stanislaus Co	W	446,997
CA	Sutter Co	P	25,014
CA	Tulare Co	W	368,021
CA	Tuolumne Co	W	54,501
CA	Ventura Co	P	753,197
CA	Yolo Co	W	168,660
CO	Adams Co	W	348,618
CO	Arapahoe Co	W	487,967

State	8-hour Ozone Nonattainment County	Whole (W) or Partial (P) County?	Population
CO	Boulder Co	W	269,814
CO	Broomfield Co	W	38,272
CO	Denver Co	W	554,636
CO	Douglas Co	W	175,766
CO	Jefferson Co	W	525,507
CO	Larimer Co	P	239,000
CO	Weld Co	P	172,000
CT	Fairfield Co	W	882,567
CT	Hartford Co	W	857,183
CT	Litchfield Co	W	182,193
CT	Middlesex Co	W	155,071
CT	New Haven Co	W	824,008
CT	New London Co	W	259,088
CT	Tolland Co	W	136,364
CT	Windham Co	W	109,091
DE	Kent Co	W	126,697
DE	New Castle Co	W	500,265
DE	Sussex Co	W	156,638
DC	Entire District	W	572,059
GA	Barrow Co	W	46,144
GA	Bartow Co	W	76,019
GA	Bibb Co	W	153,887
GA	Carroll Co	W	87,268
GA	Catoosa Co	W	53,282
GA	Cherokee Co	W	141,903
GA	Clayton Co	W	236,517
GA	Cobb Co	W	607,751
GA	Coweta Co	W	89,215
GA	De Kalb Co	W	665,865
GA	Douglas Co	W	92,174
GA	Fayette Co	W	91,263
GA	Forsyth Co	W	98,407
GA	Fulton Co	W	816,006
GA	Gwinnett Co	W	588,448
GA	Hall Co	W	139,277
GA	Henry Co	W	119,341
GA	Monroe Co	P	50
GA	Murray Co	P	1,000
GA	Newton Co	W	62,001
GA	Paulding Co	W	81,678
GA	Rockdale Co	W	70,111
GA	Spalding Co	W	58,417
GA	Walton Co	W	60,687
IL	Cook Co	W	5,376,741
IL	Du Page Co	W	904,161
IL	Grundy Co	P	6,309

State	8-hour Ozone Nonattainment County	Whole (W) or Partial (P) County?	Population
IL	Jersey Co	W	21,668
IL	Kane Co	W	404,119
IL	Kendall Co	P	28,417
IL	Lake Co	W	644,356
IL	Mc Henry Co	W	260,077
IL	Madison Co	W	258,941
IL	Monroe Co	W	27,619
IL	St Clair Co	W	256,082
IL	Will Co	W	502,266
IN	Allen Co	W	331,849
IN	Boone Co	W	46,107
IN	Clark Co	W	96,472
IN	Dearborn Co	P	10,434
IN	Delaware Co	W	118,769
IN	Elkhart Co	W	182,791
IN	Floyd Co	W	70,823
IN	Greene Co	W	33,157
IN	Hamilton Co	W	182,740
IN	Hancock Co	W	55,391
IN	Hendricks Co	W	104,093
IN	Jackson Co	W	41,335
IN	Johnson Co	W	115,209
IN	Lake Co	W	484,564
IN	La Porte Co	W	110,106
IN	Madison Co	W	133,358
IN	Marion Co	W	860,454
IN	Morgan Co	W	66,689
IN	Porter Co	W	146,798
IN	St Joseph Co	W	265,559
IN	Shelby Co	W	43,445
IN	Vanderburgh Co	W	171,922
IN	Vigo Co	W	105,848
IN	Warrick Co	W	52,383
KY	Boone Co	W	85,991
KY	Boyd Co	W	49,752
KY	Bullitt Co	W	61,236
KY	Campbell Co	W	88,616
KY	Christian Co	W	72,265
KY	Jefferson Co	W	693,604
KY	Kenton Co	W	151,464
KY	Oldham Co	W	46,178
LA	Ascension Par	W	76,627
LA	East Baton Rouge Par	W	412,852
LA	Iberville Par	W	33,320
LA	Livingston Par	W	91,814
LA	West Baton Rouge Par	W	21,601

State	8-hour Ozone Nonattainment County	Whole (W) or Partial (P) County?	Population
ME	Androscoggin Co	P	3,390
ME	Cumberland Co	P	252,907
ME	Hancock Co	P	29,805
ME	Knox Co	P	33,563
ME	Lincoln Co	P	28,504
ME	Sagadahoc Co	W	35,214
ME	Waldo Co	P	604
ME	York Co	P	164,997
MD	Anne Arundel Co	W	489,656
MD	Baltimore Co	W	754,292
MD	Calvert Co	W	74,563
MD	Carroll Co	W	150,897
MD	Cecil Co	W	85,951
MD	Charles Co	W	120,546
MD	Frederick Co	W	195,277
MD	Harford Co	W	218,590
MD	Howard Co	W	247,842
MD	Kent Co	W	19,197
MD	Montgomery Co	W	873,341
MD	Prince George's Co	W	801,515
MD	Queen Anne's Co	W	40,563
MD	Washington Co	W	131,923
MD	Baltimore (City)	W	651,154
MA	Barnstable Co	W	222,230
MA	Berkshire Co	W	134,953
MA	Bristol Co	W	534,678
MA	Dukes Co	W	14,987
MA	Essex Co	W	723,419
MA	Franklin Co	W	71,535
MA	Hampden Co	W	456,228
MA	Hampshire Co	W	152,251
MA	Middlesex Co	W	1,465,396
MA	Nantucket Co	W	9,520
MA	Norfolk Co	W	650,308
MA	Plymouth Co	W	472,822
MA	Suffolk Co	W	689,807
MA	Worcester Co	W	750,963
MI	Allegan Co	W	105,665
MI	Benzie Co	W	15,998
MI	Berrien Co	W	162,453
MI	Calhoun Co	W	137,985
MI	Cass Co	W	51,104
MI	Clinton Co	W	64,753
MI	Eaton Co	W	103,655
MI	Genesee Co	W	436,141
MI	Huron Co	W	36,079

State	8-hour Ozone Nonattainment County	Whole (W) or Partial (P) County?	Population
MI	Ingham Co	W	279,320
MI	Kalamazoo Co	W	238,603
MI	Kent Co	W	574,335
MI	Lapeer Co	W	87,904
MI	Lenawee Co	W	98,890
MI	Livingston Co	W	156,951
MI	Macomb Co	W	788,149
MI	Mason Co	W	28,274
MI	Monroe Co	W	145,945
MI	Muskegon Co	W	170,200
MI	Oakland Co	W	1,194,156
MI	Ottawa Co	W	238,314
MI	St Clair Co	W	164,235
MI	Van Buren Co	W	76,263
MI	Washtenaw Co	W	322,895
MI	Wayne Co	W	2,061,162
MO	Franklin Co	W	93,807
MO	Jefferson Co	W	198,099
MO	St Charles Co	W	283,883
MO	St Louis Co	W	1,016,315
MO	St Louis	W	348,189
NV	Clark Co	P	1,348,864
NH	Hillsborough Co	P	336,518
NH	Merrimack Co	P	11,721
NH	Rockingham Co	P	266,340
NH	Strafford Co	P	82,134
NJ	Atlantic Co	W	252,552
NJ	Bergen Co	W	884,118
NJ	Burlington Co	W	423,394
NJ	Camden Co	W	508,932
NJ	Cape May Co	W	102,326
NJ	Cumberland Co	W	146,438
NJ	Essex Co	W	793,633
NJ	Gloucester Co	W	254,673
NJ	Hudson Co	W	608,975
NJ	Hunterdon Co	W	121,989
NJ	Mercer Co	W	350,761
NJ	Middlesex Co	W	750,162
NJ	Monmouth Co	W	615,301
NJ	Morris Co	W	470,212
NJ	Ocean Co	W	510,916
NJ	Passaic Co	W	489,049
NJ	Salem Co	W	64,285
NJ	Somerset Co	W	297,490
NJ	Sussex Co	W	144,166
NJ	Union Co	W	522,541

State	8-hour Ozone Nonattainment County	Whole (W) or Partial (P) County?	Population
NJ	Warren Co	W	102,437
NY	Albany Co	W	294,565
NY	Bronx Co	W	1,332,650
NY	Chautauqua Co	W	139,750
NY	Dutchess Co	W	280,150
NY	Erie Co	W	950,265
NY	Essex Co	P	1,000
NY	Genesee Co	W	60,370
NY	Greene Co	W	48,195
NY	Jefferson Co	W	111,738
NY	Kings Co	W	2,465,326
NY	Livingston Co	W	64,328
NY	Monroe Co	W	735,343
NY	Montgomery Co	W	49,708
NY	Nassau Co	W	1,334,544
NY	New York Co	W	1,537,195
NY	Niagara Co	W	219,846
NY	Ontario Co	W	100,224
NY	Orange Co	W	341,367
NY	Orleans Co	W	44,171
NY	Putnam Co	W	95,745
NY	Queens Co	W	2,229,379
NY	Rensselaer Co	W	152,538
NY	Richmond Co	W	443,728
NY	Rockland Co	W	286,753
NY	Saratoga Co	W	200,635
NY	Schenectady Co	W	146,555
NY	Schoharie Co	W	31,582
NY	Suffolk Co	W	1,419,369
NY	Wayne Co	W	93,765
NY	Westchester Co	W	923,459
NC	Alamance Co	W	130,800
NC	Alexander Co	W	33,603
NC	Burke Co	P	69,970
NC	Cabarrus Co	W	131,063
NC	Caldwell Co	P	64,254
NC	Caswell Co	W	23,501
NC	Catawba Co	W	141,685
NC	Chatham Co	P	21,320
NC	Cumberland Co	W	302,963
NC	Davidson Co	W	147,246
NC	Davie Co	W	34,835
NC	Durham Co	W	223,314
NC	Edgecombe Co	W	55,606
NC	Forsyth Co	W	306,067
NC	Franklin Co	W	47,260

State	8-hour Ozone Nonattainment County	Whole (W) or Partial (P) County?	Population
NC	Gaston Co	W	190,365
NC	Granville Co	W	48,498
NC	Guilford Co	W	421,048
NC	Haywood Co	P	28
NC	Iredell Co	P	39,885
NC	Johnston Co	W	121,965
NC	Lincoln Co	W	63,780
NC	Mecklenburg Co	W	695,454
NC	Nash Co	W	87,420
NC	Orange Co	W	118,227
NC	Person Co	W	35,623
NC	Randolph Co	W	130,454
NC	Rockingham Co	W	91,928
NC	Rowan Co	W	130,340
NC	Swain Co	P	260
NC	Union Co	W	123,677
NC	Wake Co	W	627,846
OH	Allen Co	W	108,473
OH	Ashtabula Co	W	102,728
OH	Belmont Co	W	70,226
OH	Butler Co	W	332,807
OH	Clark Co	W	144,742
OH	Clermont Co	W	177,977
OH	Clinton Co	W	40,543
OH	Columbiana Co	W	112,075
OH	Cuyahoga Co	W	1,393,978
OH	Delaware Co	W	109,989
OH	Fairfield Co	W	122,759
OH	Franklin Co	W	1,068,978
OH	Geauga Co	W	90,895
OH	Greene Co	W	147,886
OH	Hamilton Co	W	845,303
OH	Jefferson Co	W	73,894
OH	Knox Co	W	54,500
OH	Lake Co	W	227,511
OH	Licking Co	W	145,491
OH	Lorain Co	W	284,664
OH	Lucas Co	W	455,054
OH	Madison Co	W	40,213
OH	Mahoning Co	W	257,555
OH	Medina Co	W	151,095
OH	Miami Co	W	98,868
OH	Montgomery Co	W	559,062
OH	Portage Co	W	152,061
OH	Stark Co	W	378,098
OH	Summit Co	W	542,899

State	8-hour Ozone Nonattainment County	Whole (W) or Partial (P) County?	Population
OH	Trumbull Co	W	225,116
OH	Warren Co	W	158,383
OH	Washington Co	W	63,251
OH	Wood Co	W	121,065
PA	Adams Co	W	91,292
PA	Allegheny Co	W	1,281,666
PA	Armstrong Co	W	72,392
PA	Beaver Co	W	181,412
PA	Berks Co	W	373,638
PA	Blair Co	W	129,144
PA	Bucks Co	W	597,635
PA	Butler Co	W	174,083
PA	Cambria Co	W	152,598
PA	Carbon Co	W	58,802
PA	Centre Co	W	135,758
PA	Chester Co	W	433,501
PA	Clearfield Co	W	83,382
PA	Cumberland Co	W	213,674
PA	Dauphin Co	W	251,798
PA	Delaware Co	W	550,864
PA	Erie Co	W	280,843
PA	Fayette Co	W	148,644
PA	Franklin Co	W	129,313
PA	Greene Co	W	40,672
PA	Indiana Co	W	89,605
PA	Lackawanna Co	W	213,295
PA	Lancaster Co	W	470,658
PA	Lebanon Co	W	120,327
PA	Lehigh Co	W	312,090
PA	Luzerne Co	W	319,250
PA	Mercer Co	W	120,293
PA	Monroe Co	W	138,687
PA	Montgomery Co	W	750,097
PA	Northampton Co	W	267,066
PA	Perry Co	W	43,602
PA	Philadelphia Co	W	1,517,550
PA	Tioga Co	W	41,373
PA	Washington Co	W	202,897
PA	Westmoreland Co	W	369,993
PA	Wyoming Co	W	28,080
PA	York Co	W	381,751
RI	Bristol Co	W	50,648
RI	Kent Co	W	167,090
RI	Newport Co	W	85,433
RI	Providence Co	W	621,602
RI	Washington Co	W	123,546

State	8-hour Ozone Nonattainment County	Whole (W) or Partial (P) County?	Population
SC	Anderson Co	W	165,740
SC	Greenville Co	W	379,616
SC	Lexington Co	P	181,265
SC	Richland Co	P	313,253
SC	Spartanburg Co	W	253,791
SC	York Co	P	102,000
TN	Anderson Co	W	71,330
TN	Blount Co	W	105,823
TN	Cocke Co	P	20
TN	Davidson Co	W	569,891
TN	Hamilton Co	W	307,896
TN	Hawkins Co	W	53,563
TN	Jefferson Co	W	44,294
TN	Knox Co	W	382,032
TN	Loudon Co	W	39,086
TN	Meigs Co	W	11,086
TN	Montgomery Co	W	134,768
TN	Rutherford Co	W	182,023
TN	Sevier Co	W	71,170
TN	Shelby Co	W	897,472
TN	Sullivan Co	W	153,048
TN	Sumner Co	W	130,449
TN	Williamson Co	W	126,638
TN	Wilson Co	W	88,809
TX	Bexar Co	W	1,392,931
TX	Brazoria Co	W	241,767
TX	Chambers Co	W	26,031
TX	Collin Co	W	491,675
TX	Comal Co	W	78,021
TX	Dallas Co	W	2,218,899
TX	Denton Co	W	432,976
TX	Ellis Co	W	111,360
TX	Fort Bend Co	W	354,452
TX	Galveston Co	W	250,158
TX	Guadalupe Co	W	89,023
TX	Hardin Co	W	48,073
TX	Harris Co	W	3,400,578
TX	Jefferson Co	W	252,051
TX	Johnson Co	W	126,811
TX	Kaufman Co	W	71,313
TX	Liberty Co	W	70,154
TX	Montgomery Co	W	293,768
TX	Orange Co	W	84,966
TX	Parker Co	W	88,495
TX	Rockwall Co	W	43,080
TX	Tarrant Co	W	1,446,219

State	8-hour Ozone Nonattainment County	Whole (W) or Partial (P) County?	Population
TX	Waller Co	W	32,663
VA	Arlington Co	W	189,453
VA	Botetourt Co	W	30,496
VA	Charles City Co	W	6,926
VA	Chesterfield Co	W	259,903
VA	Fairfax Co	W	969,749
VA	Frederick Co	W	59,209
VA	Gloucester Co	W	34,780
VA	Hanover Co	W	86,320
VA	Henrico Co	W	262,300
VA	Isle Of Wight Co	W	29,728
VA	James City Co	W	48,102
VA	Loudoun Co	W	169,599
VA	Madison Co	P	1
VA	Page Co	P	1
VA	Prince George Co	W	33,047
VA	Prince William Co	W	280,813
VA	Roanoke Co	W	85,778
VA	Spotsylvania Co	W	90,395
VA	Stafford Co	W	92,446
VA	York Co	W	56,297
VA	Alexandria	W	128,283
VA	Chesapeake	W	199,184
VA	Colonial Heights	W	16,897
VA	Fairfax	W	21,498
VA	Falls Church	W	10,377
VA	Fredericksburg	W	19,279
VA	Hampton	W	146,437
VA	Hopewell	W	22,354
VA	Manassas	W	35,135
VA	Manassas Park	W	10,290
VA	Newport News	W	180,150
VA	Norfolk	W	234,403
VA	Petersburg	W	33,740
VA	Poquoson	W	11,566
VA	Portsmouth	W	100,565
VA	Richmond	W	197,790
VA	Roanoke	W	94,911
VA	Salem	W	24,747
VA	Suffolk	W	63,677
VA	Virginia Beach	W	425,257
VA	Williamsburg	W	11,998
VA	Winchester	W	23,585
WV	Berkeley Co	W	75,905
WV	Brooke Co	W	25,447
WV	Cabell Co	W	96,784

State	8-hour Ozone Nonattainment County	Whole (W) or Partial (P) County?	Population
WV	Hancock Co	W	32,667
WV	Jefferson Co	W	42,190
WV	Kanawha Co	W	200,073
WV	Marshall Co	W	35,519
WV	Ohio Co	W	47,427
WV	Putnam Co	W	51,589
WV	Wayne Co	W	42,903
WV	Wood Co	W	87,986
WI	Door Co	W	27,961
WI	Kenosha Co	W	149,577
WI	Kewaunee Co	W	20,187
WI	Manitowoc Co	W	82,887
WI	Milwaukee Co	W	940,164
WI	Ozaukee Co	W	82,317
WI	Racine Co	W	188,831
WI	Sheboygan Co	W	112,646
WI	Washington Co	W	117,493
WI	Waukesha Co	W	360,767
		Total	159,271,919

## Appendix 3B: PM Nonattainment

**Table 3B-1. PM<sub>2.5</sub> Nonattainment Areas and Populations (data is current through September 2005 and the population numbers are from 2000 census data)**

PM <sub>2.5</sub> 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 3B-2. PM<sub>10</sub> Nonattainment Areas and Populations (data is current through September 29, 2005 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
Lamar, CO	Moderate	1	9	8	CO
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
Lyons Twsp., IL	Moderate	1	109	5	IL
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 Haven Co, CT	Moderate	1	124	1	CT
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
Southeast Chicago, IL	Moderate	1	3	5	IL
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
55 Total Areas		54	28,918		

## Appendix 3C: Visibility Tables

**Table 3C-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 Geronio 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 <sup>a</sup>	43,243	USDI-NPS
	Hells Canyon Wilderness Area	83,800	USDA-FS
	Sawtooth Wilderness Area	216,383	USDA-FS
	Selway-Bitterroot Wilderness Area <sup>b</sup>	988,770	USDA-FS
	Yellowstone NP <sup>c</sup>	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 <sup>d</sup>	251,930	USDA-FS
	U. L. Bend Wilderness Area	20,890	USDI-FWS
	Yellowstone NP <sup>e</sup>	167,624	USDI-NPS
Nevada	Jarbridge 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 <sup>f</sup>	273,551	USDI-NPS
	Joyce Kilmer-Slickrock Wilderness Area <sup>g</sup>	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 <sup>a</sup>	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 <sup>f</sup>	241,207	USDI-NPS
	Joyce Kilmer-Slickrock Wilderness <sup>g</sup>	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 Rainier 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 <sup>h</sup>	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 3C-2. Current (1998-2002) Visibility, Projected (2015) Visibility, and Natural Background Levels for the 20% Worst Days at 116 IMPROVE Sites**

<b>Class I Area Name<sup>a</sup></b>	<b>State</b>	<b>1998-2002 Baseline Visibility (deciviews)<sup>b</sup></b>	<b>2015 CAIR Control Case Visibility<sup>c</sup> (deciviews)</b>	<b>Natural Background (deciviews)</b>
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

<b>Class I Area Name<sup>a</sup></b>	<b>State</b>	<b>1998-2002 Baseline Visibility (deciviews)<sup>b</sup></b>	<b>2015 CAIR Control Case Visibility<sup>c</sup> (deciviews)</b>	<b>Natural Background (deciviews)</b>
James River Face	VA	28.5	25.1	11.2
Jarbridge	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 Geronio	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

<b>Class I Area Name<sup>a</sup></b>	<b>State</b>	<b>1998-2002 Baseline Visibility (deciviews)<sup>b</sup></b>	<b>2015 CAIR Control Case Visibility<sup>c</sup> (deciviews)</b>	<b>Natural Background (deciviews)</b>
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: 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 gasoline container (gas can) 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 latest year for which we have complete data. 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.<sup>A</sup> 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. Become 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

Previously, it has been relatively easy to characterize manufacturers as "domestic" or

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<sup>A</sup> 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.

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.<sup>1</sup> 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.

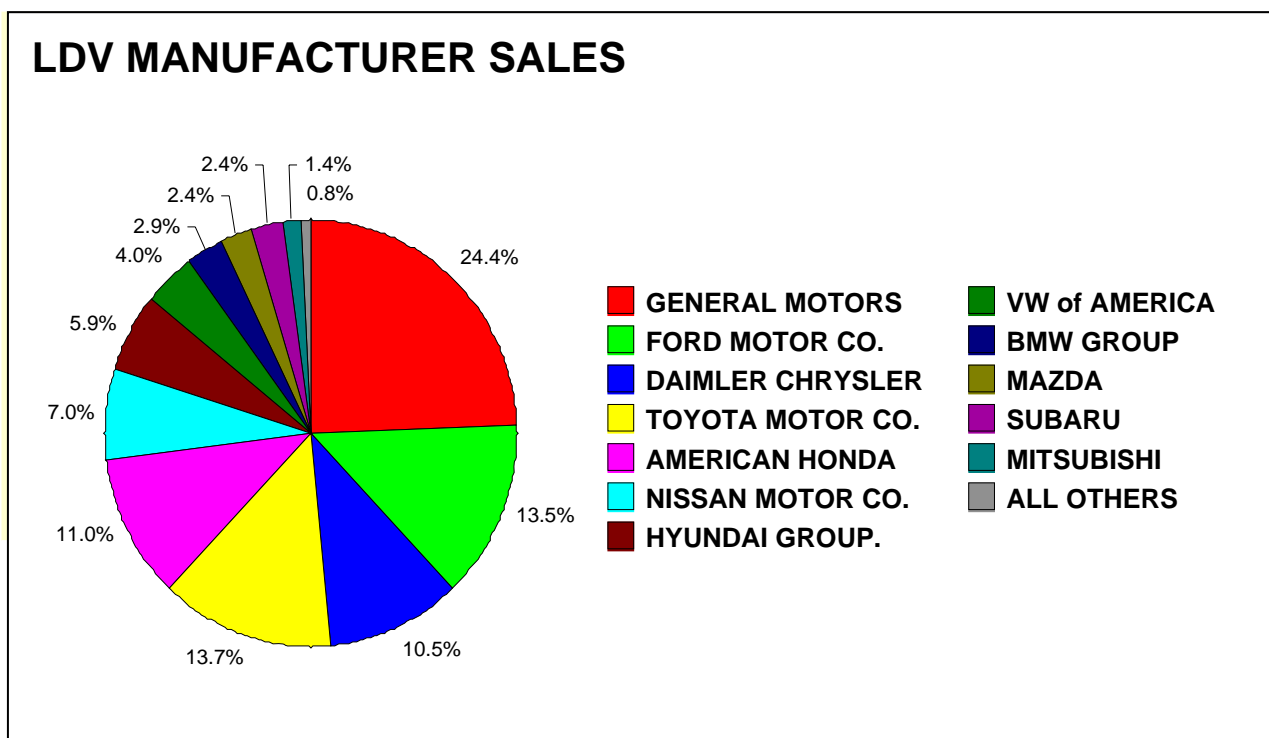
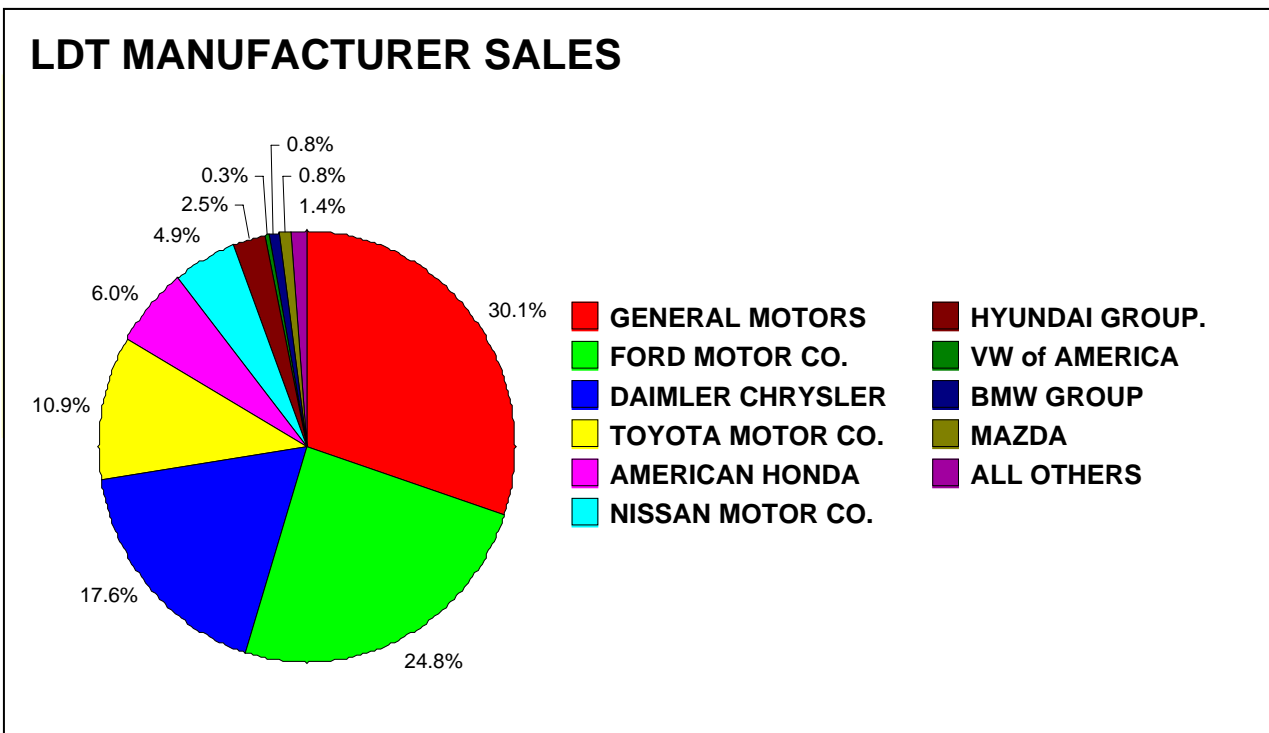


Figure 4.1-2.



For regulatory purposes, LDVs and LDTs were formerly 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, except in some cases for medium duty passenger vehicles (MDPVs), i.e. passenger vehicles over 10,000 lbs. GVW, certified to engine-dynamometer standards. These are primarily the very large SUVs.

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.<sup>B</sup> 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 behavior.<sup>2</sup> The information contained in the report is summarized below, supplemented by additional information found in this RIA and in other sources.

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<sup>B</sup> 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).

### **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.<sup>3</sup>

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.<sup>4</sup>

### **4.3 Portable Gasoline Container (Gas Can) Industry**

EPA also contracted with RTI International for a characterization of the gas can 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.<sup>5</sup> This report is also summarized below, and is again supplemented by additional information found in this RIA and in other sources.

#### **4.3.1 Manufacture and Distribution**

Portable gasoline containers (gas cans) 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. Gas cans range in capacity from a gallon or less to over 6 gallons. Standard gas cans 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 gas cans 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, all gas cans are colored red during the manufacturing process. Industry and other sources indicate that gas cans are distributed by manufacturers through their distribution centers to major retail establishments.

#### **4.3.2 Gas Can Use**

Gas cans 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.<sup>6</sup> 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 gas can will have a life expectancy of 3 to 5 years before it needs to be replaced.

The demand for gas cans 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. So 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.

Gas can sales for 2002, the latest year for which we were able to develop data, were about 22 million units. Although the gas can manufacturing industry has become fairly concentrated, with one firm accounting for more than half of all U.S. 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 gas can 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). There are other gas can 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 other safety cans used in an industrial setting), which would not be covered by the proposed standards. These companies include Eagle Manufacturing, Protectoseal Company, and Scribner Plastics. These firms all meet the SBA criteria for small businesses. Table 4.3-1 provides relevant data about these firms.

### **4.3.4 Market Entry**

There are very few barriers to entering the gas can market. Only about 2 percent of the gas cans 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 gas cans are in fact classified in the U.S. Economic Census as "All other plastics product manufacturing." Since manufacturing such gas cans 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	SPECIATY CONTAINERS
THE PLASTIC GROUP	WEDCO MOLDED PROD.	20-50	600	CONSUMER MARKET

\* BUSINESSES ENGAGED IN NAICS CODE 326119, ALL OTHER PLASTICS 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

<sup>1</sup> Source: Ward's "World Motor Vehicle Data, 2004."

<sup>2</sup> "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.

<sup>3</sup> Table 1-1 in **Final Report**. Data Source: DOE, EIA Petroleum Supply Annual 2002.

<sup>4</sup> Table 4-4. **Final Report**. Source DOE EIA Petroleum Supply Annual 2002.

<sup>5</sup> "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.

<sup>6</sup> 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 NLEV program, contain stringent standards for light-duty vehicles that have further 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 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 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 hardware content 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 NO<sub>x</sub> emissions. To achieve these NO<sub>x</sub> 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 NO<sub>x</sub> controls, manufacturers had significant experience in NMOG controls, and therefore NMHC controls, primarily from the stringent NMOG standards under the NLEV and LEV I programs. In fact, the NMOG standards for a Tier 2 Bin5 package are the same as the passenger car (PC) and light-duty truck (LDT1) as those established under the NLEV program. The largest challenge manufacturers have encountered under the Tier 2 program is possibly 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 readiness 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 readiness 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 done 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 as a method 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, further assisting in 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, which is 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 provides the catalyst with a preferable mixture composed of less lost fuel in the form of hydrocarbons, 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 than desirable.

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 is much more effective than either feature used independently, and the resulting emission reductions can be much higher than sum of each feature measured independently. Additionally, utilizing elevated idle speeds while retarding the timing can offset any engine vacuum level concerns encountered when only retarding 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 result in the generation of highly desirable, 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 a new technology. 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. With the advent of the three way catalyst (TWC), manufacturers began to use engine control modules (ECM) to activate electric air pumps to reduce start emissions only at 75° F, typically on vehicle packages with specific 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 vehicle models common to Europe and the U.S. that are equipped with secondary air injection do appear to be using this technology at 20° F on models sold in the U.S., based on our analysis of the certification data. This is attributable to common 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.<sup>1</sup>

#### 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 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 states, 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 are detailed in past Society of Automotive Engineers (SAE) papers<sup>2</sup>.

#### 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.

#### 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.<sup>3</sup> 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 proposed 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 proposed 20° F NMHC standard.

### **5.1.2 Data Supporting Cold NMHC Standard Technical Feasibility**

Data to support the feasibility of complying with a 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 industry average.

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. Specifically, they will 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.

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 the EPA, were not subject to EPA standards. The data represent the cold NMHC emissions as tested, and only suggest that a significant number of vehicles are within reach of today's proposed standards

#### **5.1.2.1 Certification Emission Level**

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, light-duty trucks, and medium-duty passenger vehicles. 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, 2005, and 2006 model year full useful life certification data for vehicles certified to nationwide Tier 2 standards, NLEV program standards, and the 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 is 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, 5.1-4, and 5.1-5 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	Total Car Lines
2004	41	13	54
2005	42	16	58
2006	44	22	68

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 proposed cold temperature NMHC standards. Though the number of LDV/LLDT configurations at or near the proposed cold NMHC standards significantly outnumber the heavier HLDT/MDPVs, EPA is proposing a later phase-in for HLDT/MDPVs due to the unique challenges related to these heavier vehicles, as discussed in Section VI of the Preamble. The number of configurations approaching the proposed standard increases for both LDV/LLDTs and HLDT/MDPVs from 2004 to 2006, as vehicles have adopted more stringent emission controls to meet the Tier 2 standards.

This analysis does not necessarily imply that manufacturers could have certified these vehicles to meet the proposed 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 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 proposed cold NMHC standard**

MANUFACTURER	CAR LINE	COLD TOTAL HC LEVEL
<b>LDV/LLDTs</b>		
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
<b>HLDT/MDPVs</b>		
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 proposed cold NMHC standard**

MANUFACTURER	CAR LINE	COLD TOTAL HC LEVEL
<b>LDV/LLDTs</b>		
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
<b>HLDT/MDPVs</b>		
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 proposed cold NMHC standard**

MANUFACTURER	CAR LINE	COLD TOTAL HC LEVEL
<b>LDV/LLDTs</b>		
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
<b>HLDV/MDPVs</b>		
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

### 5.1.2.2 EPA Test Program

To determine the feasibility of meeting the proposed NMHC standard with only changes to the calibration, EPA performed a test program involving a Tier 2 vehicle that was deemed very challenging. The vehicle selection criteria for a feasibility study include several key aspects. First, the vehicle needs to currently produce 20° F NMHC levels that are significantly higher than the industry average. Second, since vehicle weight was determined to be a potential disadvantage, a heavier GVWR vehicle is preferable for feasibility testing. Finally, the technological approach chosen by the manufacturer to meet stringent 75° F Tier 2 standards was also considered. Specifications for the test vehicle are included 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 2-WD	5550 lbs.	Tier 2 Bin 5	36,500

The vehicle was tested at 20° F following EPA cold FTP test procedures established in 40 CFR 86.230-94. In addition to regulated pollutant measurements, additional measurements included NMHC, oxides of nitrogen (NO<sub>x</sub>), and 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.<sup>A</sup> 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.<sup>B</sup>

**Table 5.1-7. EPA 20° F Cold Test Vehicle Settings**

Vehicle	Test Weight	20° F Target Coefficients
<b>2004 Chevrolet Trailblazer</b>	<b>5000 lbs.</b>	<b>A=38.97</b> <b>B=1.2526</b> <b>C=.02769</b>

<sup>A</sup> "Cold Chamber Sampling System Diagram," PDF file from test lab.

<sup>B</sup> Available at [www.epa.gov/otaq/cert/dearmfr/dearmfr.htm](http://www.epa.gov/otaq/cert/dearmfr/dearmfr.htm).

#### 5.1.2.2.1 2004 Chevrolet Trailblazer Feasibility

As indicated earlier, the selection criteria of the vehicle candidate for the feasibility study were designed to meet several key goals. The 2004 Chevrolet Trailblazer was chosen as a candidate because it met the desired criteria. 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. This is because the Bin 5 emission standards represent the required EPA fleet average for NO<sub>x</sub> 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. Different Trailblazer models fall above and below 6000 lbs. GVWR, but do not have any 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, 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 at and below freezing cold start temperatures due to potential water freezing in the system which would prevent proper system operation. This is, however, 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.<sup>4</sup>

A key element of the feasibility test program was to imitate emission control system behaviors observed at the currently regulated start temperatures of 75° F and 50° F (California-only requirement). In the case of the Trailblazer, while not all behaviors could be demonstrated,

several of the most important behaviors were replicated. First, the operation of the secondary air injection system was determined to be a requirement. Second, elevated idle speeds, similar to what the Trailblazer currently uses after the start at the regulated start temperatures, were also required.

The 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. Several delay periods from the start of the engine until the secondary air system was activated were tested to measure benefits of earlier introduction of the air injection. The secondary air was always run until 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 to 1600 RPM idle speed in park/neutral, mimicking the same desired 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). Ideally, utilizing the electronically controlled throttle to achieve a target idle speed would have been the best method, but control of the electronic throttle was not available. 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, but also in the defroster tests. The tests with defroster operation were included to assess any emission impacts of defroster-on, which is being proposed in a fuel economy rule.<sup>C</sup>

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 ECM to control NMHC and NOx emissions simultaneously, as compared to this test program's limitations.

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<sup>C</sup> Fuel Economy Final Rule XX Defroster Operation Requirement for Cold FTP.

CO and PM measurements also indicate significant reductions when NMHC controls are activated. CO, the only currently regulated pollutant at 20° F, demonstrated consistent reductions over baseline levels with each of the control combinations. PM generally also indicated reductions; however, it 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
<b>Proposed Standard <math>\leq</math> 6000 lbs GVWR</b>			<b>.3</b>				
<b>Proposed Standard &gt; 6000 lbs GVWR</b>			<b>.5</b>				
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	<b>.29</b>	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 proposed standard for the  $\leq$  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. 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., 0.3g/mi) with some additional minor calibration changes.

While emissions results for the 20° F cold CO test are reported as a weighted three-bag average, bag one (the first 505 seconds of the test) provides a better indication of emission reductions achieved with controls. Since 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 level of reductions in emissions with the different control changes are more obvious as measured in the first phase of the test. NMHC, CO and PM reductions can be clearly seen from the results. NMHC and CO reductions occur with all the control attempts but achieve the best results with control test #6 and #8, in which secondary air injection was activated immediately upon engine cranking. PM reductions also follow similar behavior as NMHC but 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 Additional Tier 2 Vehicle Feasibility

We are entertaining expanding the feasibility testing to additional Tier 2 vehicles utilizing the technologies described earlier in the calibration and controls technology section. Any additional studies are contingent on our ability to access and modify these emission control technologies in the time window of this rulemaking.

## 5.2 Feasibility of Evaporative Emissions Standards for Vehicles

The proposed standards for evaporative emissions, which are equivalent to the California LEV II standards, are technologically feasible now. As discussed in Section VI of the preamble for today's proposed 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, some manufacturers view the programs as similar in stringency. See Section VI.B.2.c of today’s proposed rule for further discussion of such test differences (e.g., test temperatures and fuel volatilities). Thus, some manufacturers have indicated that they will produce 50-state evaporative systems that meet both sets of standards (manufacturers sent letters indicating this to EPA in 2000).<sup>5, 6, 7</sup> In addition, a review of recent model year certification results indicates that essentially all manufacturers certify 50-state evaporative emission systems.<sup>8</sup> Therefore, harmonizing with California’s LEV-II evaporative emission standards would streamline certification and be an “anti-backsliding” measure – that is, it would prevent future backsliding as manufacturers pursue cost reductions. It also would codify the approach manufacturers have already indicated they are taking for 50-state evaporative systems.

## References for Chapter 5

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- <sup>1</sup> Memo to docket “Discussions Regarding Secondary Air System Usage at 20° F with European Automotive Manufacturers and Suppliers of Secondary Air Systems,” December 2005.
- <sup>2</sup> 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.
- <sup>3</sup> 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.
- <sup>4</sup> Memo to docket “Discussions Regarding Secondary Air System Usage at 20° F with European Automotive Manufacturers and Suppliers of Secondary Air Systems,” December 2005.
- <sup>5</sup> DaimlerChrysler, Letter from Reginald R. Modlin to Margo Oge of U.S. EPA, May 30, 2000. A copy of this letter can be found in Docket No. EPA-HQ-OAR-2005-0036.
- <sup>6</sup> Ford, Letter from Kelly M. Brown to Margo Oge of U.S. EPA, May 26, 2000. A copy of this letter can be found in Docket No. EPA-HQ-OAR-2005-0036.
- <sup>7</sup> General Motors, Letter from Samuel A. Leonard to Margo Oge of U.S. EPA, May 30, 2000. A copy of this letter can be found in Docket No. EPA-HQ-OAR-2005-0036.
- <sup>8</sup> U.S. EPA, Evaporative Emission Certification Results for Model Years 2004 to 2006, Memorandum to Docket EPA-HQ-OAR-2005-0036 from Bryan Manning, February 9, 2006.

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## **Chapter 6: Feasibility of Complying with a Benzene and Other Control Standards**

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 proposed benzene standard. Next the lead time to apply the various control technologies and to comply with the proposed standard is evaluated. Finally, the energy and supply impacts of the proposed rule 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.

The diagram illustrates the complex refining process starting from two main feedstocks: Natural Gas and Crude Oil.

- Natural Gas Path:** Natural Gas enters a **Hydrogen Plant** to produce  $H_2$ . It then goes to a **Gas Plant**, which produces **Fuel Gas** and **LPG**. The remaining gas stream undergoes **Polymerization** and **Alkylation** to contribute to **Gasoline**.
- Crude Oil Path:** Crude Oil enters a **Crude Tower**. The overheads go to a **Straight Run Splitter**, which produces **Gasoline** and feeds into a **Naphtha Splitter**. The **Naphtha Splitter** separates the stream into several fractions:
  - Light Ends:** Go to **Isomerization** and then to **Gasoline**.
  - Hydrotreater Feed:** Goes to a **Hydrotreater**, which produces **Gasoline** and feeds into a **Reformer**.
  - Reformer Feed:** Goes to a **Reformer**, which produces **Hydrogen ( $H_2$ )** and feeds into an **Aromatics Extraction** unit.
  - Aromatics Extraction:** Produces **Aromatics** and feeds into a **Distillate Hydrotreater**.
  - Hydrocracker Feed:** Goes to a **Hydrocracker**, which produces **Hydrogen ( $H_2$ )** and feeds into the **Distillate Hydrotreater**.
  - Distillate Hydrotreater:** Produces **Kerosine**, **Jet Fuel**, **On-Highway Diesel**, and **Off-road Diesel**.
  - Bottoms:** Go to a **Vacuum Tower**, which separates them into **Fuel Oil**, **Resid**, and **Coke**.
- Other Processes:** A **Fluidized Cat Cracker** takes feed from the **Crude Tower** and produces **Gasoline**, **Hydrocracker Feed**, and **Distillate Hydrotreater Feed**.

The final products of the refinery are: **Fuel Gas**, **LPG**, **Gasoline**, **Aromatics**, **Kerosine**, **Jet Fuel**, **On-Highway Diesel**, **Off-road Diesel**, **Fuel Oil**, **Resid**, and **Coke**.

*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.<sup>1</sup>

### 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<sub>5</sub>'s and C<sub>6</sub>'s in order to assure the C<sub>6</sub>'s and heavier were fed to the reformer.<sup>2</sup>

### *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.<sup>3</sup>

### *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). 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.<sup>4</sup>

### *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.<sup>5</sup>

### *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 separates 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.<sup>6</sup>

### *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.<sup>7</sup>

#### *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 0.94 volume percent for gasoline produced in and imported into the U.S. in 2003, 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 2003 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 2003  
(vol%)**

	U.S. Production (excluding CA)	Imports	Production plus Imports	CA	Production plus Imports Plus CA
CG Summer	1.129	1.022	1.126		1.126
CG Winter	1.086	0.826	1.078		1.078
Total CG	1.107	0.914	1.101		1.101
% by total volume	65	2	67	0	67
RFG Summer	0.598	0.682	0.605	0.620	0.610
RFG Winter	0.637	0.715	0.645	0.620	0.636
Total RFG	0.620	0.701	0.627	0.620	0.625
% by total volume	20	2	22	11	33
Summer CG & RFG Avg.	1.009	0.850	1.002	0.62	0.965
Winter CG & RFG Avg.	0.966	0.768	0.965	0.62	0.923
CG & RFG Avg.	0.991	0.804	0.982		0.942
% by total volume	85	4	89	11	100

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.**

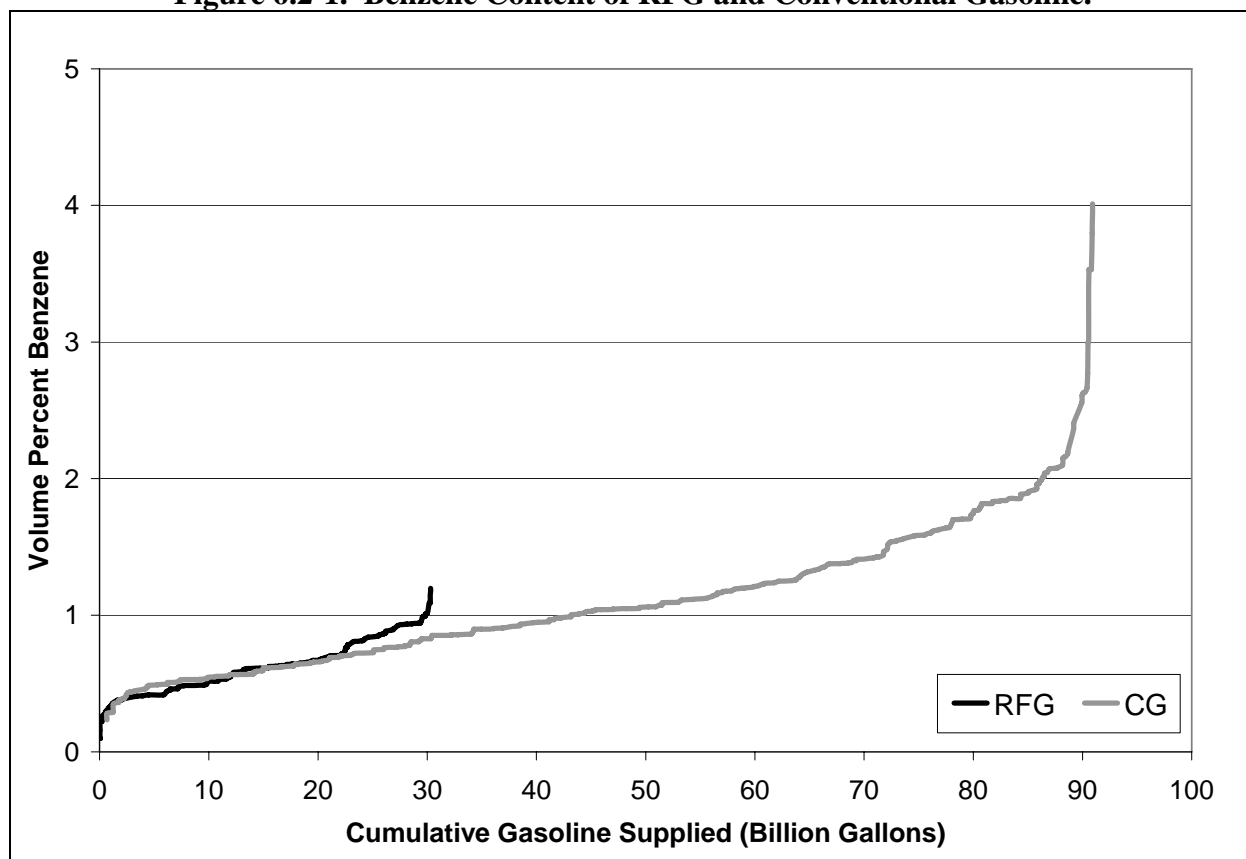
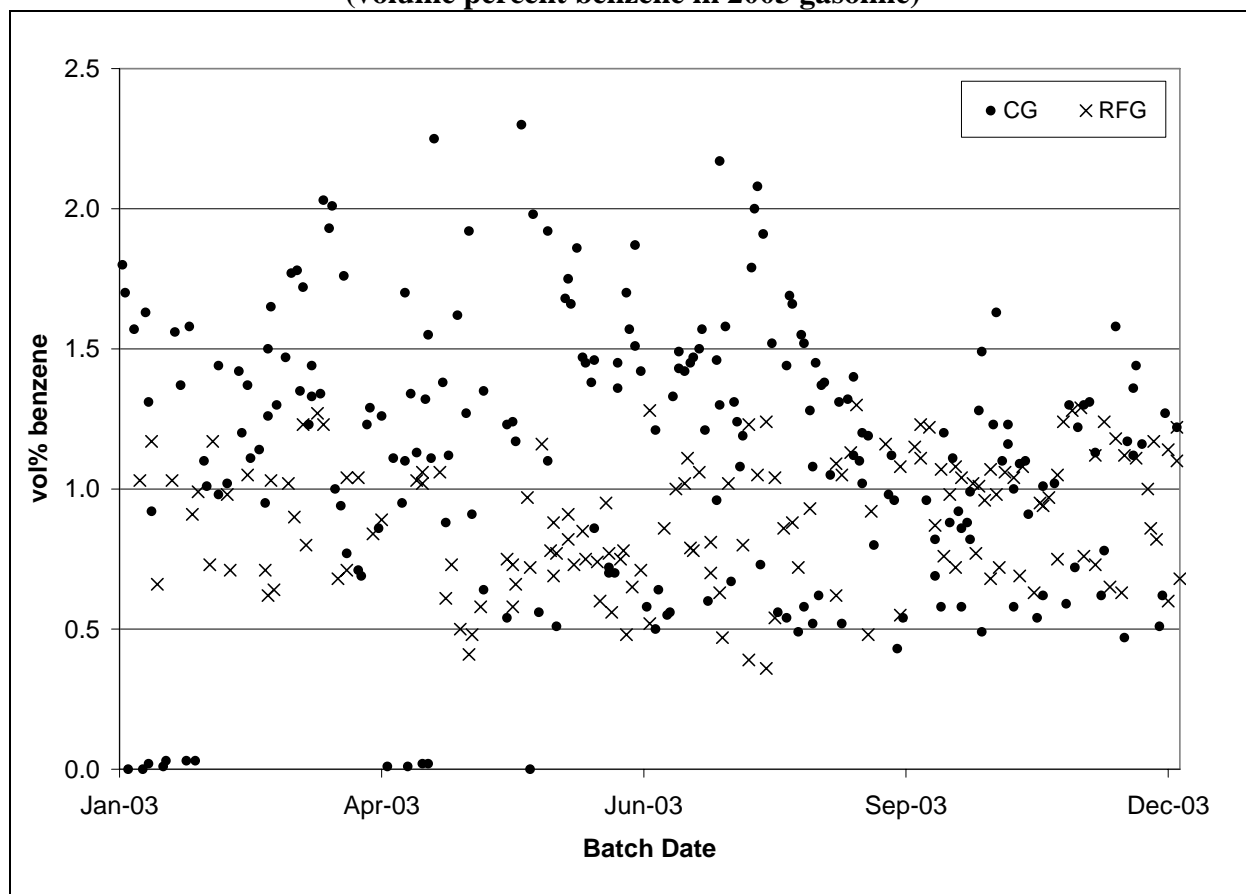


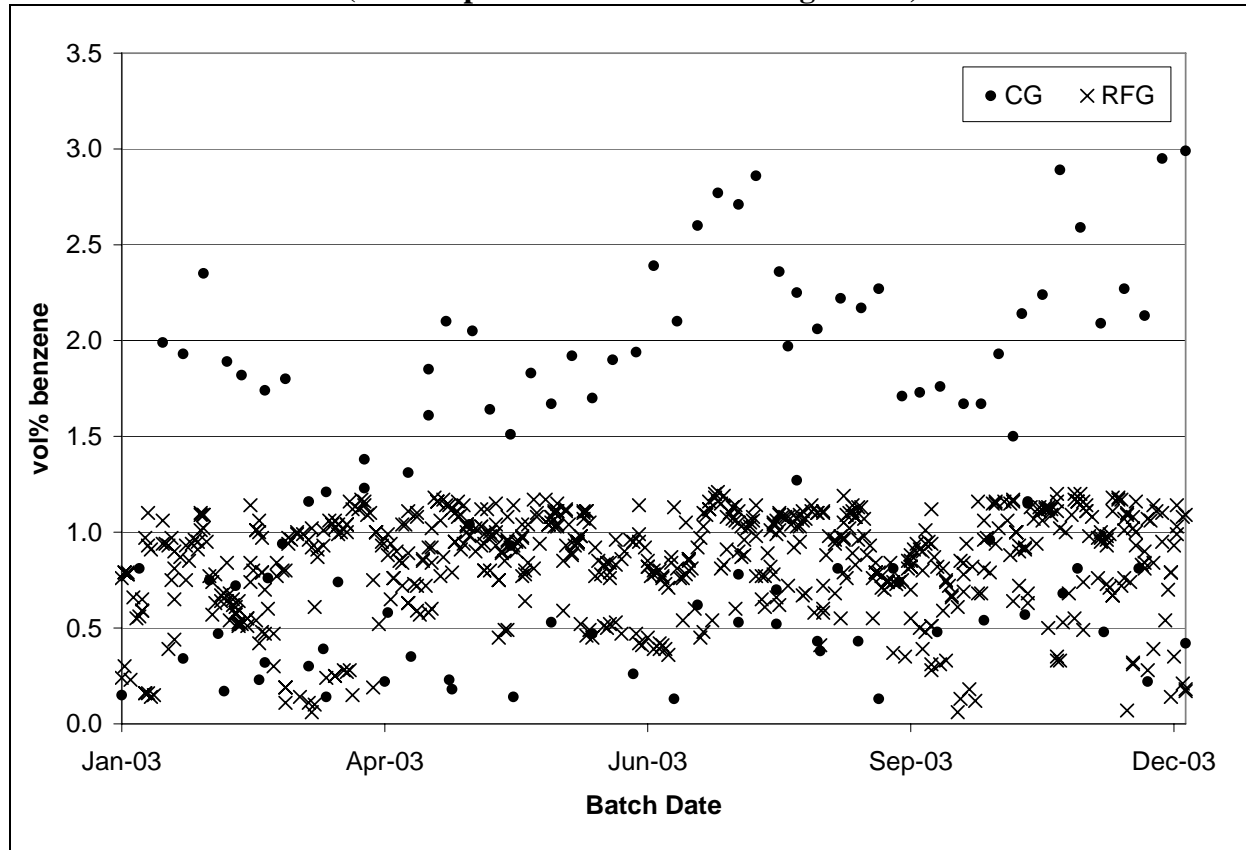
Figure 6.2-1 shows that the annual average benzene levels of conventional gasoline produced by individual refineries varies from 0.3 to 3.5 volume percent. The volume-weighted average is 1.10 volume percent. As expected, the annual average benzene levels of reformulated gasoline as produced by individual 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 0.62 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.

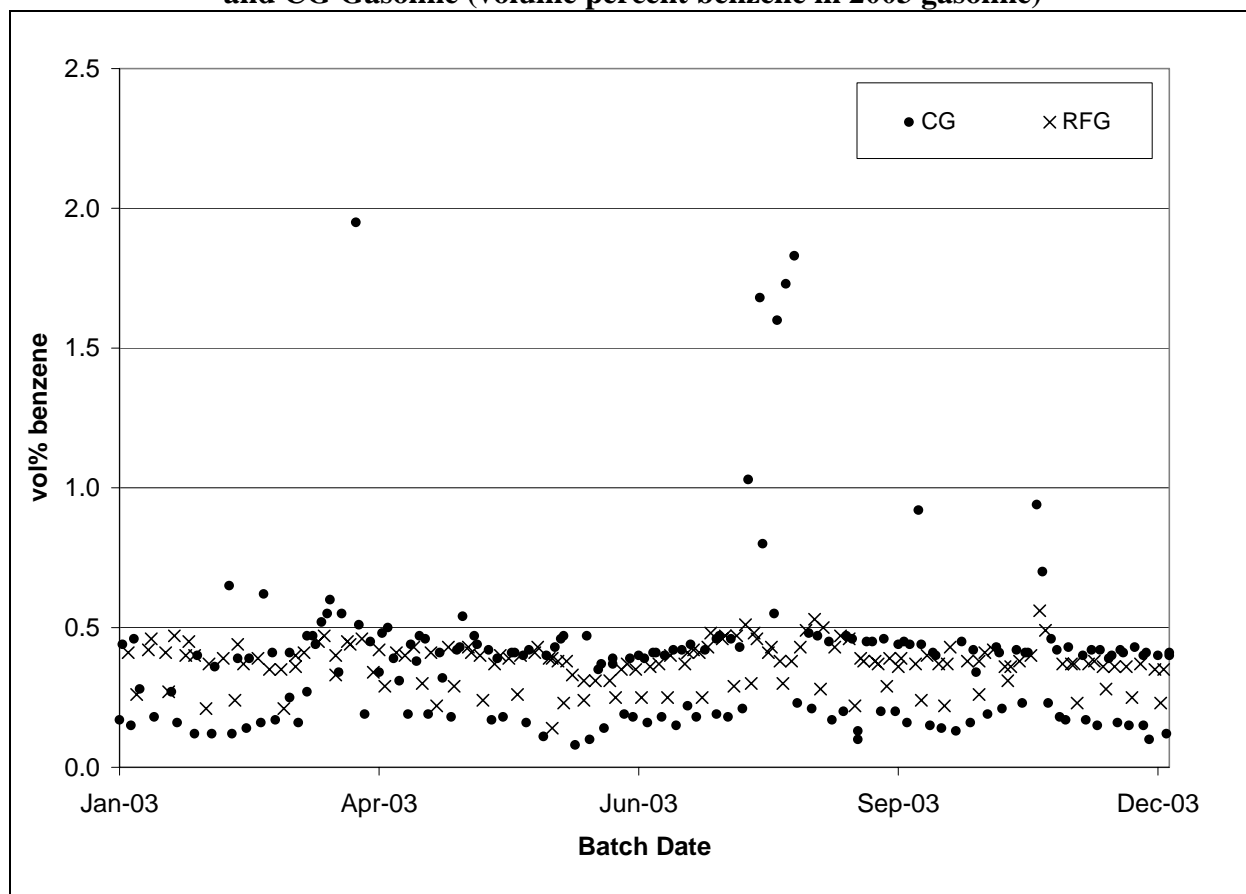
**Figure 6.2-2. RFG and CG Batch-by-Batch Benzene Levels for Refinery “A”  
(volume percent benzene in 2003 gasoline)**



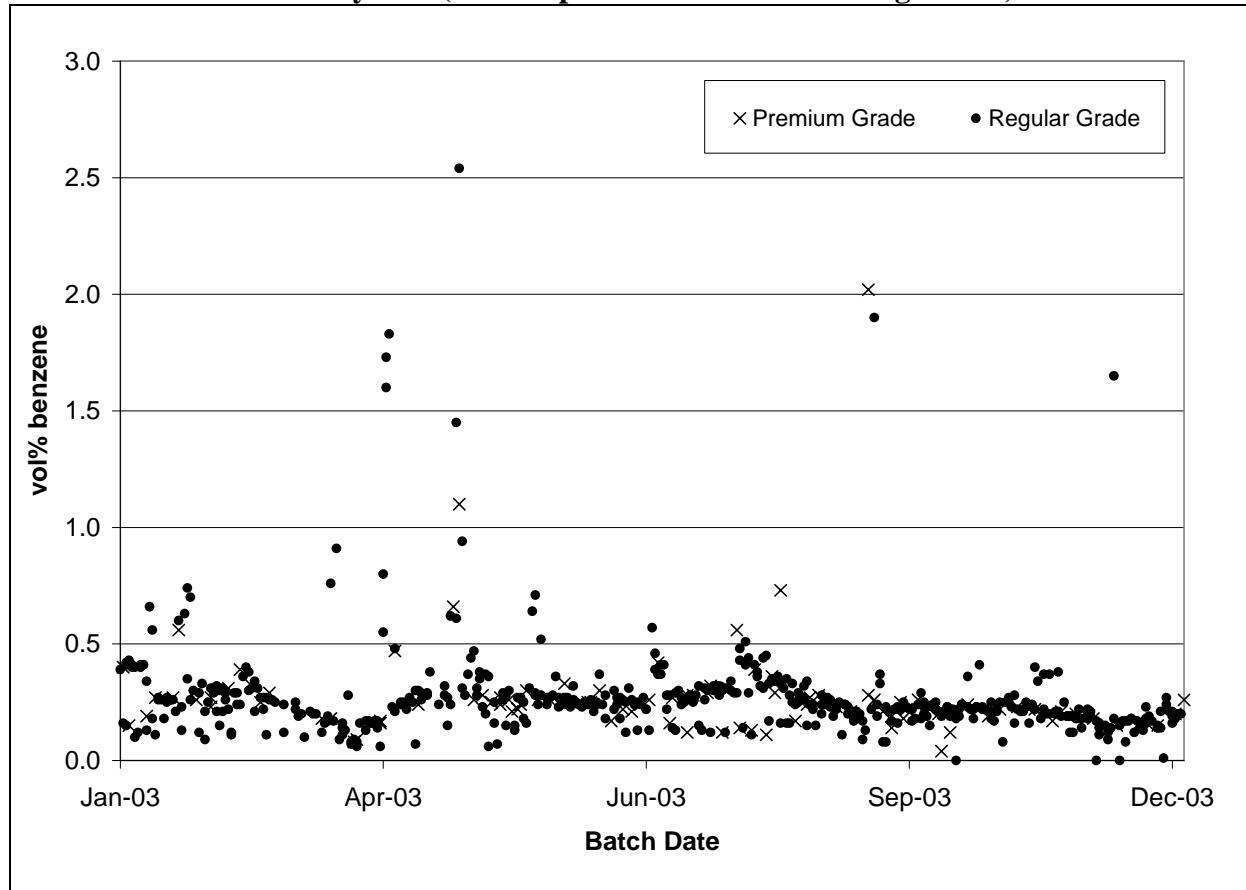
**Figure 6.2-3. RFG and CG Batch-by-Batch Benzene Levels for Refinery “B”  
(volume percent benzene in 2003 gasoline)**



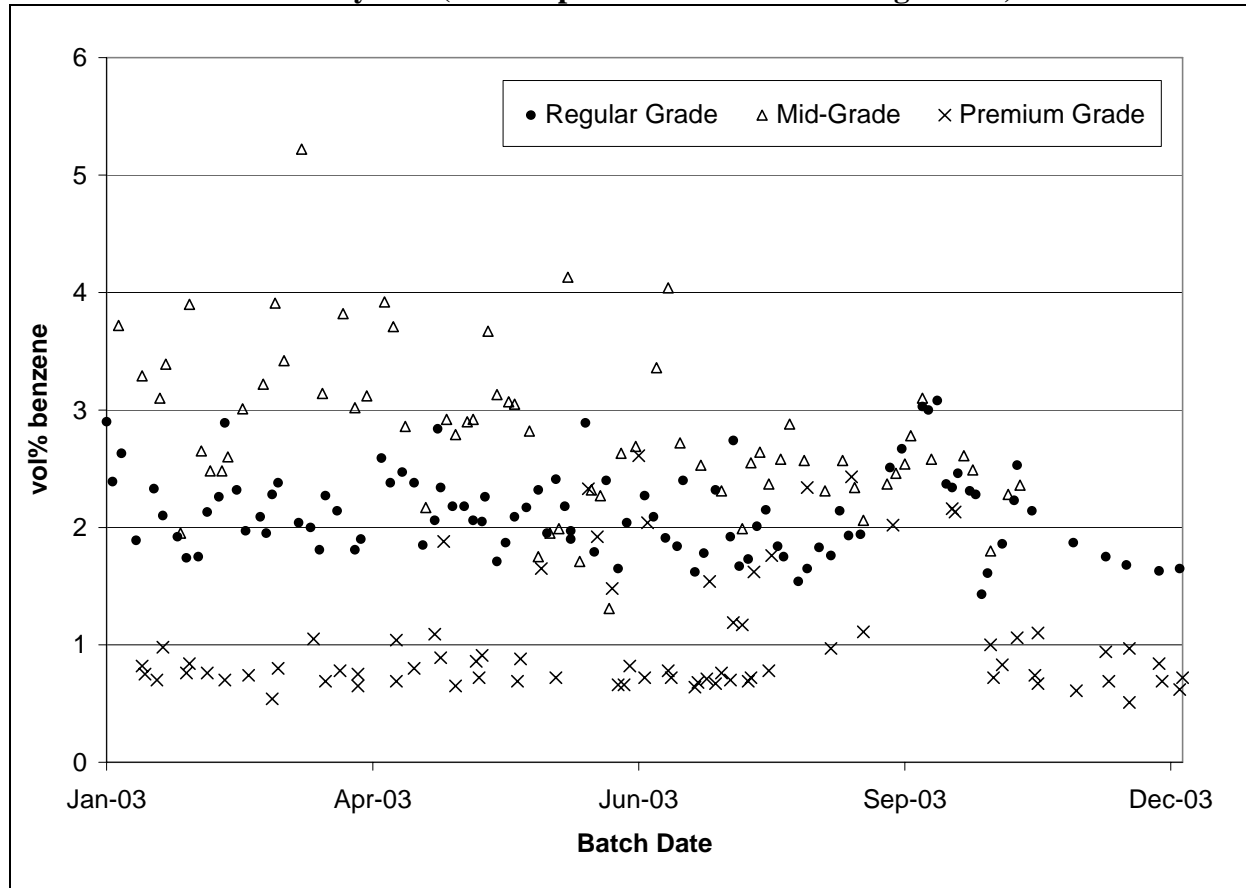
**Figure 6.2-4. Batch-by-Batch Benzene Levels for Refinery “C” that Produces both RFG and CG Gasoline (volume percent benzene in 2003 gasoline)**



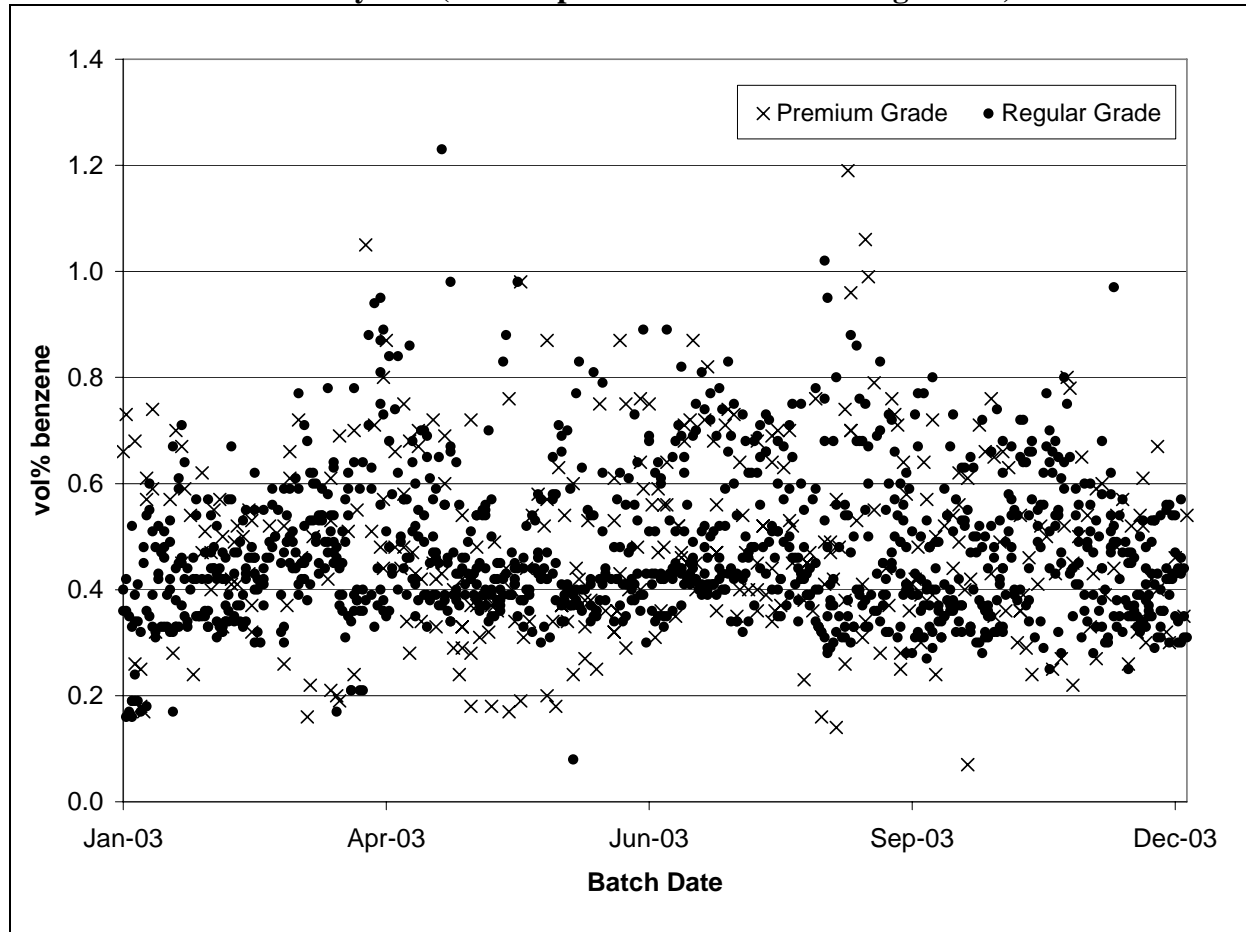
**Figure 6.2-5. Premium and Regular Grade Gasoline Batch-by-Batch Benzene Levels for Refinery “D” (volume percent benzene in 2003 gasoline)**



**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. 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 in the RFG areas.

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 2003.<sup>8</sup> The information is presented for both conventional gasoline and reformulated gasoline.

**Table 6.2-2. 2003 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	1.39	0.94	1.54	1.79	0.63	1.11
Reformulated Gasoline	0.60	0.82	0.56	N/A	N/A	0.62	0.62
Gasoline Average	0.70	1.28	0.87	1.54	1.79	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 percent)	Typical Volume in Gasoline (percent)
Reformate	3 – 11	30
FCC Naphtha	0.5 – 2	36
Alkylate	0	12
Isomerate	0	4
Hydrocrackate	1 – 5	3
Butane	0	4
Light Straight Run	0.3 – 3	4
MTBE/Ethanol	0.05	3
Natural Gasoline	0.3 – 3	3
Coker Naphtha	3	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.<sup>9</sup> 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 conversion 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.<sup>10 11</sup>

### *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 too 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.<sup>A</sup> 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 feed/effluent exchangers and fed to the high pressure separator. One of the principal byproducts

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<sup>A</sup> Internal document.

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.<sup>12</sup>

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.

The above information has been presented from a conceptual point of view. For an informative discussion see<sup>13</sup>

### **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.<sup>B</sup> One is to prefractionate the feed, thus the benzene precursors out of the reformer. The other is to post-fractionate reformat 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 Prefractionation 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 C<sub>5</sub>s from being sent to the reformer. This means that most of the C<sub>6</sub>s are sent to the reformer along with the C<sub>7</sub>s, C<sub>8</sub>s and sometimes the C<sub>9</sub>s. The cut-point could be changed from between the C<sub>5</sub>'s and C<sub>6</sub>'s to between the C<sub>6</sub>'s and C<sub>7</sub>'s; in so doing the benzene precursors are also cut out of the reformer. To assure that most of the C<sub>6</sub>'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 C<sub>6</sub>s and C<sub>7</sub>s, which would also cut some C<sub>7</sub>'s out of the reformer feed. Cutting some of the C<sub>7</sub>s out of the heavy straight run going

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<sup>B</sup> 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.

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 C7s. They would accomplish this by 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.

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 reformat 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<sub>7</sub>'s, C<sub>8</sub>'s, and C<sub>9</sub>'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<sub>8</sub> and C<sub>9</sub> alkanes, all of which reduces the net effect of the original reduction. Even so, the benzene content will be lower than prior to prefractionation. 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 reformat is formed by the cracking of heavy aromatics, thus some benzene would remain in reformat. 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 licensor 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<sub>2</sub>) 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<sub>5</sub>'s with some C<sub>6</sub>'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.<sup>14</sup>

### **6.3.2.3 Reformate Postfractionation with Benzene Saturation**

Another method for reducing reformate benzene is to postfractionate reformate into heavy and light cuts; the light, C<sub>6</sub>, cut would contain the reformate benzene which could be treated to remove benzene, while the C<sub>7</sub>+ 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 C<sub>7</sub>s. 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 C<sub>6</sub> stream. The refinery would design this unit as appropriate for the refinery considering their particular economics and refinery situation. The C<sub>6</sub> 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<sup>15</sup> 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% to 18%.

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.<sup>16</sup>

### *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<sup>17</sup>. 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<sup>18</sup>. 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  $C_6/C_7$  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 C<sub>6</sub> stream from the rest of reformate using a reformate splitter. This C<sub>6</sub>, 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 be 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 C<sub>6</sub>s 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 than with benzene saturation.

After separation, the C<sub>6</sub> 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 reformat splitter since refineries omitting the heavy straight run naphtha from the reformer feed (omitting the C9+ fraction) could send all the reformat 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."<sup>19</sup>

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."<sup>20</sup> 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.<sup>21</sup> A full-boiling range light reformat 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.

#### **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 Prefractionation 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 proposed 0.62 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 proposed 0.62 benzene standard. RFG averages 0.62 volume percent benzene – the same level as the proposed 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 proposed 0.62 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 reformat to other refineries with extraction units. While this demonstrates that achieving the proposed benzene 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 proposed 0.62 benzene standard using this technology. This technology is clearly insufficient for achieving the proposed benzene control standard by itself.

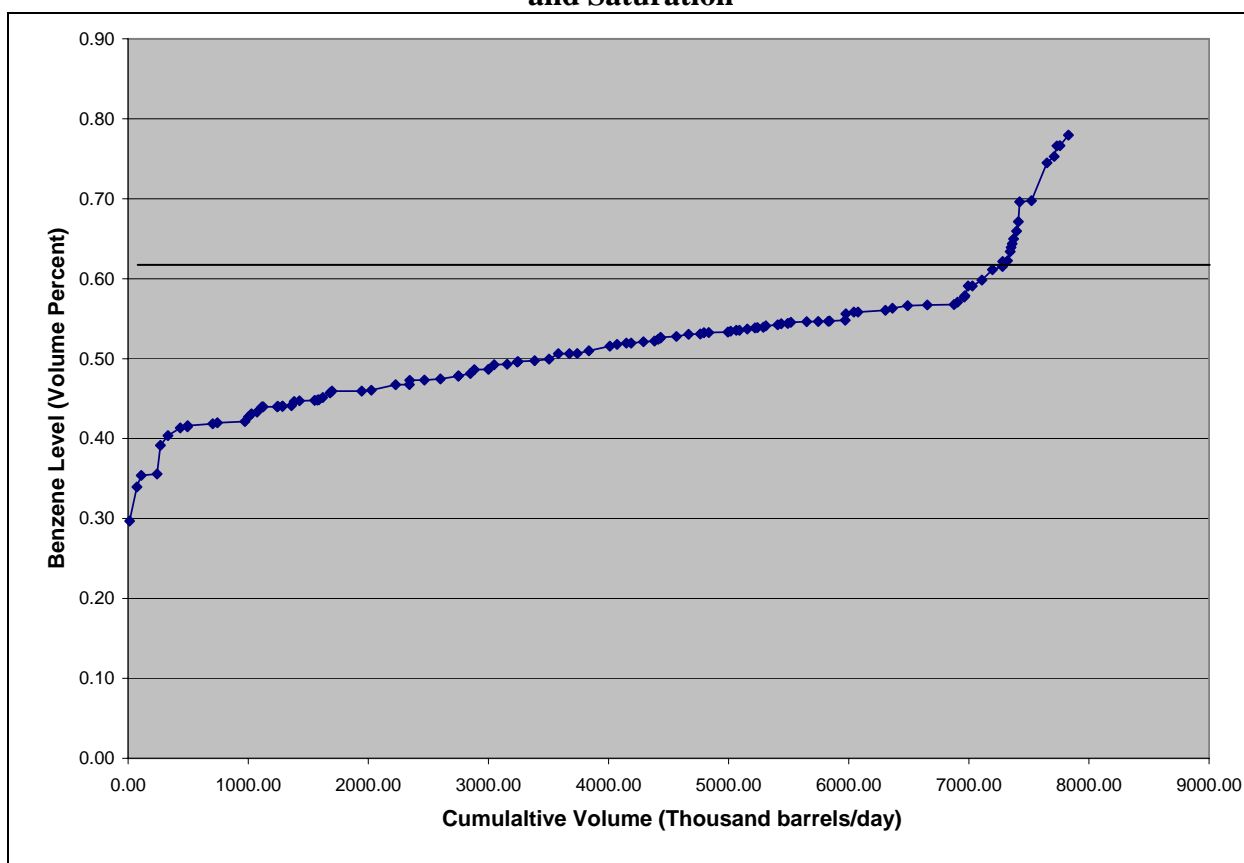
Those refineries with isomerization units would be able to route their rerouted benzene precursors to this unit further reducing their benzene levels by saturating the naturally occurring benzene in this stream. The refinery-by-refinery cost model shows that on average these refineries would be able 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 proposed 0.62 benzene standard. Averaged across the U.S. refineries, benzene precursor rerouting can achieve about a 60 percent reduction in reformat benzene levels. When benzene precursor rerouting is combined with isomerization, about an 80 percent reduction in reformat 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 proposed 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 reformat.

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 reformat – that formed from the six carbon hydrocarbons, that formed from the cracking of heavier aromatics to benzene in heavy reformat, 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 reformat 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 reformat 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 0.52 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 0.52 volume percent ranging between 0.29 to 0.78 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 proposed 0.62 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, 13 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 proposed 0.62 benzene standard. 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 technologies that could be used to reduce gasoline benzene levels in addition to the reductions modeled in the refinery-by-refinery cost model. Although we have not quantified their costs, they are expected to be more expensive and therefore less attractive for achieving benzene reductions than the reformat treating technologies identified above.

One of these less attractive 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 reformat splitter and sending this additional benzene to their saturation or extraction unit. Normally refiners attempt to optimize the capital and operating costs with the amount of benzene removed when splitting a benzene-rich stream out of the reformat 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 reformat 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 reformat 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 reformat 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 reformat splitter, or their benzene saturation or extraction units with this end in mind. On the one hand, they could design their reformat 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 reformat splitter. On the other hand, they could maintain the optimized reformat splitter but design additional excess capacity in their downstream saturation and extraction units to handle the additional seven carbon hydrocarbons that would be sent to these units. In the case of benzene saturation, the benzene saturation reaction would have to be sized larger. In the case of benzene extraction, the benzene extraction unit would have to be designed to handle the increased six and seven carbon hydrocarbons forwarded to it by the reformat splitter. The aromatics distillation equipment downstream of the extraction unit would also have to be sized larger to separate the additional toluene and benzene sent to this unit. For each of the 13 refineries which the refinery-by-refinery cost shows could not achieve 0.62 volume percent benzene, we estimate the extent that benzene levels could be further reduced by capturing the

remaining reformat benzene and treating it in a saturation unit or extracting it from gasoline, and summarize this in Table 6.4-1 below.

Another means for further reducing the benzene levels for 5 of these 13 refineries which have hydrocrackers or cokers is to reduce the benzene content of one of the products of the hydrocracker or coker units, the light hydrocrackate naphtha or light coker naphtha streams. Light hydrocrackate and light coker naphtha are normally blended directly into gasoline. These streams are estimated to contain on average 2 volume percent benzene. While this level of benzene is moderate relative to the benzene levels of reformat, its benzene contribution to the gasoline pool for these refineries is significant. Light hydrocrackate or light coker naphtha could be treated by routing these streams to an isomerization unit, similar to how refiners isomerize the six-carbon straight run naphtha as discussed above. Isomerizing this stream would increase its vapor pressure and could require additional steps to counter the vapor pressure increase by lowering the vapor pressure of the FCC naphtha as described below discussing the methodology for achieving vapor pressure reductions. Alternatively, the refiners could use additional distillation equipment to cut the light hydrocrackate and coker naphtha more finely. In this way, more of the benzene could be shifted to the “medium” hydrocrackate and coker streams, which are sent to the reformer and thus would be treated along with the rest of reformat in benzene saturation or extraction units. 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 way that the gasoline benzene levels of most of these refineries could be further reduced would be to treat the benzene in natural gasoline. 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. We assume that this material is blended directly into gasoline 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 for reducing its benzene content. However, by 2011 which is when this rule would take effect, refiners may be treating this stream in the refinery to reduce its sulfur level. 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, it could be treated in the reformer to both reduce its sulfur as well as improve its octane. If this stream is treated in the reformer to treat its sulfur, it would also be treated for benzene if reformat benzene control are later added to meet a benzene control standard. Another way that the sulfur of the light portion (that which contains the benzene) could be treated for reducing its sulfur is with an extractive caustic treater such as a Merox unit (see the section below on sulfur control). While this technology would address the sulfur in this stream it would not reduce, nor would it place this stream in the position to reduce, the benzene level of this stream. Another way that these refineries with high benzene levels could deal with the benzene of natural gasoline is to simply stop purchasing all or a part of the natural gasoline that it currently purchases. This volume of natural gasoline that could be rejected by these refineries could then be purchased by other refineries. For each of the refineries which are assumed to be purchasing natural gasoline in the refinery-by-refinery cost model, and which could not achieve 0.62 volume percent benzene with reformat benzene

control, we estimated the extent that treating the benzene in natural gasoline could lower their gasoline benzene levels 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 shown in Table 6.3-1 above, FCC naphtha contains less than 1 percent benzene on average. Despite the low concentration of benzene in FCC naphtha, the large volumetric contribution of this stream to gasoline results in this stream contributing a significant amount of benzene to gasoline as well. There are no proven processes which treat benzene in FCC naphtha. This is likely because its benzene concentration is low as well as because FCC naphtha contains a high concentration of olefins. 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. Such a stream could probably be sent to an extraction unit, but this would be expensive to treat because of the low benzene concentration in this stream. There may be another way that a few refiners could further reduce their benzene levels. 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.<sup>22</sup> 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 reformat 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.

**Table 6.4-1. Additional Benzene Reduction Achievable by non-Reformat Means of Control for Refineries Unable to Achieve the Proposed 0.62 Standard using Reformat Control**

Refinery Number	Gasoline Benzene Level after Reformat Benzene Control	Treating last 4% of Reformat Benzene	Treating 96% of Light Hydrocrackate and Coker Naphtha Benzene	Treating 96% of Natural Gasoline Benzene
1	0.78	-0.06	-0.03	-0.07
2	0.77	-0.11	-0.37	-0.13
3	0.70	-0.06	N/A	-0.07
4	0.75	-0.10	-0.38	-0.12
5	0.66	-0.05	N/A	-0.07
6	0.64	-0.07	N/A	-0.09
7	0.63	-0.06	N/A	-0.09
8	0.67	-0.11	-0.37	-0.15
9*	0.77	-0.07	N/A	-0.03
10	0.64	-0.08	N/A	-0.03
11	0.70	-	-0.23	-0.27
12	0.74	-	-0.42	-0.02
13	0.65	-0.06	N/A	-0.07

\* Refinery #9 is shown to have added an isomerization unit after 2003 that is estimated to reduce its gasoline benzene level 0.12 volume percent. This will be modeled in the final rule.

## 6.5 Averaging, Banking, and Trading (ABT) Program

We are proposing that refiners and importers could use credits generated under the averaging, banking, and trading program (ABT) to meet the 0.62 vol% benzene standard in 2011 and beyond. This regulatory impact analysis<sup>C</sup> begins with a discussion of starting refinery benzene levels then explains the strategies refineries would take to meet the standard. For refineries that plan to reduce actual benzene levels, we have explained when the benzene reducing steps would occur and how early process changes made prior to 2011 would generate early credits that could provide the refining industry with additional lead time to make their final investments. We also explain the basis and derivation of early credit baselines, early credit trigger points, and the trigger point value. We have provided an analysis of how the early credit program would enable a gradual phase in of the standard and an amortization of refinery compliance costs. We also explain which refinery improvements would be postponed until 2011 or later as early credits permit. We conclude with a discussion of ending refinery benzene levels and an explanation of how program credits would be generated and traded to meet the 0.62vol% standard on an average nationwide basis.

### 6.5.1 Starting Gasoline Benzene Levels

In order to begin the ABT analysis, it was first necessary to establish a baseline benzene level for each refinery. Batch benzene concentrations are provided to EPA as part of the existing RFG/anti-dumping refinery requirements. In summer 2003, the benzene content of gasoline produced by 115 U.S. refineries ranged from 0.41 to 3.81 vol% with an overall volume-weighted average of 0.97 vol% as shown in Table 6.5-1.

**Table 6.5-1. Starting Benzene Levels**

	No. of Refineries by Gasoline Benzene Level (vol%)						Benzene Level (vol%)*			
	<0.5	0.5-<1.0	1.0-<1.5	1.5-<2.0	2.0-<2.5	>=2.5	MIN	MAX	RANGE**	AVG***
PADD 1	4	3	3	0	2	0	0.41	2.19	1.77	0.62
PADD 2	0	5	8	11	1	1	0.60	2.85	2.25	1.32
PADD 3	4	18	10	7	0	2	0.41	3.10	2.69	0.86
PADD 4	0	1	4	6	3	2	0.60	3.56	2.96	1.60
PADD 5****	0	0	1	3	2	2	1.36	3.81	2.44	2.06
California	0	12	0	0	0	0	0.51	0.77	0.26	0.63
<b>Total</b>	<b>8</b>	<b>39</b>	<b>26</b>	<b>27</b>	<b>8</b>	<b>7</b>	<b>0.41</b>	<b>3.81</b>	<b>3.39</b>	<b>0.97</b>

\* Starting benzene levels based on summer 2003 batch data

\*\* Range in benzene level (MIN-MAX)

\*\*\* Average volume-weighted benzene level

\*\*\*\* PADD 5 excluding California

The ABT analysis for this proposal includes all U.S. refineries including California since the decision to exclude California gasoline from this proposal was made subsequent to this analysis. For the final rule, the analysis presented here would be redone using the best available

<sup>C</sup> This analysis includes small refiners

batch gasoline data and excluding California refineries. We predict that there would be some changes in the results of the analysis (i.e. who/where the benzene reductions come from, compliance costs, etc.) however, we believe the overall outcome would be relatively unaffected.

We anticipate very few changes as a result of using more current batch data since there have not been any changes in gasoline benzene regulation that would significantly impact starting benzene levels. We also believe there would be few changes associated with excluding California refineries from the analysis since their average starting benzene levels are already near the proposed 0.62 vol% standard based on existing state fuel programs. Our current ABT analysis does not predict them to make very many changes in benzene level nor does it suggest they would be a key player in the proposed credit generation and trading program. As such, removing them from the analysis should have very little impact.

There is currently a wide variation in nationwide gasoline benzene levels. The variation (explained in more detail in 6.2) is primarily attributed to crude oil quality, use of low-benzene blendstocks, benzene control technology, and refinery operating procedures.

The variation or range in starting benzene levels has been calculated to equal 3.39 vol% overall or 1.77, 2.25, 2.69, 2.96, and 2.44 vol% for PADDs 1-5, respectively as shown in Table 1.

In part due to this variation in starting benzene level, we predict that it would be much more difficult for some refiners to comply with the 0.62 vol% gasoline benzene standard in 2011 and beyond based on actual levels than others. As such, we are proposing an ongoing nationwide averaging, banking, and trading (ABT) program that would allow some refineries to maintain gasoline benzene levels above 0.62 vol%, provided they are equivalently offset by refineries below the standard. Refineries that elect to maintain gasoline benzene levels above the standard would have to purchase benzene credits generated by refineries for early reduction efforts and/or overcompliance with the standard.

### **6.5.2 Refinery Compliance Strategies**

As discussed in Chapter 9, our cost analysis assumes that refiners would choose the most economical strategy for complying with the gasoline benzene standard in 2011 and beyond. We predict that the majority of refinery compliance strategies would involve making at least some sort of process change to reduce benzene levels. For some refineries, it is economical to reduce gasoline benzene levels to  $\leq 0.62$  vol%, while for others it is more economical to make incremental reductions in gasoline benzene level to  $> 0.62$  vol% and rely partially upon benzene credits. For the refineries whose compliance strategies do not involve reducing benzene levels, most are already below the standard so no further action is required. For the remaining refineries, it is more economical to rely solely upon credits than to make any process improvements to reduce gasoline benzene. A summary the model-predicted refinery compliance strategies are 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*	CA	Total
Yes, reduce Bz levels to $\leq 0.62$ vol%	No	4	7	23	1	2	2	39
Yes, reduce Bz levels to $> 0.62$ vol%	Yes	4	18	8	14	5	0	49
No, Bz levels are already $\leq 0.62$ vol%	No	4	0	7	1	0	7	19
No, maintain Bz levels $> 0.62$ vol%	Yes	0	1	3	0	1	3	8
Total Number of Refineries		12	26	41	16	8	12	115

\*Refers to PADD 5 excluding the State of California

### 6.5.3 Benzene Reduction Strategies

We believe that most refiners planning on reducing gasoline benzene levels would 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 most refiners would choose this strategy since it is capable of getting the greatest benzene reductions and the technology is known and readily available. For our ABT analysis, we have specifically focused on the following forms of reformate control: light naphtha splitting, isomerization, benzene extraction, and benzene saturation. These technologies are discussed in more detail in 6.3.2.

Our refinery cost model predicts which benzene reducing step(s) each individual refinery would take based on the lowest overall cost strategy to meet the proposed 0.62 vol% standard nationwide. The benzene control strategy a refinery selects depends on existing equipment, proximity to the petrochemical market, and technology costs compared to the cost of buying credits. The cost model also contains estimates of the timing necessary for each refinery to make the predicted refinery process changes. A refinery's ability to make benzene reductions earlier than required is dependent on the nature of the improvement(s), required planning time, and associated capital costs.

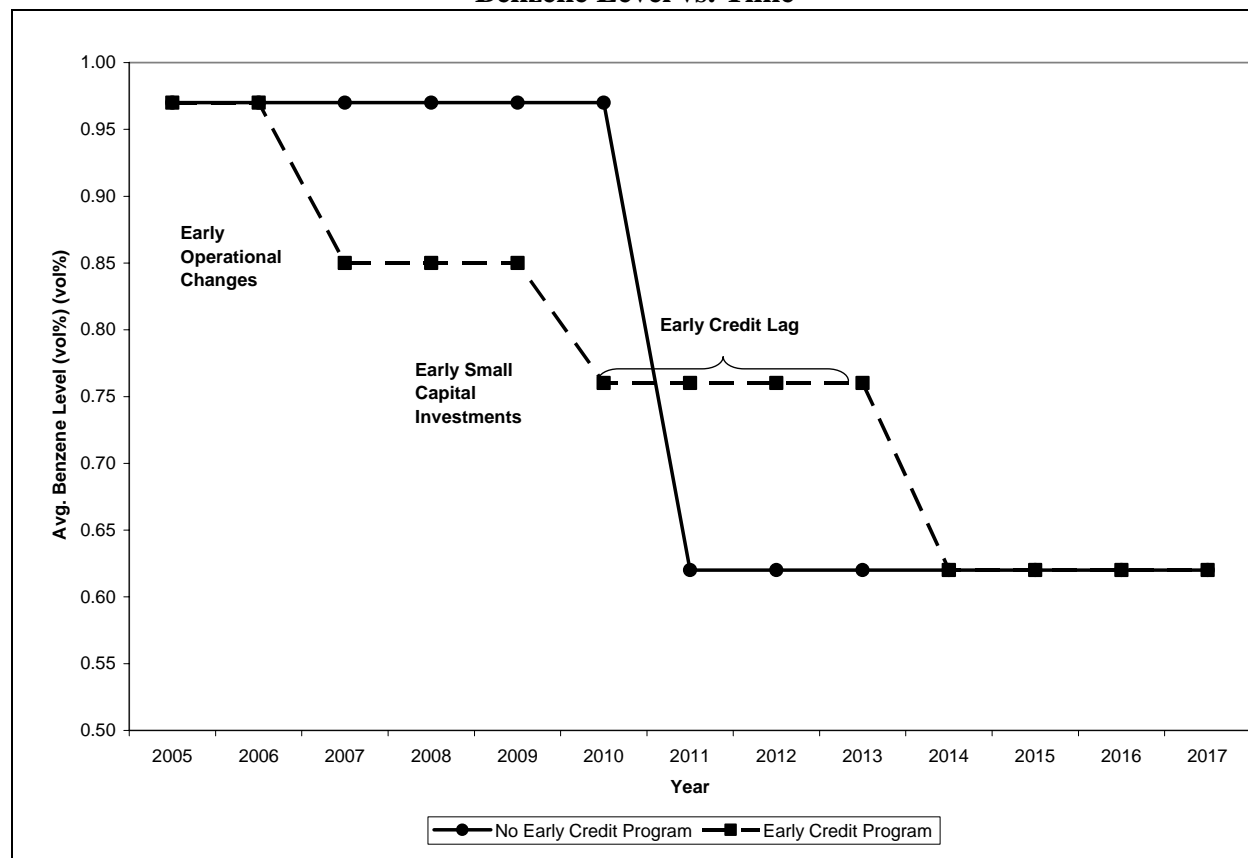
#### 6.5.3.1 Early Process Changes Completed Prior to January 1, 2011

In many cases there are benzene reductions strategies consistent with refineries' overall compliance strategies that could be implemented earlier than required. To encourage early introduction of benzene control technology, we are proposing that refiners could generate early benzene credits from June 1, 2007 to December 31, 2010 by making qualifying reductions from their pre-determined refinery baselines. A discussion of how refinery baselines are established and what constitutes a qualifying benzene reduction is found in the paragraphs to follow.

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. As discussed in the subsections that follow, we predict that prior to January 1, 2011, refiners could implement operational changes and/or make small capital investments to reduce gasoline benzene. These

actions would create a two-step phase down in gasoline benzene levels prior to 2011 as shown in Figure 6.5-1. The early credits generated could be used to postpone refiners' final, most expensive, benzene control technology investments.

**Figure 6.5-1. ABT Program with Early Credit Generation**  
**Benzene Level vs. Time**



#### *Early Operational Changes*

We estimate that the first phase of early benzene reductions could occur as early as June 1, 2007 after the rule is signed, published, and congressional review is complete. These refinery modifications would consist of operational changes made to the reformer that could be implemented with virtually no capital investment. The early operational changes we predict to occur are light naphtha splitting and isomerization. For refineries that already have light naphtha splitters in place, 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 our refinery cost model, we predict that 48 of the 115 U.S. refineries would take advantage of the early credit opportunity and make the early operational changes described

above. These operational changes would result in an overall 13% reduction in gasoline benzene levels from 0.97 vol% to 0.84 vol%. The changes would also result in an overall 28% reduction in benzene level variation from 3.39 vol% to 2.43 vol%. A summary of these reductions and resulting benzene levels are 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-<1.0	1.0-<1.5	1.5-<2.0	2.0-<2.5	>=2.5	MIN	MAX	RANGE**	AVG***
PADD 1	4	4	2	0	2	0	0.41	2.19	1.77	0.61
PADD 2	0	13	11	1	0	1	0.56	2.85	2.28	0.99
PADD 3	4	21	12	3	0	1	0.41	2.71	2.30	0.80
PADD 4	0	2	10	3	0	1	0.60	2.51	1.91	1.27
PADD 5****	0	0	3	2	3	0	1.01	2.19	1.18	1.57
California	0	12	0	0	0	0	0.51	0.77	0.26	0.63
<b>Total</b>	8	52	38	9	5	3	0.41	2.85	2.43	0.84

\* Starting benzene levels based on summer 2003 batch data

\*\* Range in benzene level (MIN-MAX)

\*\*\* Average volume-weighted benzene level

\*\*\*\* PADD 5 excluding California

#### *Early Technology Changes Requiring a Small Capital Investment*

We estimate that a second phase of early benzene reductions would occur 2-3 years after the rule is signed or by about the end of 2009. These refinery modifications would consist of upgrades in reformate benzene control technology which require a relatively small capital investment. For the purpose of this analysis, the refinery cost model defines a small capital investment as investments that cost up to \$8MM<sup>D</sup>. The early technology changes we predict to occur include light naphtha splitting, isomerization, and benzene extraction. For refineries that already have light naphtha splitters in place or those that do not, we assume that technological upgrades could be made to re-route 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, we predict that the light naphtha would be combined with the light straight run to make gasoline. We also predict that refineries currently extracting benzene could make modifications to their existing extraction units (up to \$8MM) to improve the benzene separation and in turn reduce the concentration of benzene in the final gasoline product.

Based on our refinery cost model, we predict that 55 of the 115 U.S. refineries would make early technology changes which require a small capital investment. These changes along with the operational changes discussed above would result in an overall 22% reduction in gasoline benzene levels from 0.97 vol% to 0.76 vol%. These changes would also result in an overall 51% reduction in benzene level variation from 3.39 vol% to 1.67 vol%. A summary of these reductions and resulting benzene levels are found in Table 6.5-5.

<sup>D</sup> At a revamped extraction unit cost of \$8MM and above, the investment was judged to be sufficiently complicated that the revamp would require the full lead time period to complete. Revamping an extraction unit can be complicated because they are comprised of several major refinery units combined together and all of them could require a significant revamp above the identified investment cost threshold.

**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-<1.0	1.0-<1.5	1.5-<2.0	2.0-<2.5	>=2.5	MIN	MAX	RANGE**	AVG***
PADD 1	4	4	2	1	1	0	0.41	2.09	1.67	0.58
PADD 2	1	21	2	2	0	0	0.49	1.95	1.46	0.79
PADD 3	7	21	11	1	1	0	0.41	2.07	1.65	0.75
PADD 4	0	6	9	1	0	0	0.60	1.94	1.34	1.09
PADD 5****	0	1	4	3	0	0	0.81	1.84	1.04	1.48
California	0	12	0	0	0	0	0.51	0.77	0.26	0.63
<b>Total</b>	12	65	28	8	2	0	0.41	2.09	1.67	0.76

\* Starting benzene levels based on summer 2003 batch data

\*\* Range in benzene level (MIN-MAX)

\*\*\* Average volume-weighted benzene level

\*\*\*\* PADD 5 excluding California

### *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 the trigger point and the company's need for early credits. Our ABT analysis assumes that refiners would only make reductions predicted by the refinery cost model early if both of the following conditions were satisfied:

1. The reduction was significant enough to allow them to generate early credits. A refiner would not make a model-predicted early benzene reduction if it did not satisfy the 10% reduction trigger point (discussed in more detail in the sections to follow). Applying this assumption reduced the number of predicted early operational changes from 58 to 49 and the number of early small capital investments from 61 to 56.
2. The company had a need for early credits because their average starting benzene concentration was higher than the standard. To prove this point, consider the opposite. If a company's average benzene level was 0.62 vol% or lower to begin with, they would not have a need to generate early credits to postpone compliance since they could do nothing and 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 early operational changes from 49 to 48 and the number of early small capital investments from 56 to 55.

For refiners whose decision to make early reductions was impacted by these two provisions, our ABT analysis assumes that the model-predicted benzene reductions would eventually occur, just not earlier than required.

### *How are early credits calculated?*

Before we can calculate early credits we must first explain how early credit baselines and

annual average benzene levels are computed as well as how the proposed trigger point would impact credit generation. Additionally, we will explain the assumptions made to perform this preliminary ABT analysis.

We are proposing that any refiner planning on making early reductions establish individual refinery benzene baselines in order to provide a starting point for early credit calculations. Refinery baselines would be defined as the annualized volume-weighted benzene content of gasoline produced at a refinery from January 1, 2004 to December 31, 2005. For the purpose of this ABT analysis, we used the summer 2003 starting gasoline benzene levels reflected in Table 6.5-1 to represent refinery baselines.

The benzene level from which early credits are calculated is the average volume-weighted benzene concentration of all batches of gasoline produced during a given averaging period. This is referred to as the annual average benzene concentration. For the purpose of this ABT analysis, we have 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.

In order to qualify to generate early credits, refiners would first need to reduce gasoline benzene levels to 0.90 times their refinery benzene baseline during a given averaging period. A further explanation of how we arrived at the 10% reduction trigger point can be found in subsections to follow. Once the 10% reduction trigger point was met, refineries could 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  $0.90 \times 2.00 = 1.80$  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).

*How many early credits does our refinery cost model predict?*

By applying these criteria to the refinery cost model, we estimate that refineries making early operational changes and small capital investments in reformat technology from June 1, 2007 to December 31, 2010 would generate over 650 million gallons of early benzene credits as shown in Table 6.5-6.

**Table 6.5-6. Early Credits Generated by PADD**

	Early Credits Generated by Year (gal Bz)				
	2007	2008	2009	2010	Total
PADD 1	1,276,497	2,188,280	2,188,280	6,143,596	11,796,653
PADD 2	53,145,796	91,107,079	91,107,079	148,719,615	384,079,568
PADD 3	16,919,006	29,004,010	29,004,010	57,451,088	132,378,113
PADD 4	7,512,220	12,878,091	12,878,091	20,115,709	53,384,110
PADD 5*	12,361,833	21,191,714	21,191,714	25,268,439	80,013,701
California	0	0	0	0	0
<b>Total</b>	<b>91,215,351</b>	<b>156,369,173</b>	<b>156,369,173</b>	<b>257,698,447</b>	<b>661,652,145</b>

\* Refers to PADD 5 excluding the State of California

*How much lead time would be generated by early credits?*

Under the proposed ABT program, we assume that early credits generated prior to 2011 could be used to provide refineries with additional lead time to postpone their final investments in benzene control technology. This would essentially postpone the full implementation of the 0.62 vol% benzene standard by a certain period of time, providing a more gradual phase-in of the standard.

To calculate the potential “lag” in compliance, we first calculated the demand for early credits by refineries which the cost model predicted would still be above the 0.62 vol% standard in 2010 after the early small capital investment period. This included refineries which the cost model predicted to make future investments as well as those predicted to rely on credits as part of their ongoing compliance strategy.

The early credit demand was calculated individually for each refinery above the standard as demonstrated in the following example. If in 2010 a refinery’s annual average benzene level was 0.80, it’s early credit demand would be determined based on the difference between the annual benzene level and the standard ( $0.80 - 0.62 = 0.18$  vol%) divided by 100 and multiplied by it’s annual average production volume (early credit demand expressed in gallons of benzene per year). The total early credit demand by PADD is found in Table 6.5-7.

**Table 6.5-7. Demand for Early Credits by PADD**

	Refineries with Bz Levels >0.62 vol% in 2010			
	Total Number of Refineries	Average Benzene Level (vol%)	Gasoline Production (MMgal/yr)	Early Credit Demand (gal Bz/yr)
PADD 1	7	0.83	5,394	11,176,350
PADD 2	20	0.84	22,566	49,124,851
PADD 3	26	0.99	28,791	94,888,243
PADD 4	15	1.13	3,550	18,190,371
PADD 5*	8	1.48	4,341	37,276,799
California	4	0.74	7,073	8,139,253
<b>Total</b>	<b>80</b>	<b>0.93</b>	<b>71,716</b>	<b>218,795,867</b>

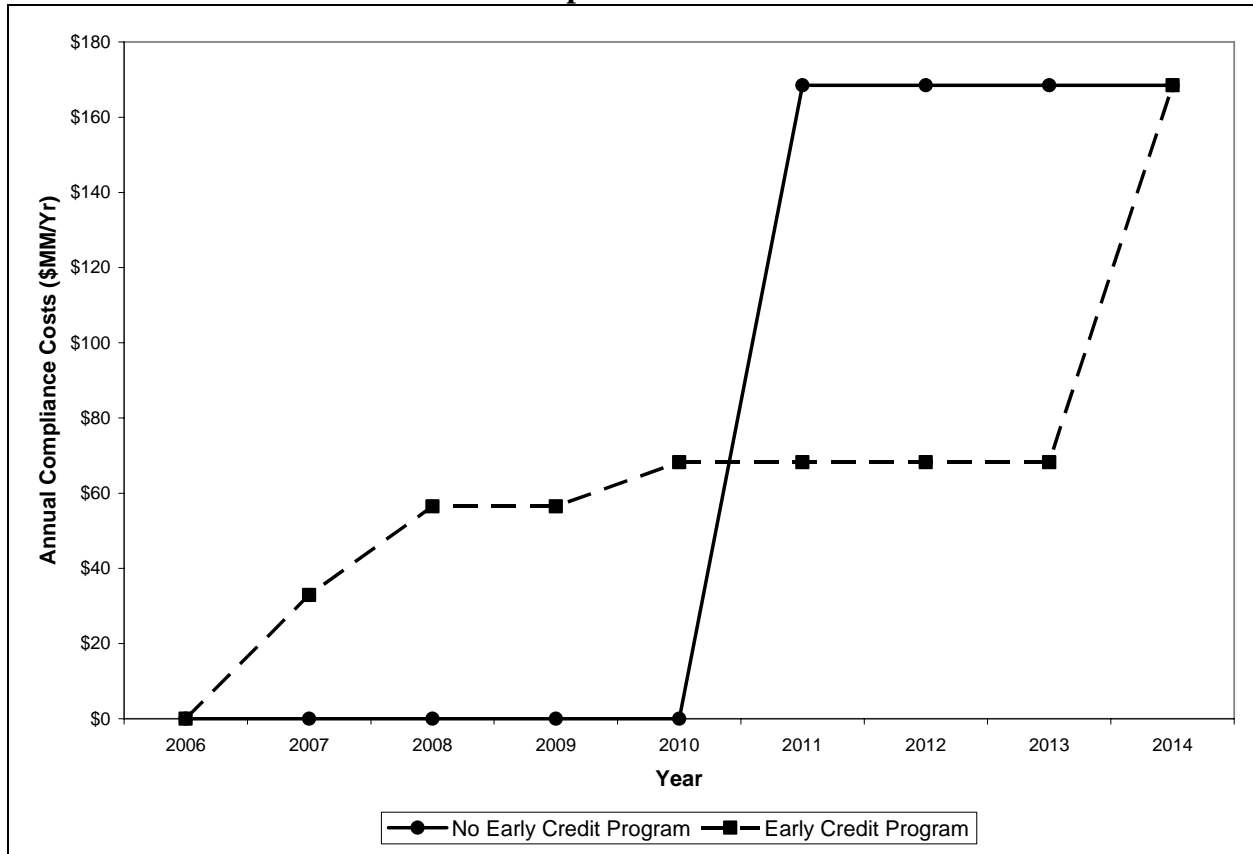
\* Refers to PADD 5 excluding the State of California

Finally, the length of the early credit lag was computed as the total number of early credits generated (661,652,145 gal Bz) divided by the early credit demand (218,795,867 gal/yr). The lag was found to be 3.02 years which could postpone compliance with the 0.62 vol% standard from 2011 to 2014 as shown in Figure 6.5-1. Based on this theoretical early credit lag, a matching 3-year early credit life was proposed.

*What is the value of the proposed early credit program?*

Not only does the early credit program result in sooner benzene emission reductions for the environment, it also results in a cost savings to the refining industry. With no early credit program, all refiners would implement their benzene control strategies around the same time causing a sharp \$168 million increase in compliance costs in 2011 (annualized capital plus operating costs). With the early credit program, refineries would have incentive to implement some of their technologies sooner. The early credits generated could be used to delay final investments as much as three years, as calculated above and allowed by the three-year early credit expiration date. This would spread out industry-wide demand for recourses and total compliance costs over time. This gradual phase in of costs is represented in Figure 6.5-2 and would result in a net savings of \$86 million to the refining industry during the 2007-2014 period. This net cost savings has been computed as the difference between the areas under the curves.

**Figure 6.5-2. ABT Program with Early Credit Generation  
Annual Compliance Costs vs. Time**



### *Early Credit Trigger Points*

*What is the purpose of an early credit trigger point?*

In order to qualify to generate early credits, refiners would first need to reduce gasoline benzene levels to 0.90 times their refinery benzene baseline during a given averaging period. 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.

*What trigger points did we consider?*

In designing the early credit generation program, we considered a variety of different types of trigger points. We performed sensitivity analyses around absolute level trigger points (refineries must reduce gasoline benzene levels to a certain concentration in order to generate credits), fixed reduction trigger points (refineries must reduce gasoline benzene levels by a certain concentration in order to generate credits), and percent reduction trigger points (refineries

must reduce gasoline benzene by a percentage in order to generate). The results of these analyses are found in Table 6.5-8, Table 6.5-9, and Table 6.5-10, respectively. For comparison purposes, we have focused on trigger points resulting in an approximate three-year early credit lag.

**Table 6.5-8. Absolute Level Trigger Point (ALTP) Credit Generation**

Absolute Level Trigger Point (vol%)	Early Credit Generation by Starting* Bz Level (vol%)						Early Credit Lag (Years)
	**0.5 to <1	1 to <1.5	1.5 to <2	2 to <2.5	>=2.5	TOTAL	
2.00	57,435,070	212,079,916	290,561,782	75,954,122	29,226,711	665,257,600	3.09
<b>1.90</b>	<b>57,435,070</b>	<b>212,079,916</b>	<b>290,561,782</b>	<b>75,842,055</b>	<b>26,344,612</b>	<b>662,263,434</b>	<b>3.04</b>
1.80	57,435,070	212,079,916	290,561,782	75,842,055	19,571,551	655,490,374	2.94
1.70	57,435,070	212,079,916	290,561,782	75,842,055	6,267,344	642,186,166	2.83
1.60	57,435,070	212,079,916	290,561,782	50,651,118	6,267,344	616,995,229	2.64
1.50	57,435,070	212,079,916	290,561,782	47,932,394	6,267,344	614,276,505	2.63
1.40	57,435,070	212,079,916	241,777,402	28,052,007	1,045,758	540,390,152	2.15
1.30	57,435,070	212,079,916	207,685,666	18,460,791	1,045,758	496,707,200	1.89
1.20	57,435,070	209,454,644	206,244,587	2,977,994	1,045,758	477,158,052	1.73
1.10	57,435,070	195,161,525	172,872,517	2,977,994	1,045,758	429,492,864	1.51
1.00	57,435,070	187,483,551	113,702,251	1,943,107	0	360,563,979	1.23

\* Starting benzene levels based on summer 2003 batch data

\*\* Model does not predict any early credits to be generated by refineries with starting benzene levels <0.5 vol%

As shown in Table 6.5-8, for a 1.90 vol% absolute level trigger point (ALTP), the number of early credits generated by refineries with starting benzene levels  $\geq 2.5$  vol% is 26 million. This is about half the amount of early credits generated by the same group of refineries under the proposed 10% reduction trigger point (51 million). In addition, early credit generation is reduced to zero as the absolute level trigger point decreases. As such, we conclude that absolute level trigger points are too restrictive towards refineries with high starting benzene levels. It is important not to restrict early credit generation for this class of refineries because they could arguably benefit the most from early reductions. They have the highest starting benzene levels and thus the greatest need for real benzene reductions. They would also have the greatest amount of work to do to meet the 0.62 vol% standard, so they could benefit significantly from the additional lead time provided by early credits. The lead time could be used to spread out subsequent benzene technology investments making compliance with the benzene standard more affordable. Another disadvantage of an ALTP is that there could potentially be a “windfall” of early credits generated by refineries with starting benzene levels near the trigger point. For example a refinery with a starting benzene level of 1.91 vol% could generate early credits based on minor operation fluctuations in benzene level from year to year. This would essentially generate “artificial” credits with no associated benzene reduction value.

**Table 6.5-9. Fixed Reduction Trigger Point (FRTTP) Credit Generation**

Fixed Reduction Trigger Point (vol%)	Early Credit Generation by Starting* Bz Level (vol%)						Early Credit Lag (Years)
	**0.5 to <1	1 to <1.5	1.5 to <2	2 to <2.5	>=2.5	TOTAL	
0.05	49,322,559	211,538,905	290,561,782	75,954,122	53,011,708	680,389,075	3.15
<b>0.10</b>	<b>39,520,923</b>	<b>211,113,794</b>	<b>290,561,782</b>	<b>75,954,122</b>	<b>53,011,708</b>	<b>670,162,328</b>	<b>3.08</b>
0.15	30,425,825	198,861,358	289,662,459	75,900,117	53,011,708	647,861,466	2.93
0.20	20,941,241	175,558,970	289,662,459	75,900,117	53,011,708	615,074,494	2.62
0.25	15,524,718	173,501,315	287,020,226	75,900,117	53,011,708	604,958,083	2.57
0.30	7,727,474	172,244,773	287,020,226	75,842,055	51,018,812	593,853,340	2.45
0.35	7,727,474	170,093,278	284,660,705	75,842,055	51,018,812	589,342,324	2.41
0.40	0	161,526,161	265,100,388	75,842,055	49,952,616	552,421,221	2.10
0.45	0	155,290,562	265,100,388	75,842,055	49,952,616	546,185,622	2.06
0.50	0	124,921,489	198,630,694	75,842,055	49,952,616	449,346,855	1.58
0.55	0	107,289,504	177,787,494	75,842,055	49,952,616	410,871,670	1.41
0.60	0	59,186,172	176,112,996	75,842,055	49,770,570	360,911,793	1.23

\* Starting benzene levels based on summer 2003 batch data

\*\* Model does not predict any early credits to be generated by refineries with starting benzene levels <0.5 vol%

As shown in Table 6.5-9, for a 0.10 vol% fixed reduction trigger point (FRTTP), the number of early credits generated by refineries with starting benzene levels <1 vol% is under 40 million. Not only does this trigger point generate less credits than the 10% reduction trigger point (42 million), early credit generation is reduced to zero as the fixed reduction trigger point increases. Fixed reduction trigger points are biased towards refineries with higher starting benzene levels because it is easier for them to achieve a fixed reduction than it is for a lower benzene level refinery to achieve the same reduction. Therefore, we conclude that fixed reduction trigger points are too restrictive towards refineries with low starting benzene levels. We do not feel that these innovative refineries should be penalized for already being “cleaner”.

**Table 6.5-10. Percent Reduction Trigger Point (PRTP) Credit Generation**

Percent Reduction Trigger Point (%)	Early Credit Generation by Starting* Bz Level (vol%)						Early Credit Lag (Years)
	**0.5 to <1	1 to <1.5	1.5 to <2	2 to <2.5	>=2.5	TOTAL	
5%	44,888,175	211,538,905	290,561,782	75,954,122	53,011,708	675,954,691	3.10
<b>10%</b>	<b>42,364,574</b>	<b>202,706,184</b>	<b>289,662,459</b>	<b>75,900,117</b>	<b>51,018,812</b>	<b>661,652,145</b>	<b>3.02</b>
15%	33,656,028	190,891,588	287,020,226	75,842,055	49,952,616	637,362,514	2.87
20%	25,559,561	173,501,315	284,660,705	75,842,055	49,952,616	609,516,253	2.60
25%	20,941,241	172,244,773	265,100,388	75,842,055	49,770,570	583,899,027	2.40
30%	15,524,718	159,933,137	183,845,616	50,651,118	49,770,570	459,725,159	1.65
35%	10,523,099	147,465,199	163,978,824	28,052,007	23,157,227	373,176,357	1.27

\* Starting benzene levels based on summer 2003 batch data

\*\* Model does not predict any early credits to be generated by refineries with starting benzene levels <0.5 vol%

As shown in Table 6.5-10, a 10 percent reduction trigger point (PRTP) tends to moderate credit generation better than the absolute level and fixed reduction trigger points we have

considered. This is especially true for the extreme cases where refinery starting benzene levels are  $< 1$  vol% or  $\geq 2.5$  vol%. For the 47 refineries with starting benzene levels  $< 1$  vol %, a 10 PRTP generates 42 million credits which is more than a 0.10 vol% FRTP (40 million) but less than a 1.90 ALTP (58 million). For the 7 refineries with starting benzene levels  $\geq 2.5$  vol%, a 10 PRTP generates 51 million credits which is less than a 0.10 vol% FRTP (53 million) but more than a 1.90 ALTP (26 million). As such, we concluded that a percent reduction trigger point would be the most appropriate early credit validation tool to address the wide range in starting benzene levels.

*How did we decide on a value for the trigger point?*

Once we decided that a percent reduction trigger point (PRTP) was the most suitable type of early credit trigger point, the next step was to determine the optimum value for the trigger point. In assessing the appropriate PRTP value, there were two main objectives. The first was to set a trigger point that was stringent enough to require refineries to make real improvements in benzene control technology in order to generate credits. A less stringent trigger point could potentially allow refineries to generate artificial or “windfall” credits based on normal operational fluctuations in gasoline benzene level from year to year. The second objective was to ensure that the trigger point was not too stringent as to discourage refiners from making early reductions in gasoline benzene. As mentioned in 6.2.2.9.3.1.3, we predict that refiners would not make reductions in gasoline benzene earlier than required if the trigger point was credit prohibitive. Accordingly, the closer the trigger point was to corresponding with real achievable benzene reductions, the more refineries would pursue making early process improvements. As such, a carefully selected early credit trigger point would enhance early credit generation and result in a more reliable market for trading.

To make an educated decision on the most appropriate trigger point, we evaluated the model-predicted early benzene reductions and compared them to the “normal” year-to-year variation in refinery benzene level. We started by examining the benzene reductions resulting from our model-predicted refinery process changes. Our model predicts that some refiners could make early improvements in reformate benzene control technology resulting in 2-70% benzene reductions. This indicates that any trigger point above 2% would restrict early credit generation to some degree. As such, based on credit generation alone, we would want to choose the lowest possible trigger point. However, if we were to choose a 2% trigger point, the potential for refineries to generate “windfall” credits would be high. To get a better understanding of how gasoline benzene levels currently fluctuate from year to year, we reviewed the 2002-2004 batch reports required under the RFG/antidumping regulations. As a reference point, we chose to use the 2002-2003 calendar years as the baseline period, along the same lines as the two-year early credit baseline provision in this proposal. From there, we calculated each refinery’s change in benzene level in 2004 compared to their baseline. Changes in refinery benzene level were found to range from 42% (net decrease in benzene level) to -48% (net increase in benzene level). From here, we chose to focus our analysis on only those refineries which made reductions in benzene levels, since that is how early credits would be generated under the proposed ABT program. Refineries’ 2004 benzene reductions ranged from 0.28 to 42% percent with an average refinery reduction of 11.4%. Based on this limited data, to eliminate any chances of “windfall” credit generation we considered a trigger point on the magnitude of 40%. However, as shown in Table

6.2.2.9-11, this would have a detrimental effect on refiners' decisions to make early process changes and resulting ability to generate early credits

**Table 6.5-11. Impact of Trigger Point Value on Early Reductions/Credits**

Percent Reduction Trigger Point (%)	Affect on Refineries Early Process Changes				Affect on Early Credits	
	Operational Changes	Small Technology Changes	Total Early Changes	% Reduction	Early Credits (gal Bz)	% Reduction
0%	57	60	117	N/A	682,596,896	N/A
5%	53	58	111	5%	675,954,691	1%
10%	48	55	103	12%	661,652,145	3%
15%	41	52	93	21%	637,362,514	7%
20%	38	49	87	26%	609,516,253	11%
25%	37	44	81	31%	583,899,027	14%
30%	29	41	70	40%	459,725,159	33%
35%	19	37	56	52%	373,176,357	45%
40%	8	34	42	64%	222,727,472	67%

As shown in Table 6.5-11, as the value of the trigger point increases from 0% (no trigger point) to 40%, the number of refinery-predicted process changes decreases from 117 to 42 by 64%. Accordingly, the number of early credits generated drops drastically by 67% compared to unrestricted credit generation. The proposed 10 PRTP roughly coincides with the average fluctuation in benzene level from 2002/2003 to 2004 and is also the same as that finalized in the Tier 2 gasoline sulfur rulemaking. In response to this competing relationship between windfall credits and early credits, we are proposing a 10% reduction trigger point because it strikes a balance that errs of the side of encouraging early credit generation.

### 6.5.3.2 Final Process Changes Requiring a Large Capital Investment

We estimate that the final phase of benzene reductions would begin in 2011. This phase of refinery upgrades would include modification or installation of some of the more expensive reformate control technologies – benzene extraction and benzene saturation. For refineries pursuing benzene extraction, this would include upgrades in existing benzene extraction units exceeding \$8MM and installation of new benzene extraction units. This would also include installation of new benzene saturation units. Finally, this phase of refinery improvements would also include small capital investments that were predicted to occur early but were postponed based on the value of the trigger point.

Based on our refinery cost model, we predict that 33 of the 115 U.S. refineries would make technology improvements at this time. More specifically, 16 refineries would pursue extraction and 11 refineries would pursue benzene saturation requiring a large capital investment. Additionally, 6 refineries would pursue light naphtha splitting, isomerization, or extraction requiring a small capital investment that were postponed based on lack of early credit

incentives. These final refinery technology upgrades would be completed in 2011 or up to three years later as early credits permit. These 33 total technology changes would result in an overall 36% reduction in gasoline benzene levels from 0.97 vol% to 0.62 vol%. The changes would also result in an overall 50% reduction in benzene level variation from 3.39 vol% to 1.71 vol%. A summary of these reductions and resulting benzene levels are found in Table 6.2.2.9-12.

**Table 6.5-12. Benzene Levels after Final Capital Investments by PADD**

	No. of Refineries by Gasoline Benzene Level (vol%)						Benzene Level (vol%)*			
	<0.5	0.5-<1.0	1.0-<1.5	1.5-<2.0	2.0-<2.5	>=2.5	MIN	MAX	RANGE**	AVG***
PADD 1	4	5	1	2	0	0	0.41	1.96	1.54	0.51
PADD 2	1	22	1	2	0	0	0.49	1.95	1.46	0.73
PADD 3	10	27	3	0	1	0	0.36	2.07	1.71	0.55
PADD 4	0	8	7	1	0	0	0.53	1.94	1.40	0.95
PADD 5****	0	4	2	2	0	0	0.54	1.84	1.30	1.04
California	2	10	0	0	0	0	0.46	0.77	0.31	0.60
<b>Total</b>	<b>17</b>	<b>76</b>	<b>14</b>	<b>7</b>	<b>1</b>	<b>0</b>	<b>0.36</b>	<b>2.07</b>	<b>1.71</b>	<b>0.62</b>

\* Starting benzene levels based on summer 2003 batch data

\*\* Range in benzene level (MIN-MAX)

\*\*\* Average volume-weighted benzene level

\*\*\*\* PADD 5 excluding California

#### 6.5.4 Ending Gasoline Benzene Levels

As summarized in Table 6.5-12, after full implementation of the program, the benzene content of gasoline produced by the 115 U.S. refineries would range from 0.36 to 2.07 vol% with an overall volume-weighted average of 0.62 vol%.

#### 6.5.5 Standard Credit Generation Opportunities

We are proposing that benzene credits (referred to hereafter as standard credits) could 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.

The refinery cost model discussed further in Chapter 9, predicts which refineries would reduce benzene levels in an order of precedence based on cost until the 0.62 vol% refinery average standard is achieved. Accordingly, the model predicts which refineries would overcomply with the standard in 2011 and beyond and in turn generate standard credits. Credits would be generated by two main sources.

First, standard credits would be generated by refineries whose current gasoline benzene levels are already below the 0.62 vol% standard. According to the model, 19 refineries are predicted to maintain current gasoline benzene levels and overcomply with the standard without making any additional process improvements. These refineries would generate approximately 42 million gallons of benzene credits per year without making any investment in technology. Additionally, the model predicts that 5 other refineries would reduce gasoline benzene levels even further below 0.62 vol% resulting in deeper overcompliance and an additional 6 million

gallons of benzene credits per year.

Second, standard credits would be generated by refineries whose current gasoline benzene levels are above 0.62 vol% but are predicted by the model to overcomply with the standard based on existing refinery technology, liquid capital, and/or proximity to the benzene chemical market. The model predicts that 34 refineries with gasoline benzene levels above 0.62 vol% would make process improvements to reduce benzene levels below the standard and in turn generate approximately 40 million gallons of benzene credits per year.

For the refineries which the model predicts to make process changes to overcomply with the standard, the incremental cost to overcomply is relatively small or even profitable in some cases of benzene extraction. As expected, refineries with the lowest compliance costs would have the greatest incentive to overcomply based on the value of the credits to the refining industry.

#### **6.5.5.1 How are Standard Credits Calculated?**

We are proposing that benzene credits could 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 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 gallons of gasoline produced during the 2011 calendar year (credits expressed in gallons of benzene). 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 would continue indefinitely.

#### **6.5.5.2 How Many Standard Credits would be Generated in 2011 and Beyond?**

As mentioned above, standard credits would be generated beginning January 1, 2011 by refineries that overcomply with the 0.62 vol% standard on an annual, volume-weighted basis. According to our refinery cost model we predict that approximately 88 million would be generated in 2011 and indefinitely thereafter as summarized in Table 6.5-13.

**Table 6.5-13. Standard Credits Generated/Needed in 2011 & Beyond**

	<b>Standard Credits Generated by Refineries &lt; 0.62 vol% (gal/yr)</b>	<b>Standard Credits Needed** by Refineries &gt; 0.62 vol% (gal/yr)</b>
PADD 1	21,069,691	3,033,093
PADD 2	4,997,840	34,592,643
PADD 3	50,492,943	11,785,856
PADD 4	347,760	12,939,012
PADD 5*	820,766	18,884,725
California	10,102,342	6,596,015
<b>Total</b>	<b>87,831,343</b>	<b>87,831,343</b>

\*Refers to PADD 5 excluding the State of California

\*\*After early credit lag

As shown in Table 6.5-13, PADDs 1 and 3 would have the highest annual standard credit generation. That is because refineries in these geographic regions are located in close proximity to the petrochemicals market making benzene extraction (resulting in very low benzene levels) a viable compliance strategy.

### 6.5.6 Credit Use

We are proposing that refiners and importers could 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 indefinitely thereafter. All 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, the number of benzene credits needed to comply 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 gallons of gasoline produced during the 2011 calendar year (number of credits expressed in gallons of benzene).

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 further in 6.2.2.9.6.2.2, we predict that refiners would chose to use early credits first before relying on standard credits. By the beginning of 2014, or once all early credits have been used, terminated, or become otherwise unavailable, we predict that refiners would begin relying solely on standard credits. Our refinery cost model projects that at this point the credit supply produced by refineries that overcomply with the standard would be sufficient to meet the credit demand of refineries that under-comply with the standard. The ongoing credit demand would be approximately 88 billions gallons of benzene credits per year which equals the supply as shown in Table 6.5-12.

#### 6.5.6.1 Credit Trading Area

We are proposing a nationwide credit trading area. We have not placed any geographic restrictions on where credits may or may not be traded. If PADD restrictions were placed on credit trading, there would be an imbalance between the supply and demand of credits. 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 as shown in Table 6.5-12. 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 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 being proposed 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 (PADDs) would still experience large reductions in gasoline benzene levels as shown in Table 6.5-14.

**Table 6.5-14. Total Percent Reductions in Benzene Level by PADD**

	<b>Starting* Benzene Levels (vol%)</b>	<b>Ending** Benzene Levels (vol%)</b>	<b>% Reduction in Benzene Level</b>
PADD 1	0.62	0.51	18.82%
PADD 2	1.32	0.73	44.92%
PADD 3	0.86	0.55	36.19%
PADD 4	1.60	0.95	41.12%
PADD 5***	2.06	1.04	49.69%
California	0.63	0.60	4.80%
<b>Total</b>	<b>0.97</b>	<b>0.62</b>	<b>36.03%</b>

\* Starting benzene levels based on summer 2003 batch data

\*\* Ending benzene levels based on model-predicted benzene reductions

\*\*\* PADD 5 excluding California

### 6.5.6.2 Credit Life

We are proposing that early credits generated prior to 2011 would have a three-year credit life from the start of the program. In other words, early credits would have to be applied to the 2011, 2012, and/or 2013 compliance years or they would expire.

We are proposing that standard credits generated in 2011 and beyond would have to be used within five years of the year in which they were generated. If standard credits were traded

to another party they would still have to be used during the same five-year period. In other words, standard credit life would be tied to time of generation, not the time of transfer. Standard credits not used within five years would expire.

These proposed credit life provisions are similar to those finalized in gasoline sulfur program, except the early credit life is three years instead of two. This three-year early credit expiration period corresponds with the early credit lag calculated above in Section 6.5.3.1. Additionally, we believe that three years would be more than sufficient time for all early credits generated to be utilized. We believe that this certainty that all credits could be utilized would strengthen refiners' incentive to generate early credits and subsequently establish a more reliable credit market for trading.

In addition to the above-mentioned provisions, we are proposing that credit life may be extended by two years for early credits and/or standard credits traded to approved small refiners. We are offering this provision as a mechanism to encourage more credit trading to small refineries. Small refiners are often technologically challenged, so they would tend to have more of a need to rely on credits. At the same time, they have less business affiliations than other refiners, so they could have difficulty obtaining credits. We believe this provision would be equally beneficial to refiners generating credits. This additional credit life for credits traded to small refiners would give refiners generating credits a greater opportunity to fully utilize the credits before they expire. For example, a refiner who was holding on to credits for emergency purposes or other reasons later found to be unnecessary, could trade these credits at the end of their life to small refiners who could utilize them for two more years.

#### **6.5.6.3 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 proposing to manage the credit market, credit trading would be at the generating refiners' discretion. With such a program concerns are always expressed that credits may not be made available on the market. This is always a concern of single refinery refiners. To determine the likelihood of credit availability, we have expressed credit generation and trading by company using our refinery-cost model. The results preserve refiner identity, are segregated by early credits and standard credits, and are found in Tables 6.5-15 and 6.5-16, respectively.

**Table 6.5-15. Early Credit Trading by Company**

<b>Company</b>	<b>Generation (2007-2010)</b>	<b>Need (3-Year Lag)</b>	<b>Net Early Credits</b>	<b>% of Credit Supply</b>	<b>% of Credit Need</b>	<b>Credits Used Internally</b>
Company 1	0	0	0			0
Company 2	103,072,091	70,718,784	32,353,307	13.51%		70,718,784
Company 3	32,759,678	11,654,558	21,105,120	8.82%		11,654,558
Company 4	15,613,470	27,590,955	-11,977,485		5.00%	15,613,470
Company 5	0	8,072,835	-8,072,835		3.37%	0
Company 6	54,779,242	80,868,167	-26,088,925		10.90%	54,779,242
Company 7	7,674,171	1,883,932	5,790,239	2.42%		1,883,932
Company 8	9,823,659	75,786,123	-65,962,464		27.55%	9,823,659
Company 9	12,246,166	4,671,250	7,574,916	3.16%		4,671,250
Company 10	4,729,316	9,790,231	-5,060,915		2.11%	4,729,316
Company 11	10,345,379	11,495,180	-1,149,801		0.48%	10,345,379
Company 12	112,371,363	29,269,755	83,101,608	34.71%		29,269,755
Company 13	2,659,661	81,605,213	-78,945,551		32.98%	2,659,661
Company 14	5,197,754	8,063,391	-2,865,637		1.20%	5,197,754
Company 15	17,329,072	927,373	16,401,699	6.85%		927,373
Company 16	26,996,329	40,533,634	-13,537,305		5.65%	26,996,329
Company 17	3,093,255	1,803,271	1,289,984	0.54%		1,803,271
Company 18	14,858,489	8,057,316	6,801,173	2.84%		8,057,316
Company 19	2,700,053	17,987,381	-15,287,328		6.39%	2,700,053
Company 20	61,377,633	42,898,986	18,478,647	7.72%		42,898,986
Company 21	96,304,724	82,271,317	14,033,407	5.86%		82,271,317
Company 22	7,686,770	2,620,612	5,066,158	2.12%		2,620,612
Company 23	1,388,498	0	1,388,498	0.58%		0
Company 24	58,061	919,079	-861,018		0.36%	58,061
Company 25	3,361,260	3,037,674	323,586	0.14%		3,037,674
Company 26	3,590,867	0	3,590,867	1.50%		0
Company 27	13,304,208	13,387,601	-83,393		0.03%	13,304,208
Company 28	13,443,033	992,077	12,450,955	5.20%		992,077
Company 29	2,166,784	4,632,876	-2,466,092		1.03%	2,166,784
Company 30	12,607,342	11,542,289	1,065,053	0.44%		11,542,289
Company 31	0	6,317,414	-6,317,414		2.64%	0
Company 32	0	542,056	-542,056		0.23%	0
Company 33	0	0	0			0
Company 34	1,034,887	1,205,920	-171,034		0.07%	1,034,887
Company 35	9,078,930	504,894	8,574,036	3.58%		504,894
<b>Total</b>	<b>661,652,145</b>	<b>661,652,145</b>	<b>0</b>	<b>100.00%</b>	<b>100.00%</b>	<b>422,262,892</b>

As shown in Table 6.5-15, 17 of the 35 companies have the potential to generate more early credits than they could use up in the three-year period allowed. The refinery concentration of early credits ranges from <1% to 35%. Consequently, there does not appear to be substantial credit market concentration so there should be significant potential for the 16 refiners that seek early credits to postpone future investments to find them. Additionally, intra-company trading accounts for approximately two thirds of all early credit trades which equates to a high likelihood that the predicted transfers would actually occur.

**Table 6.5-16. Standard Credit Trading by Company**

<b>Company</b>	<b>Generation (Per Year)</b>	<b>Need (Per Year)</b>	<b>Net Standard Credits/Yr</b>	<b>% of Credit Supply</b>	<b>% of Credit Need</b>	<b>Credits Used Internally</b>
Company 1	7,399,928	0	7,399,928	17.27%		0
Company 2	7,049,962	23,352,267	-16,302,306		38.04%	7,049,962
Company 3	284,168	1,295,626	-1,011,458		2.36%	284,168
Company 4	720,022	5,009,084	-4,289,062		10.01%	720,022
Company 5	7,141,365	471,475	6,669,891	15.57%		471,475
Company 6	13,265,539	5,878,620	7,386,920	17.24%		5,878,620
Company 7	205,489	568,094	-362,605		0.85%	205,489
Company 8	8,313,793	8,298,569	15,224	0.04%		8,298,569
Company 9	1,243,281	1,542,508	-299,226		0.70%	1,243,281
Company 10	0	2,807,751	-2,807,751		6.55%	0
Company 11	3,273,055	3,795,859	-522,804		1.22%	3,273,055
Company 12	7,859,848	3,319,185	4,540,663	10.60%		3,319,185
Company 13	7,478,875	0	7,478,875	17.45%		0
Company 14	0	2,662,637	-2,662,637		6.21%	0
Company 15	446,425	306,231	140,194	0.33%		306,231
Company 16	2,542,138	3,704,126	-1,161,988		2.71%	2,542,138
Company 17	0	595,464	-595,464		1.39%	0
Company 18	0	2,660,631	-2,660,631		6.21%	0
Company 19	8,056,730	5,713,982	2,342,747	5.47%		5,713,982
Company 20	1,988,254	6,809,039	-4,820,785		11.25%	1,988,254
Company 21	8,445,411	3,685,330	4,760,080	11.11%		3,685,330
Company 22	0	865,360	-865,360		2.02%	0
Company 23	326,669	0	326,669	0.76%		0
Company 24	0	303,492	-303,492		0.71%	0
Company 25	0	1,003,080	-1,003,080		2.34%	0
Company 26	68,855	0	68,855	0.16%		0
Company 27	0	581,573	-581,573		1.36%	0
Company 28	0	327,597	-327,597		0.76%	0
Company 29	0	1,529,836	-1,529,836		3.57%	0
Company 30	643,791	0	643,791	1.50%		0
Company 31	272,972	0	272,972	0.64%		0
Company 32	0	178,994	-178,994		0.42%	0
Company 33	804,773	0	804,773	1.88%		0
Company 34	0	398,211	-398,211		0.93%	0
Company 35	0	166,723	-166,723		0.39%	0
<b>Total</b>	<b>87,831,343</b>	<b>87,831,343</b>	<b>0</b>	<b>100.00%</b>	<b>100.00%</b>	<b>44,979,761</b>

As shown in Table 6.5-16, 14 of the 35 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 17%. Consequently, there does not appear to be substantial credit market concentration so there should be significant potential for the 21 refiners that need standard credits to ensure compliance to find them. Additionally, intra-company trading accounts for approximately one half of all standard credit trades which equates to a good likelihood that the predicted transfers would actually occur.

#### 6.5.6.4 Credit Value

Credits generated under the proposed ABT program would have an associated monetary value to the refining industry. This value (price) would be based on the cost to generate the credits (selling price) and the cost avoided from not having to invest in benzene control

technologies (buying price). Although EPA is not proposing to control the price of benzene credits, we can estimate that the cost of a credit based on our refinery cost model. Based on individual refinery compliance costs, we estimate the price of a credit to be around \$60 per barrel of benzene reduced. This value is between the highest cost of compliance or the last refinery to come in (\$59.40/bbl Bz) and next refinery to come in using BenSat (\$61.39/bbl Bz). A further discussion of how refinery compliance costs were calculated is found in Chapter 9.

## 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 proposed 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. Summary of the Average and Maximum Octane Number Impacts for Benzene Control Technologies Under the Proposed Benzene Control Program ((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 Proposed 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 will assess 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, which is 115 octane numbers, 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. The increasing renewable requirement in EPAct provides a synergistic match with the octane needs of the proposed 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 proposed 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 EPA's Act makes it a likely candidate for an octane replacement for a benzene standard. If all of EPA's Act'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 proposed benzene standard. The phasing-in, under the ABT program, of the benzene standard and its associated octane loss would coincide with the period that EPA's renewable requirement phases in.

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 proposed benzene control program.

## **6.7 Will the Proposed 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 proposed 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 proposed standard while other refiners would meet the proposed 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 expect today's proposed action 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 proposed 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 today's rule.

We are aware of no other gasoline property changes that might be of potential concern with reduced benzene content gasoline. Gasoline with very low benzene content is already in use.

## **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 proposed fuel 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 today's proposed 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, estimates of the number of people currently employed in these job categories are not available. 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 proposed fuel 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 2012 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<sup>23</sup> 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 today's proposed standard are light naphtha splitters (LNS) for routing benzene pre-cursors around the reformer unit, benzene saturation units, and benzene extraction units.<sup>E</sup> 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 units were expected to be new installations, while work on benzene extraction and LNS units was split between new and revamped units. Estimated resource needs for these projects are summarized in Table 6.8-1.

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<sup>E</sup> These technologies are discussed in detail in Section 6.2.2.7 of this RIA.

**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
<b>Job-hours per piece of equipment</b>					
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.<sup>F</sup> Those results provide inputs for this 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.<sup>G</sup> For purposes of comparison, a worst-case analysis was also run assuming 2011 (on-time) startup for all projects.

<sup>F</sup> Equipment choice and project timing is covered in more detail in discussions of the averaging, banking, and trading analyses done for this proposal (see Section 6.2.2.9 of this RIA).

<sup>G</sup> *Ibid.*

**Table 6.8-2. Number and timing of startup for benzene reduction projects assuming early compliance.**

Start-up date		2009 (September)	2010	2011
LNS:	New	0	14	14
	Revamp	13	13	0
Saturation:	New	0	0	11
Extraction:	New	0	0	11
	Revamp	6	6	0

### 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 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.

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.<sup>H</sup> The distribution of resources is summarized in Tables 6.8-3 and 6.8-4.

In the case of early compliance projects to be completed in 2009 and 2010, durations per project and total durations of phases starting a given calendar year for front-end design and detailed engineering were compressed to half. This seemed reasonable, given that these projects are generally revamps or new installations of LNS units, which do not require extensive design

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<sup>H</sup> 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.

work.

**Table 6.8-3. Duration of project phases.**

	<b>Front-end design (2009-10)</b>	<b>Detailed engineering (2009-10)</b>	<b>Front-end design (2011)</b>	<b>Detailed engineering (2011)</b>	<b>Construction (All years)</b>
Duration per project	3 months	5 months	6 months	11 months	14 months
Total duration for projects starting up in a given calendar year	7 months	11 months	15 months	20 months	23 months

**Table 6.8-4. Distribution of personnel requirements throughout project.**

	<b>Fraction of total hours expended by month for completion years shown</b>				
<b>Month</b>	<b>Front-end design (2009-10)</b>	<b>Detailed engineering (2009-10)</b>	<b>Front-end design (2011)</b>	<b>Detailed engineering (2011)</b>	<b>Construction (All years)</b>
1	0.100	0.030	0.050	0.020	0.030
2	0.100	0.030	0.050	0.030	0.030
3	0.200	0.050	0.050	0.040	0.030
4	0.200	0.100	0.078	0.040	0.040
5	0.200	0.200	0.078	0.040	0.040
6	0.100	0.200	0.078	0.050	0.040
7	0.100	0.200	0.078	0.050	0.040
8		0.100	0.078	0.060	0.050
9		0.050	0.078	0.065	0.050
10		0.030	0.078	0.075	0.055
11		0.030	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 2007-2011 for each job category both before and after the proposed fuel benzene program for both the early compliance and the 2011-only cases. 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 programs	Max. number of workers	758 (Mar '03)	2,720 (Mar '04)	17,646 (November '04)
	Current workforce*	40%	28%	11%
After proposed fuel benzene program (early compliance)	Max. number of workers	816 (Sept '07)	2,720 (Mar '04)	17,646 (November '04)
	Current workforce*	43%	28%	11%
After proposed fuel benzene program (on-time)	Max. number of workers	761 (Dec '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.

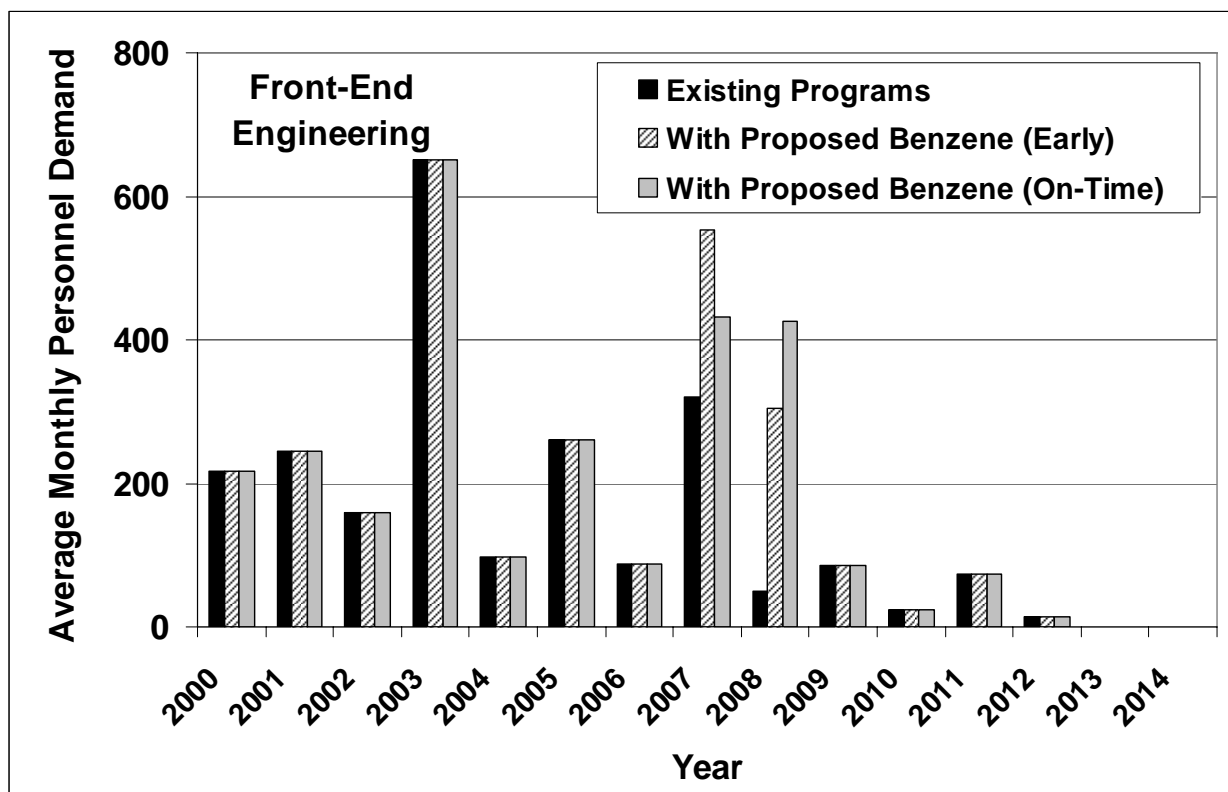
Shown in Table 6.8-5, the proposed fuel benzene program has a projected maximum monthly requirement for front end design personnel similar to the level seen in 2003 for previous programs, depending on what compliance timeline refiners follow. Peaks in the other two job categories' monthly personnel demand projected for this program remain below levels previously seen for prior programs. In either case analyzed here, 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

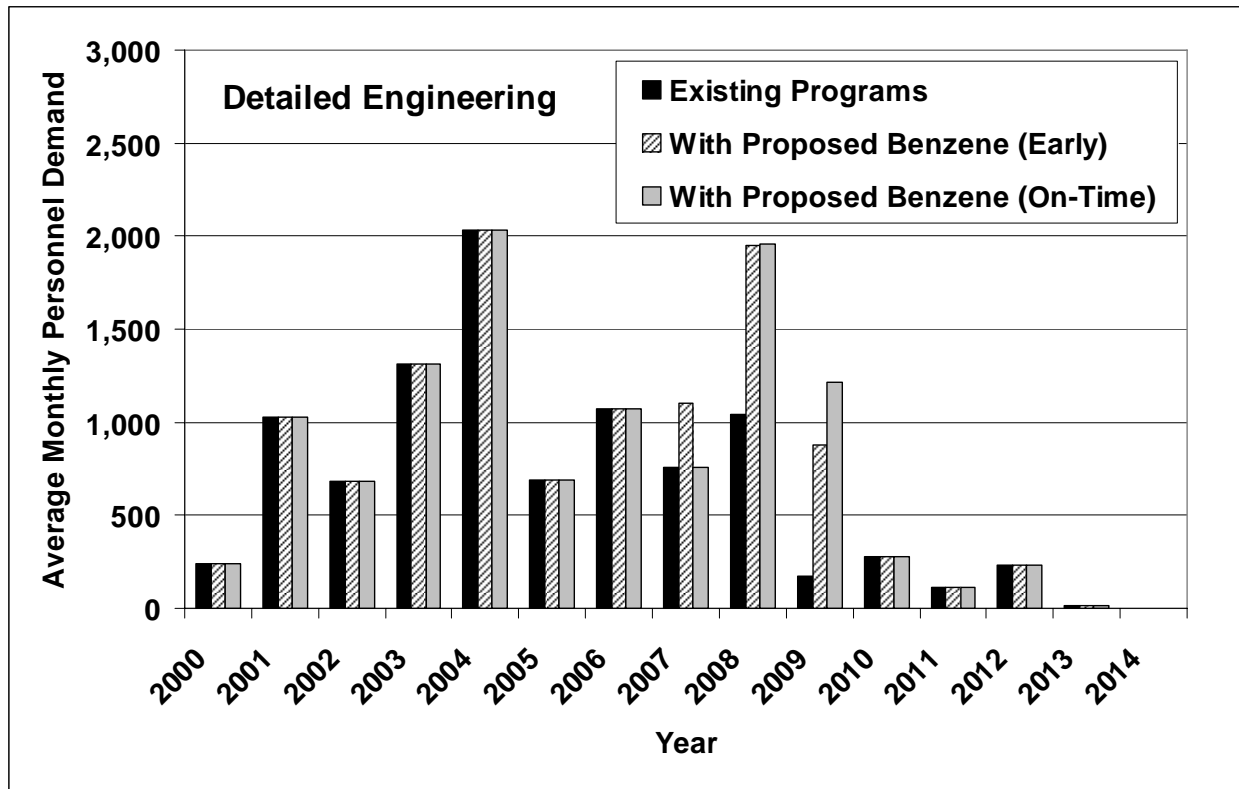
the proposed program, based on annual workload, generally occur after significant peaks related to other programs have passed. The later compliance case spreads out the peak demand for front-end engineering in 2007-08, but sharpens the peaks for the other two categories in the 2008-10 timeframe. As expected, early compliance moves some projects forward, reducing personnel demand in 2009-10.

We feel this analysis is conservative, since it does not account for banking of early credits allowed by the program as proposed. Banking could delay full compliance by some refiners for up to three years beyond 2011, spreading personnel demand and reducing peaks even further than described here. Based on these analyses, we believe that the E&C industry is capable of supplying the refining industry with the personnel necessary to comply with the proposed fuel benzene program.

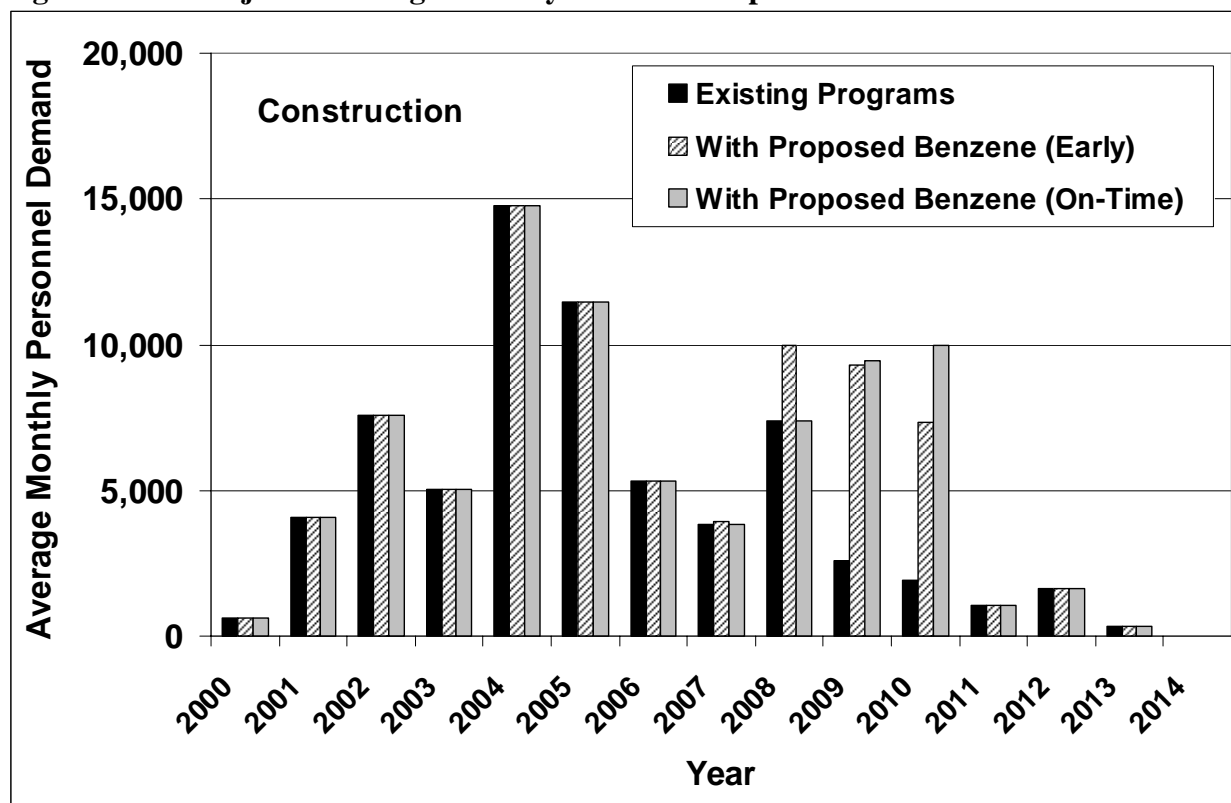
**Figure 6.8-1. Projected average monthly front-end engineering personnel demand trends 2000-2014.**



**Figure 6.8-2. Projected average monthly detailed engineering personnel demand trends 2000-2014.**



**Figure 6.8-3. Projected average monthly construction personnel demand trends 2000-2014.**



## 6.9 Time Needed to Comply with a Benzene Standard

Our proposal to begin the program on January 1, 2011 will give refiners about 4 years after the rulemaking is signed into law to comply with the program's requirements. Four years 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.

The 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 changes 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 reformat stream of a neighboring refinery. The revamp could occur in one or more places, including the reformat 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 proposed 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 proposed 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 stagger the start year of this benzene fuel standard 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 Proposed Fuel Standard Be More Protective Than Current Programs in All Areas?**

Three fuels programs (RFG, Anti-dumping and MSAT1) currently contain direct controls on the toxics performance of gasoline.<sup>1</sup> The RFG program, promulgated in 1994, contains a fuel benzene standard which requires a refinery's or importer's RFG to average no greater than 0.95

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<sup>1</sup> Other gasoline fuel controls, such as sulfur, RVP or VOC performance standards, indirectly control toxics performance by reducing overall emissions of VOCs.

vol% benzene annually, with a per-gallon cap of 1.3 vol%.<sup>24, J</sup> 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<sup>25</sup>) compared to 1990 baseline gasoline. The Anti-dumping<sup>26</sup> 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. 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<sup>27</sup>, promulgated in 2001, was overlaid onto the RFG and Anti-dumping programs. 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.

Today's proposed 0.62 vol% benzene content standard would 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 today's proposed standard compares to performance under the relevant pre-existing standards.

### **6.10.1 Modeling Approach**

Two levels of analysis were carried out to address the question posed at the top of this section. The first was an examination of the relationship between toxics performance of individual gasoline refiners (or other producers) under the proposed program and their historical or required performance. This analysis was quantitative where changes in fuel parameters could be known or 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 today's proposed standards, accounting for the complexities of oxygenate changes as well as sulfur reductions, proposed 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 2003 exhaust toxics performance for CG and 2003 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 today's proposed standards and the gasoline

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<sup>J</sup> Refiners also have the option of meeting a per gallon limit of 1.0 vol%.

sulfur standard phased in this year (30 ppm average, 80 ppm max). The results indicate that all refineries maintained or reduced their emissions of toxics over 2003. We expect large reductions in sulfur for almost all refineries under the gasoline sulfur program, and large reductions in CG benzene levels along with modest reductions in RFG benzene levels. 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. Furthermore, 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 to 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 factors (mg/mi) for air toxics under a number of existing and proposed 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 up according to PADDs (defined in 40 CFR 80.41), using PADD-aggregate fuel parameters. In looking ahead to the phase-in period of today's proposed 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 under the Energy Policy Act of 2005 (EPAct) and the use of MTBE and other ethers continues to decline. Since the scope of this analysis includes comparison of emissions under today's proposed program to baseline emissions as adjusted by EPAct, we included estimated impacts of EPAct in the future year scenarios even though Renewable Fuels Program has not been promulgated yet. It should be noted that since the Renewable Fuels Program is still being developed, we could not include its impacts in the inventories developed for this rule. A more detailed understanding of how EPAct will affect oxygenate blending patterns is needed before stable, accurate county level emission inventories which include impacts of this program can be developed.

#### **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.<sup>28</sup> However, as provided for in the Act, this action becomes unnecessary and can be avoided if today's 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 proposed standard to the

current MSAT1 program, we also compared it to standards as they would change under EPAct.

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 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 proposed program, under the proposed gasoline benzene standard only, and under both the proposed gasoline and vehicle standards. An additional case was run for year 2025 including effects of both proposed 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 proposed effective date of this standard. The future year 2025 was chosen based on a significant phase-in of vehicles (> 80% of the fleet) produced under the proposed vehicle standard. Fuel parameter data for the 2011 and 2025 cases were generated by taking the 2001-2002 baseline data and making adjustments to account for changes expected due to regulatory programs and other trends.

**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
Without Proposed Standards, 2011	2001-02 plus adjustments for: - Tier 2 sulfur - RFS - MTBE & other ethers phased out	2001-02 plus adjustments for: - Tier 2 sulfur - RFS - MTBE & other ethers phased out	2011
Proposed 2011 (Fuel standard only)	2001-02 plus adjustments for: - Tier 2 sulfur - RFS - MTBE & other ethers phased out - 0.62% benzene std - <b>no 20°F vehicle HC std</b>	2001-02 plus adjustments for: - Tier 2 sulfur - RFS - MTBE & other ethers phased out - 0.62% benzene std - <b>no 20°F vehicle HC std</b>	2011
Proposed 2011 (Fuel + vehicle standards)	2001-02 plus adjustments for: - Tier 2 sulfur - RFS - MTBE & other ethers phased out - 0.62% benzene std - <b>20°F vehicle HC std</b>	2001-02 plus adjustments for: - Tier 2 sulfur - RFS - MTBE & other ethers phased out - 0.62% benzene std - <b>20°F vehicle HC std</b>	2011
Proposed 2025 (Fuel + vehicle standards)	2001-02 plus adjustments for: - Tier 2 sulfur - RFS - MTBE & other ethers phased out - 0.62% benzene std - <b>20°F vehicle HC std</b>	2001-02 plus adjustments for: - Tier 2 sulfur - RFS - MTBE & other ethers phased out - 0.62% benzene std - <b>20°F vehicle HC std</b>	2025

### 6.10.1.2 Adjustment of Fuel Parameters for Future Years

In order to carry out the analysis as realistically as possible, adjustments had to be applied to fuel parameters when running future year cases. Starting from 2001-2002 baseline gasoline data, the changes accounted for in this analysis were sulfur reduction under the Tier 2 gasoline program, increased ethanol blending under a Renewable Fuels Standard (RFS) laid out by EPAct, continued phase-out of MTBE and other ethers by states and refiners, and reduction of gasoline benzene levels as proposed today. 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 Tier 2 program, as of January 1, 2006 all gasoline 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 Tier 2 sulfur levels.

### *Increased Blending of Ethanol*

Under the oxygenate mandate laid out by EPAct, renewable fuel blending into gasoline use must increase to 7.5 billion gallons of ethanol (or its equivalent) by 2012.<sup>29</sup> By the time the gasoline benzene standard proposed here would become effecting in 2011, this requirement will be 7.4 billion gallons, about twice the current rate of ethanol blending. Determining where this ethanol is most likely to be used and its expected effect on other properties of gasoline required several steps of analysis and adjustment.

The expected patterns of ethanol blending in future years were determined as follows. State-by-state ethanol usage data taken from the Federal Highway Administration (FHWA) statistics for 2003 (totaling 2.7 billion gallons) was scaled up to 3.5 billion gallons to represent 2004 gasoline ethanol usage.<sup>30</sup> Ethanol usage in 2004 is tracked by the Energy Information Administration (EIA) in total and specifically for several segments of the gasoline pool resulting from various state and federal regulations.<sup>31</sup> These figures are summarized in Table 6.10-2. Finally, this 2004 baseline data for ethanol and gasoline volumes was scaled up to represent 7.5 billion gallons of ethanol being blended into an appropriate volume of gasoline for 2012. Overall gasoline requirements for 2012 were projected using data from EIA's Annual Energy Outlook 2006.<sup>32</sup> Since this process required allocation of significantly more ethanol than would have been used under 'business as usual' growth, assumptions about geographic blending patterns were made based on a report issued by EIA in July 2005.<sup>33</sup> This document predicts that the most aggressive ethanol blending will occur in the midwest and mountain regions of the country, while little additional ethanol will be used in the northeast and southwest.

**Table 6.10-2. Ethanol Use in Gasoline in 2004**

Gasoline Pool	Volume (MM gal)
California reformulated	635
Connecticut reformulated	152
New York reformulated	301
All other reformulated	393
<b>Total reformulated</b>	<b>1,481</b>
Minnesota conventional	268
California conventional for export within U.S.	212
All other conventional	1,540
<b>Total conventional</b>	<b>2,020</b>
<b>Total all U.S. gasoline</b>	<b>3,501</b>

The results of this future blending allocation were aggregated into PADD-by-PADD ethanol usage for 2012, which was translated into volume percent ethanol blended. Ethanol volume percent blended in 2025 was equal to the 2012 figures, since EPAct stipulates that blending in 2013 and later be at least proportional to the ratio occurring in 2012. For the 2011 case, the blending percentages were simply scaled back according to the overall ethanol usage schedule given in EPAct. Summer and winter blending ratios were assumed to be equal. These

figures are given in Table 6.10-3.

**Table 6.10-3. Ethanol Blending Figures Used in Analyses**

PADD	2004		2011		2025	
	RFG	CG	RFG	CG	RFG	CG
I	2.50%	0.65%	2.49%	0.70%	2.52%	0.71%
II	7.36%	3.73%	9.10%	9.27%	9.23%	9.39%
III	0.07%	0.57%	0.07%	1.22%	0.07%	1.24%
IV	N/A	2.00%	N/A	9.87%	N/A	10.00%
V	5.68%	3.31%	5.68%	5.37%	5.75%	5.45%

With these large changes in ethanol blending, changes in other fuel parameters are expected. These adjustments were made for this analysis based on impacts taken from modeling work done for EPA by Abt Associates, Inc., under sub-contract from ICF, Inc. The analyses done by Abt used a combination of spreadsheet analyses and a linear programming regional refinery model to project broad impacts on gasoline supply, costs, and characteristics resulting from various statutory and regulatory scenarios.

The adjustment to gasoline quality was made in two steps. The first was an adjustment from reference gasoline data to a case that represented MTBE phase-out, oxygenate mandate removal, and increased ethanol blending. This is a situation like what we expect to see occurring by the end of the decade, but with less aggressive renewable fuel requirements.<sup>K</sup> Since more ethanol blending will be required by 2011 than represented in this case, a second adjustment was determined using the difference between a future reference case and a future oxygenate blending case, specifically taking effects for PADD II. The fuel parameter adjustment factors determined in the second step were derived from changes in PADD II gasoline because little if any MTBE is in use there, and ethanol blending is favored economically regardless of an oxygen mandate. Our intention was to derive adjustments to fuel parameters based solely on addition of more ethanol, minimizing sensitivity to changes related to MTBE or oxygen mandate that could be applied to all PADDs.

In both steps the fuel parameters adjusted were aromatics, olefins, E200 and E300 (ethanol, sulfur, and benzene content were already being changed as a direct result of regulatory actions). The impact on each of these parameters was calculated separately for each PADD by CG and RFG. For the second adjustment step, the changes in fuel properties were scaled linearly by the additional ethanol required beyond what was added in the first step, in order to reach the projected target ethanol blending given in Table 6.10-3. Shown in Table 6.10-4 are the adjustment factors as applied in the first step, while Table 6.10-5 gives the adjustment factors used per volume percent of additional ethanol required, to make the second adjustment.

**Table 6.10-4. Fuel Parameter Adjustment Factors for RFS Adjustment As Applied (Step**

<sup>K</sup> This modeling work was carried out before the final version of EPAct was published, therefore some of the details of the renewable fuel requirements and other stipulations were not known.

**One)**

PADD	RFG				CG			
	Aromatics*	Olefins*	E200**	E300**	Aromatics*	Olefins*	E200**	E300**
I	-5.03%	0.00%	-11.90	-0.20	-0.57%	6.75%	2.00	-0.58
II	13.89%	0.00%	-4.00	-2.23	-2.43%	-13.31%	1.13	0.63
III	-11.59%	-25.12%	-9.03	2.22	22.47%	-19.16%	-5.38	-2.10
IV & V	-	-	-	-	-2.55%	-1.52%	-0.37	0.49

\*Multiplicative change relative to the baseline value

\*\*Additive change relative to the baseline value

**Table 6.10-5. Fuel Parameter Adjustment Factors for Additional Ethanol Blending per vol% Additional Ethanol (Step Two)**

PADD	RFG				CG			
	Aromatics*	Olefins*	E200 <sup>a</sup>	E300 <sup>a</sup>	Aromatics*	Olefins*	E200*	E300*
All	-1.21	0.00	-0.70	0.70	-0.56	-0.69	0.87	0.00

\*This figure is multiplied by the additional ethanol required beyond step one to meet RFS requirements, then added to the value from step one.

### *Phase-out of Ether Blending*

Use of MTBE and other ethers has recently been outlawed by several states, including California, New York, and Connecticut. Several refiners we have spoken with are making plans to phase out production and blending of the material 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, most oxygenate use is expected to shift to ethanol by the end of the decade. Given these facts, ether content was assumed to be zero in gasoline parameter data 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 today's proposed gasoline benzene standard. Modeling done to evaluate the technical feasibility and cost of the program resulted in projected benzene levels for each PADD. These figures are listed in Table 6.5-12 in Section 6.5.4 above, and were used as the final benzene levels as summarized in Table 6.10-6a below. Note that projected benzene levels resulting from today's proposed standard are the same for both RFG and CG in each PADD because we are proposing a nationwide credit trading program covering both fuel types. Analysis of trends in fuel property data suggested that this reduction of benzene content is expected to be accompanied by a smaller reduction in total aromatics content, about 0.77% aromatics for each 1% reduction in benzene.<sup>34</sup> In other words, the non-benzene aromatics portion of gasoline increases slightly when benzene is decreased (by about 0.23% for each 1% benzene). 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. 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 the RFG and Anti-dumping regulatory programs, whereby refiners report gasoline batch volumes and quality information to EPA. However, following production, gasoline is 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 it was 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 2003 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 2003 report, available from the EIA website. 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. Where imports were separated between these three categories, they were summed to make one volume for imported gasoline.

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. Although 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 this is used to estimate the properties for gasoline consumed in future years, it is assumed that the ratios between flows are the same as in the 2003 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 6.10-6 shows a summary of the input figures for gasoline volumes and benzene content in summer 2003 and Table 6.10-6 shows the values after the modeled reduction to meet the proposed 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 6.10-7a shows the values after the modeled reduction to meet the proposed benzene standard. The difference in benzene levels between Tables 6.10-6a and 6.10-7a are used in Section 2.2.1.1 of the RIA for estimating fuel quality changes for the air quality analysis. 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 disposition 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 6.10-8 shows the PADD transfer volumes taken from the EIA data and used in our calculations. Figure 6.10-1 gives a conceptual view of gasoline flows between PADDs with production and consumption benzene levels for summer 2003; the relative size of the arrows indicates the relative volumes of the transfers.

**Table 6.10-6. Inputs to In-Use Analysis based on Summer 2003 Gasoline Benzene.**

PADD	Production + Imports					
	Total		CG		RFG	
	vol (MMgal)	bz v%	vol (MMgal)	bz v%	vol (MMgal)	bz v%
I	23,802	0.70	9,873	0.84	13,929	0.60
II	27,558	1.28	22,126	1.39	5,432	0.82
III	55,027	0.87	45,162	0.94	9,865	0.56
IV	4,381	1.54	4,381	1.54	0	0.00
V (ex/CA)	4,620	1.79	4,620	1.79	0	0.00
CA	<u>18,172</u>	<u>0.62</u>	<u>1,803</u>	<u>0.63</u>	<u>16,369</u>	<u>0.62</u>
ALL	133,559	0.94	87,965	1.11	45,594	0.62

\*This volume of gasoline is likely for the Phoenix area, which has a state fuels program with requirements similar to federal RFG.

**Table 6.10-6a. Estimated Benzene Levels after Benzene Control  
(vol% in 2003) Production + Imports**

PADD	CG	RFG
I	0.51	0.51

II	0.73	0.73
III	0.55	0.55
IV	0.92	0.92
V (ex/CA)	1.04	1.04
ALL	0.62	0.62

**Table 6.10-7. Outputs to In-Use Analysis based on Summer 2003 Gasoline Benzene.**

PADD	Consumption					
	Total		CG		RFG	
	vol (MMgal)	bz v%	vol (MMgal)	bz v%	vol (MMgal)	bz v%
I	48,000	0.79	29,488	0.91	18,512	0.59
II	35,913	1.19	30,251	1.26	5,661	0.80
III	21,193	0.86	16,445	0.95	4,748	0.57
IV	4,484	1.47	4,484	1.47	0	0.00
V (ex/CA)	8,946	1.27	8,946	1.27	0	0.00
CA	<u>15,023</u>	<u>0.62</u>	<u>0</u>	<u>0.63</u>	<u>15,023</u>	<u>0.62</u>
ALL	133,559	0.94	89,614	1.10	43,945	0.62

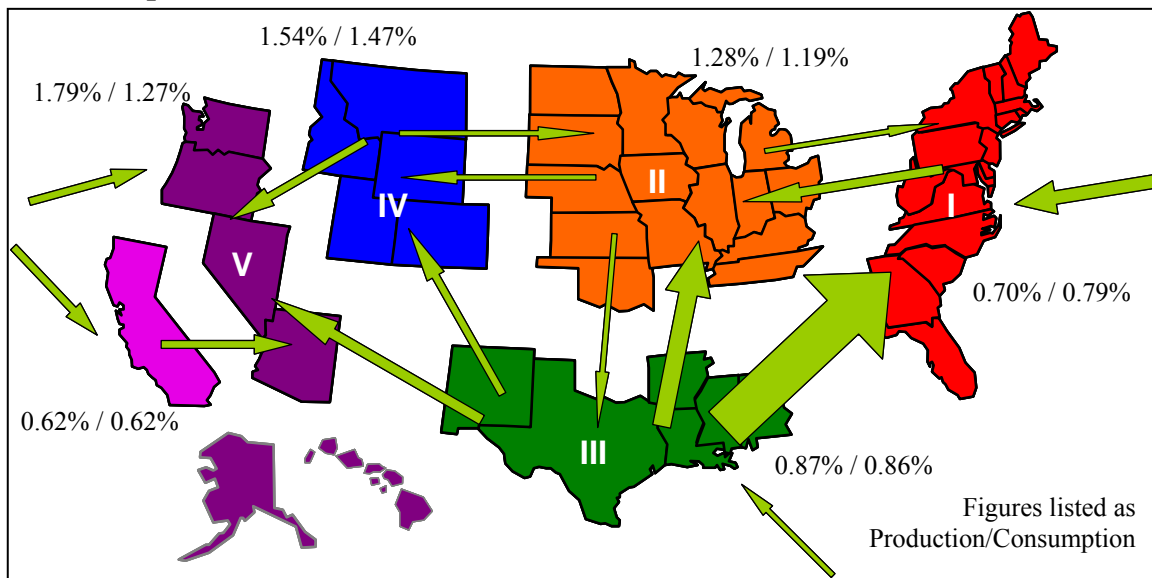
**Table 6.10-7a. Estimated Benzene Levels after Benzene Control  
(vol% in 2003) Consumption**

PADD	CG	RFG
I	0.55	0.54
II	0.68	0.71
III	0.54	0.55
IV	0.93	0.62
V (ex/CA)	0.85	0.60
ALL	0.62	0.62

**Table 6.10-8. Gasoline flows between PADDs.**

		Destination									
		CG					RFG				
		I	II	III	IV	V	I	II	III	IV	V
Source	CG	I	3,219	0	0	0	0	0	0	0	0
		II	300	258	299	0	0	0	0	0	0
		III	22,501	5,443	426	605	0	0	0	0	0
		IV	0	320	0	301	0	0	0	0	0
		V	33	0	0	0	0	0	0	0	0
		CA	0	0	0	1,803	0	0	0	0	0
	RFG	I	0	0	0	0	0	0	0	0	0
		II	0	0	0	0	0	219	0	0	0
		III	0	0	0	0	4,583	449	0	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	1,346	0	0	0	0	0

**Figure 6.10-1.**  
**Conceptual view of inter-PADD transfers and benzene levels, summer 2003.**



These results illustrate a few predominant trends. In-use levels of benzene in gasoline in PADDs I, II, and IV are generally depressed by relatively low-benzene gasoline transferred from PADD III. The same occurs in PADD V due to transfers from California.

#### 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 6.10-9, 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.

**Table 6.10-9. 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.<sup>L</sup>

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 volume percentage (vol%) the oxygenate was blended to as consumed in the vehicle. 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.

<sup>L</sup> Due to the requirements of the Tier 2 gasoline sulfur program, all cases other than the baselines were assumed to have average sulfur content of 30 ppm with 80 ppm maximum.

### *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 proposed today 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 produced in each season based on batch report data. These figures are presented in Table 6.10-10.

**Table 6.10-10. Estimated annual average total toxics performance of light duty vehicles in mg/mi under current and proposed programs.\***

Regulatory Scenario	Fleet Year	RFG by PADD			CG by PADD				
		I	II	III	I	II	III	IV	V
MSAT1 Baseline** (1998-2000)	2002	108	124	89	104	135	96	137	152
EPAct Baseline** (RFG: 2001-2002)	2002	103	121	85	104	135	96	137	152
<b>EPAct Baseline, 2011***</b>	<b>2011</b>	<b>67</b>	<b>79</b>	<b>51</b>	<b>62</b>	<b>79</b>	<b>54</b>	<b>77</b>	<b>96</b>
Proposed program, 2011*** (Fuel standard only)	2011	66	78	50	59	74	51	71	85
Proposed program, 2011*** (Fuel + vehicle standards)	2011	63	76	47	55	72	47	67	81
Proposed program, 2025*** (Fuel + vehicle standards)	2025	39	46	30	35	44	31	42	50

\* 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 controls proposed today, 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 the renewable fuels standard and the phase-out of ether blending.

## 6.10.2 Interpretation of Results

The first row in Table 6.10-10 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 proposed implementation time of the fuel standard, such as gasoline sulfur reductions and oxygenate changes, we decided to model a 'future baseline' to allow comparison with the proposed standard at the time it would become effective in 2011. As a result, the third row shows the projected mg/mi emissions in 2011 under the EPAct baseline adjustments, but without today's proposed 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 into the national fleet.

An important comparison is made between rows three and four, where the estimated toxics emissions under the proposed fuel standard only are compared to the projected emissions without the proposed standard. We also evaluated the effects of the vehicle standard being

proposed today 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 proposed fuel benzene standard applied in 2011. This is not surprising, since the level of the standard, 0.62 vol%, is near the current (and projected future) RFG benzene content. The effects of the proposed fuel program on CG are larger, as expected given the higher levels of benzene in that gasoline pool. The proposed 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 proposed fuel standards 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 today's proposed program than projected to occur without today's proposal, and much lower than would be required by adjusting RFG baselines to 2001-2002 averages. Therefore, we propose that, due to standards proposed today, 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 benzene standard proposed today 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 proposed benzene standard of 0.62 volume percent would fulfill several statutory and regulatory goals related to gasoline mobile source air toxics emissions. The proposed program would meet our commitment in the MSAT1 rulemaking to consider further MSAT control. It would 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 Feasibility for Lower RVP**

The following section details our assessment for the feasibility of lowering gasoline Reid Vapor Pressure (RVP)<sup>M</sup>. To assess the feasibility of complying with the 7.8 and 7.0 low RVP standards, it was important to understand the actual RVP levels that would result under these standards. The best way to do that is to study the current in-use RVP levels under current 7.8 and 7.0 RVP standards. We were able to determine the in-use RVP levels under current RVP control programs by evaluating survey data on gasoline quality available from the Alliance of Automobile Manufacturers (AAM). AAM surveys gasoline quality in certain U.S. cities. We averaged the RVP levels of the cities controlled by the same RVP control standard for 9.0, 7.8, 7.0 and RFG areas. The in-use RVP levels for the various RVP controlled areas are summarized in Table 6.11-1.

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<sup>M</sup> RVP is the pressure that gasoline generates when measured at a standardized condition using an American Society of Testing Materials (ASTM) testing methodology. RVP is somewhat related to the true vapor pressure generated by gasoline but tends to be somewhat higher.

**Table 6.11-1. Actual RVP Levels Associated with Various RVP Standards**

<i>Nominal RVP Level</i>	<i>9.0 RVP Limit</i>	<i>7.8 RVP Limit</i>	<i>7.0 RVP Limit</i>	<i>RFG</i>
Actual RVP Level	8.8	7.6	6.85	6.85

### 6.11.1 Means for Reducing RVP

For this analysis, gasoline can be defined as being comprised of light and heavy hydrocarbons. Heavy hydrocarbons, which comprise the majority of the gasoline pool, have six or more carbon molecules (C6+) while light hydrocarbon compounds have a carbon count less than six. The light hydrocarbon components in gasoline are butanes (C4s) and pentanes (C5s)<sup>N</sup>. The gasoline produced by more complex refineries is comprised of ten or more different streams produced by refinery processes or streams imported into the refinery. Some of these streams contain significant levels of butanes and pentanes while others do not. A refiner's gasoline pool is the volume of various hydrocarbon streams or components that are added to a refiner's gasoline volume before shipment.

In gasoline, each hydrocarbon compound has its own pure vapor pressure. However, the compounds usually contribute a different or modified vapor pressure when blended into the gasoline pool due to its physical interaction with the other constituents in the pool. For ease of making blending RVP calculations, the modified vapor pressure of a single compound is called the blending RVP and we will be using blending RVP values in this analysis. The C6+ hydrocarbons in gasoline have relatively low blending RVP values ranging from 9 PSI to near zero. Butane and pentane hydrocarbons have much higher blending RVP's; isobutane's and normal butane's blending RVPs are 71 and 65, respectively, and isopentane's and normal pentane's blending RVPs are 17 and 20, respectively. For gasoline, a high blend RVP stream to the gasoline pool will only be minimally reduced by blending in or dilution with lower RVP blend stocks streams due to the physical nature of vapor pressure. Thus, a high blend RVP hydrocarbon stream to the gasoline pool can set the lowest obtainable pool RVP.

Since butanes and pentanes have high blending RVP's, refiners control the amount blended into their gasoline pool up to the RVP allowed by the applicable environmental or other in-use gasoline standards. In the summer low RVP season, refiners are probably not adding butane, but separating some of the butanes and blending back a portion to meet RVP requirements. To accomplish a current RVP goal of say 9.0, refiners utilize existing distillation columns such as light straight run naphtha splitters, reformate splitters, FCC debutanizers, stabilizers and other existing process distillation columns to remove butanes and pentanes<sup>O</sup>.

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<sup>N</sup> These molecules can have single and/or double bonds between their carbon molecules. For this cost analysis referral to butanes and pentanes means inclusion of both single and double carbon bond type molecules.

<sup>O</sup> Distillation columns are the process equipment used to separate light from heavier hydrocarbons through the process of vaporization and condensing. The addition and removal of heat to the column is what drives the separation process. Heat is added to the column through a heat exchanger called a reboiler while heat is removed

These existing distillation columns are limited in making significant reductions in pool RVP. This is because the gasoline supply streams from these units contain only a portion of the amount of butanes and pentanes which ends up into gasoline. After these existing methods and equipment for removing light hydrocarbons from the gasoline pool are fully utilized, further lowering RVP could require a refiner to add additional distillation column capacity to remove butanes and in some cases pentanes.

Further control of RVP can be realized by reducing butanes or pentanes in their FCC gasoline blendstock. To accomplish this task, refiners would likely have to add a distillation column called a debutanizer and perhaps another column called a depentanizer, to separate these light hydrocarbons from the rest of the FCC gasoline blendstock. Debutanizers distill or separate butanes and lighter hydrocarbons off the top of the distillation column while pentanes and heavier C6+ hydrocarbons are removed from the bottom. In depentanizers, pentanes and lighter hydrocarbons (the debutanized stream) are removed from the hydrocarbon feed and drawn off the top of the column while the heavier C6+ hydrocarbon are removed from the bottom. If a refiner has a FCC depentanizer the “debutanized” FCC gasoline flows from the debutanizer to the depentanizer as hydrocarbon feed were pentanes are then removed.

In the U.S., 103 of the total 115 refineries that produce gasoline have FCCUs. The FCCU converts gas oil and resid to gasoline, which is the heavy and light hydrocarbons as defined above, and even lighter hydrocarbons, by reacting or cracking the gas oil over fluidized, heated catalyst. The gasoline volume produced by the FCCU makes up to 35-50 volume percent of refiner’s gasoline pool and is thus the largest contributor to the gasoline pool.<sup>35</sup> FCCU gasoline contains butanes, pentanes, and C6+ hydrocarbons with the amount of these hydrocarbons being set by each refiner’s FCC conversion rate and the FCCU’s gasoline distillation capability, as most of the butanes and lighter hydrocarbons are removed off of the top of the debutanizer column.<sup>P</sup> Typical ranges for butanes are 0 to 10 percent and pentanes 5 to 17 volume percent of total FCC debutanized gasoline yield, as determined by the refinery modeling analysis described below. The higher percentage of butane is likely for a 9.0 RVP gasoline, while lower percentages are consistent with lower RVP gasoline. Each refiner’s FCC conversion is set by many process parameters, including the type of FCC unit, the FCC feedstock type, feed throughput, catalyst type, unit constraints, unit bottlenecks, catalyst condition and operational mode. Higher amounts of butanes and pentanes are generated as the FCCU conversion rate is increased with a typical conversion rate being 77 percent.

It is important to determine the gasoline RVP level at which refiners will begin to remove pentanes after the butanes have all been removed. Because butanes are more volatile than pentanes, initial reductions in RVP are achieved by removal of butanes and at some point achieving further reductions in RVP requires removal of pentanes from the pool. Why this is important is because, as described below, we estimate that reducing the gasoline pool RVP by

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from the top of the column with an exchanger called a condenser. The lighter hydrocarbons are vaporized and travel up the column where they are removed as a product while the heavier hydrocarbons move down the column are drawn off the bottom. In a distillation column, there are many distillation trays which provide the mechanism for mixing and separation of the hydrocarbons.

<sup>P</sup> FCC conversion can be defined as the amount of FCC charge that is cracked into gasoline and lighter hydrocarbons.

one RVP number requires a reduction of the equivalent of 1.5 volume percent of the gasoline pool in butane, however, attaining the same RVP reduction requires a reduction of the equivalent of 7.5 percent of the gasoline pool in pentanes. This analysis applies to nationwide volatility control programs, such as nationwide RFG, since there is no higher RVP gasoline into which removed pentanes could be shifted to preserve the volume of gasoline.<sup>Q</sup>

We used several different means for estimating the point where further RVP decreases requires pentanes to be removed. We spoke to several distillation vendors who have helped refiners make process changes to lower gasoline pool RVP to meet low RVP standards that were instituted in the 1990's and year 2000. One vendor stated that most refiners currently producing a reformulated federal or low RVP (7.0, 7.2 or lower) gasoline today made modifications to their FCC debutanizers to meet the RVP specification. The modifications were achieved either through revamping the existing debutanizer by installing new high capacity trays and heat exchangers, or through the addition of a new debutanizer column. According to this vendor, approximately 40% of refiners revamped their FCC debutanizer while 60% installed a new debutanizer column. The vendor stated that a FCC gasoline RVP of about 6.7 to 7.0 is achieved by most refiners when butanes are removed to less than 0.5 volume percent of the FCC gasoline pool. He further stated that these low levels of butanes could typically be attained through FCC debutanizer modifications. Obtaining a FCC gasoline RVP of 7.0 or below would probably allow most refiners to produce a pool RVP lower than 7.0 or of a similar level. The distillation vendor also stated that half of the refiners that made debutanizer modifications also installed new FCC depentanizers. Prior to lower RVP requirements, refiners typically did not have depentanizers for depentanizing their FCC gasoline blendstock. The vendor was not sure as to why the depentanizers were added but thought that refiners only required a FCC debutanizer modification to meet lower RVP specification. The vendor also stated that current refiners producing a 7.8 to 9.0 RVP pool cap may have original unmodified debutanizers and typically do not have FCC depentanizers. The original unmodified debutanizers were designed to remove butanes down to a 1.5 to 2.0 volume percent level in FCC gasoline.

We informally surveyed several refiners who make low RVP gasoline or RFG about how they reduced the RVP of their gasoline pool. Most of the refiners reported that they had to spend capital for FCC debutanizer modifications and that these modifications allowed production of a 7.0 RVP gasoline. Most refiners reported that butanes were removed to less than a 1.0% level with a resulting FCC gasoline RVP at 7.0 or below. One refiner operating their FCCU at a low conversion rate actually made a 6.4 RVP FCC gasoline. Only, one out of five refiners reported that during the summertime production season that they had to remove some pentanes to meet the 7.0 RVP specification for their pool. During the summer low RVP gasoline season, this refiner intermittently had to remove about 20 percent of the refinery's pentanes from the gasoline pool. The other refiners reported no need to remove pentanes to meet a 7.0 RVP spec. The refiners reported that the new depentanizers the distillation vendor referred to may have been installed for several reasons; to allow segregation of the heavier gasoline C6+ components for sulfur sweetening, to remove pentanes to lower the pool RVP or to segregate the pentanes so that

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<sup>Q</sup> Based on conversations with refiners which produce ethanol-blended RFG, they maximize their gasoline production through their blending practices. When they need to remove pentanes from the RFG pool to make room for ethanol, they put the pentanes in the conventional gasoline pool, or sell them to another refiner who can, and remove a small amount of butane from the conventional pool to balance the RVP.

the pentanes may be backblended back into the pool per RVP allowance.<sup>R</sup> Some refiners produce several grades of gasoline with varying RVP specifications, thus segregating pentanes and back blending would allow a refiner to more accurately control each pool's RVP. Backblending of pentanes would be particularly important for refiners producing RBOB (reformulated blendstock for oxygenate blending) for blending with ethanol since that RBOB must be very low in RVP to accommodate the RVP boost of ethanol. We also utilized information obtained from our discussions with refiners for further input in our analysis. None of the refiners commented on the operations of their FCC debutanizers/depentanizers, but one refiner reported that pentanes would have to be removed from gasoline to get the pool below a 7.5 RVP spec.

We also evaluated information from several different refinery models in an attempt to understand the breakpoint between butane and pentane reduction to reduce RVP. For this analysis, we used a typical gasoline blend, which represents the gasoline quality for a notional refinery for PADDs 1, 2 and 3. We used this gasoline blend because it seemed like a reasonable mix of gasoline blendstocks. This gasoline blend is summarized in Table 6.11-2.

**Table 6.11-2. Baseline 9 RVP Gasoline Composition**

<i>Gasoline Blendstocks</i>	<i>% Volume</i>
Isobutanes	1.3
Normal Butane	4.1
C5s & Isom	5.8
Naphtha C5-160	3.5
Naphtha 160-250	3.7
Alkylate	12.1
Hydrocrackate	4.0
Full Range FCC Naphtha	38.1
Light Reform	5.3
Heavy Reform	21.6
MTBE	0.5
Total	100.0
RVP psi	8.5

We then applied the blending RVPs from different refinery models, which included Mathpro's, Oak Ridge National Laboratory's (ORNL) and a refining industry consultant's, to the typical gasoline blend to estimate this butane/pentane breakpoint in RVP. Before proceeding with the analysis, we needed to estimate the amount of butane entrained in the gasoline pool. Butanes remain entrained in the gasoline pool because distillation of hydrocarbons does not allow a perfect cut between the various hydrocarbons which comprise gasoline and some butanes would be expected to remain in refined streams after distillation to remove them. It is important to know how the various refinery modelers set up the input tables of their refinery models to account for this. Mathpro said that their gasoline blendstocks do not incorporate entrained

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<sup>R</sup> Send the C6+ hydrocarbons through a Merox or similar process where mercaptan sulfur molecules are converted to meet odor and corrosion requirements.

butane and that they put a lower limit on the amount of butane which can be removed from the gasoline pool. We assumed a lower limit of 1.5 percent butanes in the gasoline blend when using their gasoline blendstocks to evaluate this issue. Ensys, which has provided many of the technical inputs to the Oak Ridge National Laboratory (ORNL) refinery model, stated that the gasoline blendstocks in the ORNL refinery model were based on actual refinery streams, but did not know how much butane was in those streams. Since the blendstock qualities were based on actual refinery blendstocks, we presumed that the blendstocks did contain entrained butane. The refinery industry consultant felt that their gasoline blendstocks contained entrained butane and that they model removing all the butane in their low RVP refining studies and we did the same. The blendstock blending RVP levels are summarized in Table 6.11-3.

**Table 6.11-3. Estimated Gasoline Component Vapor Pressures (psi RVP)**

<i>Component</i>	<i>MathPro</i>	<i>ORNL</i>	<i>Consultant X</i>
Isobutanes	71	71	71
Normal Butane	65	65	65
C5s & Isomerate	13.3	13.3	13.8
Straight Run Naphtha	—	—	8.8
(C5-160 F)	13	12	---
(160-250 F)	2.5	3	---
Alkylate	3.5	6.5	4.9
Hydrocrackate	12.5	14	7.2
Full Range FCC Naphtha	3.7	6.9	7.1
Light Reformate	7.5	6.9	6.4
Heavy Reformate	3.8	3.9	3.3
MTBE	8	8	8

Our analysis here showed that applying the Mathpro blendstocks to the typical gasoline blend and limiting butane reduction to 1.5 percent yielded a lower RVP limit of lowering butane to 6.2 RVP. Applying the ORNL blendstocks to the typical gasoline blend and removing all the butane yielded a lower RVP limit for lowering butane to 7.1 RVP. Applying the other refinery industry consultant's blendstock qualities to the typical gasoline blend and removing all the butane yielded a lower RVP limit for lowering butane to 6.5 RVP. Averaging these three values yields 6.6 RVP as the lower limit for removing butane before pentanes would need to be removed.

We believe that there is a good explanation for why the butane-pentane breakpoint for RVP reduction varies so much based on the people we spoke to and also on our refinery modeling analysis. Each refiner has many differing types of gasoline production processes with varying throughputs and gasoline yield capabilities. Also, each refiner processes a differing crude oil slate, with a varying hydrocarbon composition which further contributes to each refiner producing its own unique gasoline blend stocks. Thus, differing crude slates and process units cause a refiner to yield different amounts of the light and heavy hydrocarbon components for blending into its gasoline pool.

To take into account the various RVP values for the butane-pentane breakpoint based on

the low and high figures obtained from the aforementioned discussions with the vendors, refiners, and consultants, and the refinery modeling study, we considered a range of values for this analysis. We assumed that, after butanes have been removed, pentanes would begin to be removed when a gasoline blend's RVP is lowered below a range of values between 7.5 and 6.8 RVP. However, the analysis suggests that for most refiners, the breakpoint is likely at an RVP level of 6.8. Meeting a 7.0 RVP control standard that would not control most of the current 9.0 RVP gasoline would provide refiners options of whether they would produce gasoline for sale into the new RVP controlled areas. Refiners which are faced with having to remove pentanes to comply with a 7.0 RVP standard – which would be a higher cost of compliance – would likely continue to produce 9.0 RVP gasoline leaving the production of 7.0 RVP gasoline to refiners which would only be faced with removing butanes. Therefore, it is likely that in meeting a 7.0 RVP standard that regulates only a part of the 9.0 conventional gasoline pool, that only butanes would be removed from the gasoline pool. Regardless of whether butanes only are removed from the gasoline pool, or if pentanes would also be removed, producing gasoline which meets a 7.0 RVP standard is feasible.

## **6.12 Feasibility of Removing Sulfur from Gasoline**

### **6.12.1 Source of Gasoline Sulfur**

Sulfur is in gasoline because it naturally occurs in crude oil. Crude oil contains anywhere from fractions of a percent of sulfur, such as less than 0.05 weight percent (0.05 percent is the same as 500 ppm) to as much as several percent.<sup>36</sup> The average amount of sulfur in crude oil refined in the U.S. is about one percent.<sup>37</sup> Most of sulfur in crude oil is in the heaviest part, or in the heaviest petroleum compounds, of the crude oil (outside of the gasoline boiling range). In the process of refining crude oil into finished products, such as gasoline, some of the heavy compounds are broken up into smaller compounds, or cracked, and the embedded sulfur can end up in gasoline. Thus, the refinery units which convert the heavy parts of crude oil into gasoline are the units most responsible for putting sulfur into gasoline.

The fluidized catalytic cracker (FCC) unit is a refinery processing unit that creates a high sulfur content gasoline blendstock. The FCC unit cracks large carbon molecules into smaller ones and produces anywhere from 30 to 50 percent of the gasoline in most refineries. Because the FCC unit makes gasoline out of the heavier, higher sulfur-containing compounds, more than 90 percent of sulfur in gasoline blendstocks comes from streams produced in that unit.<sup>38</sup> FCC naphtha contains from hundreds to several thousand parts per million of sulfur.

Another refinery unit which produces a gasoline blendstock with a significant amount of sulfur is the coker unit. These units produce coke from the heavy part of the crude oil. In the process of producing coke, a gasoline blendstock is produced that contains more than 3000 ppm sulfur.<sup>39</sup> This stream is normally split into two different streams. The six to nine carbon hydrocarbons are hydrotreated along with the rest of the heavy naphtha and sent to the reformer. The five carbon hydrocarbon part of coker naphtha is called light coker naphtha and usually contains on the order of several hundred percent sulfur.

Light straight run naphtha is a gasoline blendstock which contains a moderate amount of

sulfur. Straight run naphtha is the part of crude oil which after distillation in the atmospheric crude oil tower falls in the gasoline boiling range. The heaviest portion of straight run, which would have more sulfur, is normally desulfurized and reformed in the reformer (to improve its octane), so its contribution to the gasoline pool is virtually nil. The light straight run which contains the five carbon hydrocarbons contains on the order of 100 ppm sulfur and if this material is not hydrotreated and processed in an isomerization unit, it is blended directly into gasoline.

Other gasoline blendstocks contain little or no sulfur. Alkylate can have a small amount of sulfur. Most refineries have less than five ppm sulfur in this pool, however, some refineries which feed coker naphtha to the alkylate plant can have much more. On average, alkylate probably has about 10 ppm sulfur. Other gasoline blendstock streams with either very low or no sulfur are hydrocrackate, and isomerate. Oxygenates which are blended into gasoline usually have very little or no sulfur, however, during shipping through pipelines, they can pick up some sulfur. The implementation of the Tier 2 gasoline sulfur standard, though, is expected to reduce much of the sulfur which oxygenates pick up in the pipeline.

## **6.12.2 Complying with the Tier 2 Gasoline Sulfur Standard**

### **6.12.2.1 Background**

The Tier 2 sulfur standard was promulgated February 10, 2000.<sup>40</sup> The sulfur standard requires that refiners reduce their annual average gasoline sulfur levels down to 30 ppm and each gallon cannot exceed a per-gallon standard of 80 ppm. The sulfur standard phased-in starting in 2004 for most refiners, will be fully phased in by January 1, 2006. The only exceptions are for certain western refiners (GPA) and small refiners whose deadlines were extended in the highway diesel fuel sulfur rule.

A refinery's previous average gasoline sulfur level is an important factor which determined whether a refiner would need to make a substantial capital investment to meet the Tier 2 gasoline sulfur standard. We believe that those refiners with low gasoline sulfur levels to begin with (i.e., gasoline sulfur levels lower than, perhaps, 50 ppm) probably are not investing in expensive capital. These refineries have very low sulfur levels due to one or more of a number of possible reasons. For example, some of these refiners may not have certain refining units, such as a fluidized catalytic cracker (FCC) unit, or a coker, which convert heavy boiling stocks to gasoline. As stated above, these units push more sulfur into gasoline and their absence means less sulfur in gasoline. Alternatively, refiners may use a very low sulfur (sweet) crude oil, which can result in a low sulfur gasoline. Or, these refiners may have already installed a hydroprocessing unit, such as FCC feed hydrotreating, to improve the operations of their refinery which uses a heavier, higher sulfur (more sour) crude oil. This unit removes much of the sulfur from the heaviest portion of the heavy gas oil before it is converted into gasoline.

Of the refiners in this first category, the refineries with average sulfur levels below 30 ppm may not have had to do anything to meet the standard. On the other hand, those refineries which had sulfur levels above 30 ppm but below some level, such as 50 ppm, probably are meeting the 30 ppm sulfur standard employing operational changes only and are avoiding

making capital investments. Most of the refineries in this category do not have a FCC unit. If they do they probably have an FCC feed hydrotreating unit.

The vast majority of gasoline which was being produced was by refineries with higher sulfur levels, and these refiners had to either adapt some existing hydrotreating capital or install new capital equipment in these refineries to meet the Tier 2 gasoline sulfur standard. As stated above, the FCC unit is responsible for most of the sulfur in gasoline. Thus, investments for desulfurizing gasoline involved the FCC unit to maximize the sulfur reduction, and to minimize the cost. This desulfurization capital investment can be installed to treat the gas oil feed to the FCC unit, or treat the gasoline blendstock which is produced by the FCC unit. Each method has advantages and disadvantages.

For the Tier 2 and highway diesel fuel rulemakings, we estimated the number of hydrotreating units being installed and the year that they are expected to become operational. These figures are summarized in Table 6.12-1. This summary of installed units by year includes our expectations of how the small refiners will change their investment based on the small refiner provisions in the highway diesel rulemaking.

**Table 6.12-1. Number of Gasoline Desulfurization Units Becoming Operational on January 1 of the Indicated Year**

<i>Prior to 2004</i>	<i>2004</i>	<i>2005</i>	<i>2006</i>	<i>2007</i>	<i>2008</i>	<i>2009</i>	<i>2010</i>	<i>Total</i>
10	37	6	26	5	3	4	6	97

#### **6.12.2.2 FCC Feed Hydrotreating**

FCC feed hydrotreating treats the gas oil feed to the FCC unit using a hydrotreater or a mild hydrocracker. These units are designed to operate at high pressures and temperatures to treat a number of contaminants in gas oil. Besides sulfur, FCC feed hydrotreating also reduces nitrogen and certain metals such as vanadium and nickel. These nonsulfur contaminants adversely affect the FCC catalyst, so the addition of this unit would improve the yield of the highest profit-making products such as gasoline and diesel. While FCC feed hydrotreating provides these benefits which partially offsets the costs of adding this type of desulfurization, the costs are still high enough that many refiners would have a hard time justifying the installation of this sort of unit. For a medium to large refinery (i.e., 150,000-200,000 BPCD), the capital costs may exceed \$100 million. Because of the higher temperatures and pressures involved, utility costs are expensive relative to other forms of hydrotreating explained below. Another justification for this approach is that it allows refiners to switch to a heavier, more sour crude oil. These crude oils are less expensive per-barrel and can offset the increased utility cost of the FCC desulfurization unit, providing that the combination of reduced crude oil costs and higher product revenues justify the switch. Another benefit for using FCC feed hydrotreating is that the portion of the distillate pool which comes from the FCC unit would be hydrotreated as well. This distillate blendstock, termed light cycle oil, comprises a relatively small portion of the total distillate produced in the refinery (about 20 percent of on-road diesel comes from light cycle oil),

like FCC naphtha, light cycle oil contributes a larger portion of the total sulfur which ends up in distillate. Thus, FCC hydrotreating would also allow a refiner to help meet the 15 ppm highway and nonroad diesel fuel standards..

#### **6.12.2.3 FCC Naphtha Hydrotreating**

A less capital intensive alternative for reducing FCC naphtha sulfur levels is FCC naphtha hydrotreating. FCC gasoline hydrotreating only treats the gasoline produced by the FCC unit. Understandably, this unit is much smaller because only about 50 to 60 percent of the feed to the FCC unit ends up as gasoline. The unit is often smaller than that as refiners which choose to use a fixed bed hydrotreater usually choose to treat the heavier, higher sulfur portion of that stream with hydrotreating, and then treat the lighter fraction with catalytic extractive desulfurization. FCC naphtha hydrotreaters operate at lower temperatures and pressures than FCC feed hydrotreating which further reduces the capital and operating costs associated with this type of desulfurization equipment. For a medium to large refinery, the capital costs are on the order of \$50 million for a conventional hydrotreater.

One drawback of this desulfurization methodology is that the octane value and/or some of the gasoline yield may be lost depending on the process used for desulfurization. Octane loss occurs by the saturation of high octane olefins which are produced by the FCC unit. Most of the olefins are contained in the lighter fraction of FCC naphtha. With increased olefin saturation comes increased hydrogen consumed. There can be a loss in the gasoline yield caused by mild cracking which breaks some of the gasoline components into smaller fractions which are too light for blending into gasoline. If there is octane loss, it can be made up using the same octane recovery methods described above.

The loss of octane and gasoline yield caused by FCC naphtha hydrotreating is lower with technologies which were recently developed. These processes preserve much of the octane and gasoline yield because they were designed for treating gasoline blendstocks. Octane is preserved because their catalysts are specially designed to either avoid saturating olefins, or if the process does saturate olefins, it causes other reactions to occur which improves the octane of the hydrotreated naphtha. These processes may also operate at less severe conditions than conventional hydrotreaters which preserves yield compared to conventional hydrotreating processes. The less severe conditions lowers the capital and operating costs for this process. Typical capital cost for these newer desulfurization technologies ranges from \$20 to \$40 million for a medium to large sized refinery. The lower operating costs arise out of the reduced utility requirements (e.g., process heat, electricity), octane losses and hydrogen consumption. For example, because these processes are less severe, there is less saturation of olefins, which means that there is less hydrogen used. Less olefin saturation also translates into less octane loss which would otherwise have to be made up by octane boosting processing units in the refinery. The lower capital and operating costs of these newer FCC gasoline hydrotreaters are important incentives for refiners to choose this desulfurization methodology over FCC feed hydrotreating. For this reason, refiners are choosing to use the more recently developed FCC gasoline hydrotreating technologies for meeting the gasoline sulfur standard.

#### **6.12.2.4 FCC Naphtha Desulfurization Technologies**

We know of six FCC naphtha desulfurization technologies. These are Mobil Oil Octgain 125, Octgain 220, Exxon Scanfining, IFP Prime G, CDTech's CDHydro and HDS, and Phillips S-Zorb. The functioning of each of these technologies is discussed below.

Of the list of FCC naphtha hydrotreaters, Mobil Oil Octgain 125, Octgain 220, Exxon Scanfining, IFP Prime G, are fixed bed desulfurization technologies and they function similar to each other. These processes are called fixed bed because the catalyst resides in a fixed bed reactor.<sup>41</sup> The high sulfur gasoline blendstock is heated to a high temperature (on the order of 600 degrees Fahrenheit) and pumped to a high pressure, to maintain the stream as a liquid, and is combined with hydrogen before it enters the reactor. The reactions occur over the bed of the catalyst. While the petroleum is in contact with the catalyst in the reaction vessel, the sulfur is removed from the petroleum compounds and is converted to hydrogen sulfide. Also, depending on the process, some of the olefin compounds which are present in the cracked stream are saturated which increases the amount of octane lost and hydrogen consumed. The difference between these and conventional hydrotreating processes is that these technologies have a way for either minimizing the loss in octane or compensating for it, either by minimizing the loss of olefins, or by recovering the lost octane through octane producing reactions. The catalyst may cause yield loss through cracking of some of the petroleum compounds. After the reactor, the gaseous compounds, which include unreacted hydrogen, hydrogen sulfide, and any light end petroleum compounds which may have been produced in the reactor by cracking reactions, are separated from the liquid compounds. The hydrogen sulfide must be stripped out from the other compounds and then converted to elemental sulfur in a separate sulfur recovery unit, and the recovered sulfur is then sold. If there is enough hydrogen and it can be economically recovered, it is separated from the remaining hydrocarbon stream and recycled. Otherwise, it would probably be burned with the light hydrocarbons as fuel gas.

Each of these desulfurization technologies are a little different. The Octgain 125 process saturates all the olefins, but recovers the lost octane through isomerization and alkylation.<sup>42</sup> It needs to be run at fairly severe conditions for it to recover octane, so this process is more appropriate for refiners with higher sulfur levels which requires severe hydrotreating to reach the sulfur target. While octane loss can be eliminated with the proper operating conditions, yield loss can be significant. It has been commercially demonstrated at Mobil's refinery in Joliet, Illinois.

Exxon's Scanfining process preserves octane by saturating very few olefins, however, at severe operating conditions for higher levels of desulfurization, octane loss can be high. The Scanfining catalyst causes very little yield loss. This process has been demonstrated for a total of over 4 years in two of Exxon's refineries.<sup>43</sup>

IFP's (Intitute Francais du Petrole) Prime G desulfurization process largely preserves olefins as its strategy for diminishing octane loss.<sup>44,45</sup> Like Scanfining, Prime G is less severe and cracks the petroleum compounds less resulting in less yield loss. Prime G has been commercially demonstrated for over 7 years in two U.S. refineries, and in an Asian refinery.

The Mobil 220 process uses a fixed bed for its catalyst.<sup>46</sup> Octgain 220 preserves most of

the olefins and recovers lost octane through isomerization reactions.<sup>47,48</sup> The less severe operating conditions also causes less yield loss, as the conditions are less favorable for causing cracking of the larger petroleum compounds to smaller compounds. For high levels of desulfurization, yield and octane loss increase significantly for this process so Mobil recommends that refiners use the 125 process for these desulfurization cases. Mobil loaded the 220 catalyst into their Joliet hydrotreater during March of 1999, so the process has some commercial experience.

To limit the octane impacts of fixed bed hydrotreating of FCC naphtha, the fixed bed hydrotreaters are limited to treating the heavy portion of FCC naphtha. The heavy part of FCC naphtha contains a lower concentration of olefins which limits the saturation of olefins and reduces the octane impact of hydrotreating. The light FCC naphtha, which contains a high concentration of olefins, can either be treated using a different process or, for some refineries, can be left untreated. Refineries which process a sweet crude oil or a lighter crude oil which results in a lower amount of FCC naphtha in their finished gasoline, may not need to treat their light FCC naphtha to meet the Tier 2 sulfur standard. Most refineries will need to treat their light FCC naphtha and will use a caustic treating process. Caustic treating processes can only treat mercaptans which are in the five carbon and part of the six carbon portion of FCC naphtha. [provide more information on caustic treating] There are two caustic treating processes. One is called Merox and is licensed by UOP. The second is licensed by Merichem.

The CDTECH process is significantly different from the fixed bed hydrotreating technologies and is a little more complex to describe. The CDTECH process utilizes catalytic distillation.<sup>49,50,51</sup> Catalytic distillation is a technology which has been applied for a number of different purposes. CDTECH is currently licensing the technology to produce MTBE and selective hydrogenation processes, including a benzene saturation technology described above. As the name implies, distillation and desulfurization, via a catalyst, take place in the same vessel. This design feature saves the need to add a separate distillation column normally required with fixed bed hydrotreating. All refineries have a distillation column after the FCC unit (called the main fractionation column) which separates the gasoline from the most volatile components (such as liquid petroleum gases), the distillate or diesel (light cycle oil), and the heavy ends or residual oil. However, if a refiner only wishes to treat a portion of the FCC naphtha, then a second distillation column would need to be added after the main FCC fractionation column to separate off the portion of the FCC gasoline which he wishes not to treat. With the CDTECH process, the refiner can choose to treat the entire pool or a portion of the pool, but choosing to treat a part of the pool can be an option in how the CDTECH hardware is applied, thus negating any need for an additional distillation column.

The most important portion of the CDTECH desulfurization process is a set of two distillation columns loaded with desulfurization catalyst in a packed structure. The first vessel, called CDHydro, treats the lighter compounds of FCC gasoline and separates the heavier portion of the FCC naphtha for treatment in the second column. The second column, called CDHDS, removes the sulfur from the heavier compounds of FCC naphtha. All of the FCC naphtha is fed to the CDHydro column. The 5 and 6 carbon petroleum compounds boil off and head up through the catalyst mounted in the column, along with hydrogen which is also injected in the bottom of the column. The reactions in this column are unique in that the sulfur in the column are not

hydrotreated to hydrogen sulfide, but they instead are reacted with dienes in the feed to form thioethers. Their higher boiling temperature causes the thioethers to fall to the bottom of the column. They join the heavier petroleum compounds at the bottom of the column and are sent to the CDHDS column. Because the pressure and temperature of the first column is much lower than conventional hydrotreating, saturation of olefins is reduced to very low levels (according to CDTECH, the saturation which does occur is desirable to eliminate diolefins). Thus, little excess hydrogen is consumed. An option for the refiner is to put in an additional catalyst section in the CDHydro column to increase octane. This octane enhancing catalyst isomerizes some of the olefins which increases the octane of this stream by about three octane numbers, and few of the olefins are saturated to degrade this octane gain.

The seven-carbon and heavier petroleum compounds leave the bottom of the CDHydro unit and are fed into the CDHDS column. There, the heavier compounds head down the column, and the lighter compounds head up. Both sections of the CDHDS column have catalyst loaded into them which serve as hydrotreating reaction zones. Similar to how hydrogen is fed to the CDHydro column, hydrogen is fed to the bottom of the CDHDS column.

The temperature and pressure of the CDTech process columns are lower than fixed bed hydrotreating processes, particularly in the upper section of the distillation column, which is where most of the olefins end up. These operating conditions minimize yield and octane loss. While the CDTech process is very different from conventional hydrotreating, the catalyst used for removing the sulfur compounds is the same. Thus, if concerned about the reliability of the process, refiners can look at the track record of the catalyst in conventional hydrotreating to get an indication of its expected life, and then adjust that expectation based on the milder conditions involved. One important different between the CDTech process and conventional hydrotreating is that CDTech mounts its catalyst in a unique support system, while conventional catalyst is simply dumped into the fixed bed reactor. Although the CDTech desulfurization process is different from conventional hydrotreating processes, the use of a distillation column as the basis for the process is very familiar to refiners. Every refinery has distillation in its refinery, thus, refiners are very skilled in its application.

CDTech has numerous CDHydro units in operation for producing MTBE and saturating benzene. A CDHDS unit was started up in the Motiva refinery in Port Arthur, Texas starting March of 2000. Additionally, a combined CDHydro/HDS unit is expected to be operational in North America in October of 2000, and another license agreement has been signed for an installation in Europe. An installation of an HDS unit is planned for the Transamerican refinery in Louisiana, however, that refinery is currently shutdown and the startup date of the refinery and the planned CDHDS unit is unclear.

Phillips Petroleum Co. has commercialized an adsorption desulfurization technology. This technology uses a chemical adsorption process, instead of hydrotreating, as the principal methodology for the removal of sulfur from gasoline. Adsorption has the benefit of operating at much lower pressure and temperatures, which lowers operating costs.

An adsorption process by Phillips, called S-Zorb, uses two separate columns and is constantly moving an adsorption catalyst from the reactor vessel to the regeneration column, and

back again.<sup>52</sup> The untreated FCC naphtha and hydrogen are fed to the reaction vessel where the catalyst catalytically removes the sulfur from the petroleum compound facilitated by the hydrogen present in the reactor. The catalyst which begins to accumulate the removed sulfur, is transferred over to the regeneration column on a continual basis where the sulfur is removed from the catalyst using hydrogen as the scavenging compound. Then the hydrogen disulfide is converted to sulfur dioxide and sent to the sulfur recovery unit. Because the process still relies upon catalytic processing in the presence of hydrogen, there is some saturation of olefins, with a commensurate reduction in octane.

We surveyed the vendors of FCC naphtha hydrotreating technology and they provided us the number of hydrotreating units they are licensing to refiners for Tier 2. Their estimates are summarized in Table 6.12-2.

**Table 6.12-2. Results of Vendor Survey for the Number of FCC Naphtha Technologies being installed for Tier 2**

	Exxon-Mobil Scanfining	Exxon-Mobil Octgain 125	Exxon-Mobil Octgain 220	IFP	CDTech	S-Zorb
Vendor Estimate	17			27	17	5

### 6.12.3 Meeting a 10 ppm Gasoline Sulfur Standard

Mathpro, the contractor that conducted the 10 ppm sulfur cost estimate for us, estimates that a 10 ppm gasoline sulfur standard can be met by reducing the sulfur level of FCC naphtha to 10 ppm. The 10 ppm sulfur level would be a reduction from the estimated 60 to 70 ppm sulfur level for this stream after the Tier 2 standard is met. Desulfurizing FCC naphtha is an obvious choice for achieving a 10 ppm gasoline sulfur level for two reasons. First, even after complying with the Tier 2 sulfur standard, FCC naphtha has a relatively high sulfur level and it comprises a large part of the gasoline pool. The second reason why it makes sense to focus on the FCC naphtha for achieving 10 ppm sulfur is because FCC naphtha hydrotreaters will already be in place that can be retrofitted to realize the sulfur reductions. The post Tier 2 sulfur levels for FCC naphtha and the other blendstocks which make up gasoline, as well as the projected sulfur levels under a 10 ppm sulfur standard, are summarized in Table 6.12-3.

**Table 6.12-3. Estimated Typical Gasoline Blendstock Volumes and Sulfur Levels after Tier 2 and after a 10 ppm Sulfur Standard**

Gasoline Blendstock	Percent of Total Volume	Sulfur Levels (ppm)	
		30 ppm Tier 2 Sulfur Standard	10 ppm Sulfur Standard
FCC Naphtha	36	65	10
Reformate	30	1	1
Alkylate	12	12	12
Isomerate	4	1	1
Butane	4	4	4
Light Straight Run Naphtha	4	10	10
Hydrocrackate	3	15	15
MTBE/Ethanol	3	10	10
Coker Naphtha	1	1	1
Natural Gasoline	1	150	150
Other Gasoline Blendstocks	2	80	80
Total/Sulfur Average	100	30	10

Reducing FCC naphtha from 60 to 70 ppm to 10 ppm would likely be accomplished in different ways depending on the desulfurizing technology used for Tier 2. Based on the figures in Table 6.12-2 there are an estimated 45 fixed bed hydrotreaters (17 Exxon-Mobil technologies and 27 IFP Prime G plus units), 17 catalytic distillation units and 5 Phillips S-Zorb units installed for Tier 2.<sup>S</sup> There are also a sizable number of refineries meeting the Tier 2 sulfur standard solely using FCC feed hydrotreating. Despite the use of FCC feed hydrotreaters by some refiners to comply with the Tier 2 sulfur standard, additional desulfurization to 10 ppm gasoline is expected to be met using FCC naphtha hydrotreaters. Each of the installed post-treat technologies used to meet the Tier 2 sulfur standard could be used to comply with a 10 ppm sulfur standard by either increasing their severity or revamping the units recently added to comply with Tier 2. For those refineries which relied on FCC feed hydrotreating to comply with Tier 2, a small, new FCC naphtha hydrotreater would have to be added. Understanding the operations for these revamped or new units to produce 10 ppm FCC naphtha requires an understanding of desulfurization chemistry.

Desulfurizing FCC naphtha gasoline is conducted by reacting the sulfur containing hydrocarbons with excess hydrogen over a catalyst. The products of the hydrotreating reaction are the desulfurized hydrocarbons and hydrogen sulfide. These FCC naphtha desulfurization technologies are an improvement over conventional desulfurization technologies because they preserve the olefin hydrocarbons present in the FCC naphtha. Except for the S-Zorb adsorption process, the challenge is after-the-fact when there is a lot of hydrogen sulfide in the reactor exposed to the olefinic compounds in the FCC naphtha. The hydrogen sulfur compounds tend to react with the olefinic hydrocarbon compounds forming mercaptan sulfur compounds. This reaction is called “recombination” because the removed sulfur recombines with the olefinic hydrocarbons. The recombination reactions occur more readily if the hydrotreater is operated more severely (at a higher temperature) to increase the sulfur removal. However, while

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<sup>S</sup> This estimate is based on an informal survey conducted in early 2006 to gain a sense for the types of investments being made for Tier 2.

operating this type of hydrotreater more severely can result in the further removal of the original sulfur present in the hydrocarbons, it also can result in the formation of more recombination mercaptans that results in a “floor” reached for the amount of sulfur contained in the hydrocarbons. This cycle of sulfur removal and simultaneous recombination reactions that does not further reduce the sulfur level of FCC naphtha results in the saturation of more olefins and an associated higher hydrogen consumption.

The recombination issue is dealt with in a number of ways for the FCC naphtha hydrotreaters installed for Tier 2. For a small portion of the refineries complying with the Tier 2 sulfur standard, there was probably no recombination reaction issue to be concerned about. These refineries may be refining a very sweet crude oil or have an FCC feed hydrotreater treating at least a portion of the feed to the FCC unit. For most refineries, FCC naphtha hydrotreaters were constructed to address the recombination issue in a couple of different ways. One way was to install a larger than necessary hydrotreater which allows the treating of the FCC naphtha at a lower severity and can allow feeding a high volume of hydrogen to the hydrotreating reactor that dilutes the hydrogen sulfide produced from the hydrotreating reactions. If the concentration of hydrogen sulfide is lower from a large supply of hydrogen, there are fewer recombination reactions. The other primary way that the recombination issue was addressed was to add a second reactor in series with the main hydrotreating reactor. The main hydrotreating reactor accomplishes the bulk of the hydrotreating at a low severity. The products from the first reactor are fed to a separator drum where the gaseous contents, including the hydrogen disulfide, are separated from the FCC naphtha. The FCC naphtha is then fed to a second reactor. In the case of CDTech, the second reactor is a small fixed bed hydrotreater which completes the desulfurization, much of which are mercaptans. For Scanfining units, the second reactor is an Exomer reactor which is a caustic extractive process developed by Merichem similar to the caustic extractive processes used to treat the light FCC naphtha. IFP Prime G uses range of strategies, including a single reactor operated with a higher hydrogen concentration, depending on the refinery’s situation.

Because the strategy for meeting the 30 ppm sulfur standard differs even for each vendor’s technology depending on how the process was implemented, the exact means for how individual refiners would respond to a 10 ppm sulfur standard is difficult to anticipate. It seems certain that an FCC naphtha hydrotreater installed for Tier 2 which does not have a technology for dealing with recombination reactions would require it for achieving 10 ppm gasoline. If the FCC naphtha hydrotreating unit is designed to handle recombination, then the refiner’s ability to fund capital projects to make up lost octane, and supply hydrogen would also factor into a refiner’s decision of how to proceed. For example, a refiner which, because of its financial situation, does not have access to capital, but does have excess hydrogen supply and octane production capacity may choose to run its existing naphtha hydrotreater at a high severity, at the expense of octane and hydrogen demand, to meet a 10 ppm standard. Refiners which are not capital adverse are likely to install additional capital, even beyond that installed to address recombination, to minimize the octane loss and the hydrogen consumed.

An advantage of the Phillips S-Zorb adsorption process is that because the sulfur is cleaved from the hydrocarbon compound, adsorbed onto the catalyst and converted to hydrogen disulfide in another vessel, there are no recombination reactions that occur. This process can be

operated more severely to achieve 10 ppm. The more severe operating conditions cause the saturation of olefins so there is a practical limit to the degree that any single unit can be operated to produce 10 ppm sulfur. In particular, if a unit was designed to only process a portion of the FCC naphtha, such as the heavy portion, it likely would have to be revamped to handle the entire FCC feed.

The refineries with FCC feed hydrotreaters would have to add an FCC naphtha hydrotreater to achieve a 10 ppm sulfur standard. It is expected that the FCC hydrotreater would only need to treat the heavy portion of the FCC naphtha as the lighter portion would be adequately treated to sufficiently low sulfur levels by the FCC feed hydrotreater. Any of the post treat technologies would work for this situation, and because of the very low starting sulfur in the FCC naphtha, recombination reactions would not be an issue.

#### **6.12.3.1 Feasibility of Meeting a 10 ppm Gasoline Sulfur Standard**

The feasibility of meeting 10 ppm gasoline sulfur standard can be demonstrated in two distinct ways. The first way is to assess whether there is technology available, or that can reasonably be expected to be available in the lead time provided to the refining industry to meet such a standard. These technologies are discussed above. The second way is to determine if refiners are already demonstrating that they can meet a 10 ppm gasoline sulfur standard. Evidence that a large number of refineries having various configurations are already meeting a stringent gasoline sulfur program is a more compelling example of feasibility since the technology is clearly already available if very low sulfur gasoline is already being produced.

It is indeed the case that there are very low sulfur gasoline programs already in place. The State of California requires gasoline sold in the State to meet a 20 ppm gasoline sulfur standard on average and a 30 ppm cap, among a number of other fuel standards.<sup>53</sup> Furthermore, refiners can produce gasoline which varies in composition, provided that the California Predictive Emissions Model (which, like EPA's Complex Model, estimates vehicle emissions from fuels of varying composition) confirms that the proposed fuel formulation meets or exceeds the emissions reduction that would occur based on the default fuel requirements. California refineries are using the flexibility provided by the Predictive Model to surpass the prescriptive standards for gasoline sulfur and are producing gasoline which contains 15 ppm sulfur on average. They are making this very low sulfur gasoline despite using Californian and Alaskan crude oils which are poorer quality than most other crude oils being used in the U.S. today. Thus, the experience in California demonstrates that commercial technologies already exist to permit refiners to produce very low sulfur gasoline.

## **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 been 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 highlight 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  $650^\circ$  to  $700^\circ$  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 heavier 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 begin 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 the 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 steam 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<sub>5</sub>'s thru C<sub>11</sub>'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<sub>5</sub>'s and some C<sub>6</sub>'s into the overhead while most of the C<sub>6</sub>'s and C<sub>7</sub>+ 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<sub>6</sub>'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<sub>6</sub>'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 C<sub>5</sub>'s and C<sub>6</sub>'s, providing a C<sub>5</sub> minus cut to the isom and the C<sub>6</sub> - 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 to 15 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<sub>9</sub>-C<sub>12</sub> 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, reformat, 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 to as “the gasoline pool.” We also note that multiple units produce blendstocks of a similar type. For example, three different reformers usually produce reformat 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<sub>5</sub> to C<sub>12</sub> 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 used 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: Gas Can 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 gas can emissions. Chapter 10 discusses the economic feasibility of gas can controls and the fuel savings associated with controlling gas can emissions. This chapter presents the technological feasibility of controlling emissions from gas cans. All of these analyses and information form the basis of EPA's belief that the proposed 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 proposed test procedures for determining evaporative emissions.

Evaporative emissions from gas cans can be very high. This is largely because gas cans are often left open and vent to the atmosphere and because materials used in the construction of the plastic gas cans generally have high permeation rates. Evaporative emissions can be grouped into two main categories:

**DIURNAL:** Gasoline evaporation increases as the temperature rises during the day, heating the gas can and venting gasoline vapors.

**PERMEATION:** Gasoline molecules can saturate plastic gas cans, resulting in a relatively constant rate of emissions as the fuel continues to permeate through these components.

The use of gas cans 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 portable fuel containers with no emissions controls.<sup>1,2</sup> 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 collected using the ARB Test Method 513.<sup>3</sup> 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 Gas Cans Tested by ARB**

Gas Can 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 gas cans using California certification fuel.<sup>4</sup> 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 gas cans is 0.35 g/gal/day; however, there was a wide range in effectiveness of the sulfonation process for these gas cans. Some of the data outliers were actually higher than baseline emissions. This was likely due to leaks in the gas cans 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 Gas Cans Tested by ARB**

Gas Can 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 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.<sup>5</sup>

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.<sup>6,7</sup> These fuel tanks were 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 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<sup>2</sup>/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 has the effect of reducing 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.<sup>8</sup> 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<sup>2</sup>/day at 40°C<sup>9</sup> which was less than half of what the CARB testing showed on their constant temperature test at 40°C.<sup>10</sup> A list of resins and additives that are compatible with the sulfonation process is included in the docket.<sup>11,12</sup>

**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 <sup>2</sup> /day	10.4	10.4	10.4	10.4
Set #1 Sulfonated	g/m <sup>2</sup> /day	0.73	0.82	1.78	1.11
	% reduction	93%	92%	83%	89%
Set #1 Sulfonated & Sloshed	g/m <sup>2</sup> /day	1.04	1.17	2.49	1.57
	% reduction	90%	89%	76%	85%
Set #2 Average Baseline	g/m <sup>2</sup> /day	12.1	12.1	12.1	12.1
Set #2 Sulfonated	g/m <sup>2</sup> /day	1.57	1.67	1.29	1.51
	% reduction	87%	86%	89%	88%
Set #2 Sulfonated & Sloshed	g/m <sup>2</sup> /day	2.09	2.16	1.70	1.98
	% reduction	83%	82%	86%	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<sup>2</sup>/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 <sup>2</sup> /day	13.9	13.7	14.4	14.0
Sulfonated	g/m <sup>2</sup> /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.<sup>13</sup> 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, gas cans 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 gas cans would be treated. As an alternative, containers can be fluorinated on-line by exposing the inside surface of the gas can 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 fluorinator 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<sup>2</sup>/day), which represents more than a 95 percent reduction from baseline. We then began soaking this fuel tank on E10, subjected it to the proposed 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<sup>2</sup>/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 proposed durability testing requirements.

The California Air Resources Board (ARB) collected test data on permeation rates from fluorinated fuel containers using California certification fuel.<sup>14, 15</sup> 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 gas cans; 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.<sup>16</sup> The ARB data is presented in Table 7.2-5.

**Table 7.2-5. Permeation Rates for Fluorinated Plastic Gas Cans Tested by ARB**

Barrier Treatment*	Gas Can Capacity [gallons]	Permeation Loss [g/gal/day]
Level 4 (average =0.09 g/gal/day)	1	0.05
	1	0.05
	1	0.06
	5	0.11
	5	0.11
	5	0.15
Level 5 (average =0.07 g/gal/day)	1	0.03
	1	0.04
	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 (average =0.04 g/gal/day)	5	0.04
	5	0.04
	5	0.04

\*designations used in ARB report; shown in order of increasing treatment

All of the data on fluorinated gas cans presented above were based on gas cans 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.<sup>17</sup>

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.<sup>18,19</sup> 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<sup>2</sup>/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 <sup>2</sup> /day	10.4	10.4	10.4	10.4
Set #1 Fluorinated	g/m <sup>2</sup> /day % reduction	1.17 89%	1.58 85%	0.47 96%	1.07 90%
Set #1 Fluorinated & Sloshed	g/m <sup>2</sup> /day % reduction	2.38 77%	2.86 73%	1.13 89%	2.12 80%
Set #2 Approximate Baseline	g/m <sup>2</sup> /day	12.1	12.1	12.1	12.1
Set #2 Fluorinated	g/m <sup>2</sup> /day % reduction	0.03 >99%	0.00 >99%	0.00 >99%	0.01 >99%
Set #2 Fluorinated & Sloshed	g/m <sup>2</sup> /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<sup>2</sup>/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 <sup>2</sup> /day	13.9	13.7	14.4	14.0
Fluorinated	g/m <sup>2</sup> /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.<sup>20</sup> 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.<sup>21</sup>

### 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 proposed standard, which is based on testing with a 10 percent ethanol fuel.

We tested several portable gas cans 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 advantage of EVOH is that it has much better resistance to alcohol than nylon. Five of the nylon based fuel tanks were tested on certification gasoline. 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. The purpose of the soak period was to ensure that the fuel permeation rate had stabilized. We soaked the containers with gasoline for 22 weeks and the tanks with E10 for 37 weeks. 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 gas cans 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 <sup>2</sup> /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<sup>2</sup>/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 a permeation rates of 2.8 and 2.7 g/m<sup>2</sup>/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 gas cans 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 Gas Cans  
with Barrier Platelets Tested by ARB on California Fuel**

Percent Selar®*	Container Capacity [gallons]	Permeation Loss [g/gal/day]
4%  (average =0.12 g/gal/day)	5	0.08
	5	0.09
	5	0.13
	5	0.16
	5	0.17
	6	0.08
	6	0.10
6%  (average =0.09 g/gal/day)	5	0.07
	5	0.07
	5	0.07
	5	0.08
	5	0.12
	5	0.17
	6	0.06
8%  (average =0.07 g/gal/day)	5	0.08
	5	0.10
	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.<sup>22</sup> 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 <sup>2</sup> /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

Gas cans may also be constructed out of multiple layers of materials, and some gas can 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.<sup>23</sup>

Another study looks at the permeation rates, using ARB test procedures, through multi-layer vehicle fuel tanks.<sup>24</sup> 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 gas cans. Gas cans as a system also emit evaporative emissions from seals and spouts. Gas cans 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 gas can standards and concluded that a 0.3 g/gal/day standards was feasible in the 2009 time-frame.<sup>25</sup> CARB conducted testing of three different gas cans designed to meet emissions standards. They were tested in two ways: with the spout attached and with the spouts removed and the gas cans 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 gas cans 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 Gas Can	Gas Can 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 gas can 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 gas cans and do not allow evaporative emissions to escape.

## 7.4 Testing Procedures

The proposed test procedure for diurnal emissions is to place the gas can with the spout attached in a SHED<sup>A</sup>, vary the temperature over a prescribed profile, and measure the hydrocarbons escaping from the fuel tank. 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 gas can capacity. The proposed test procedure is based on the automotive evaporative emission test described in 40 CFR Part 86, Subpart B, with modifications specific to gas can applications. The hydrocarbon loss would be measured either by weighing the cans before and after the diurnal or by measuring emissions directly from the SHED. Three identical containers would be tested for three diurnal cycles. The daily emissions for each container would be averaged together for comparison with the standard, rounded to the nearest one-tenth of a gram. Each container would need to meet the standard to demonstrate compliance with the standard.

We are proposing that manufacturers would test cans in their most likely storage configuration. The key to reducing evaporative losses from gas cans 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 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

<sup>A</sup> Sealed Housing for Evaporative Determination

proposing to require that containers be tested in their open condition. If the gas cans have any openings that consumers could leave open (for example, vents with caps), these openings thus would need to be left open during testing. This would apply 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.

We propose that spouts would be in place during testing because this would be the most likely storage configuration for the emissions compliant cans. Spouts would still be removable so that consumers would 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 would 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 would 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**

We are proposing that gas cans would 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 gas cans, we do not believe that a three day test would be necessary. Prior to the first day of testing, the fuel would be stabilized at the initial test temperature. Following this stabilization, a single 24-hour diurnal temperature cycle would 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 gas can as well. The fill level at the start of the test would be 50% of the nominal capacity of the gas can. Nominal capacity, defined as the volume of fuel to which the gas can can be filled when sitting in its intended position, would be specified by the manufacturer. The vapor space that normally occurs in a gas can, even when "full," would not be considered in the nominal capacity of the gas can.

#### **7.4.2 Test Fuel**

Consistent with the automotive test procedures, we are proposing 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 proposing the use of E10, which is a blend of 90% certification gasoline blended with 10% ethanol for diurnal testing of gas cans. 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 gas cans. 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 proposing to apply the same preconditioning and durability testing requirements for gas cans that we have established for permeation control requirements for recreational vehicles. We are also proposing a durability demonstration for spouts. As with the diurnal testing, the preconditioning and durability testing would be performed on the complete gas can with the spout attached and in the configuration that it would most likely be stored by the consumer.

#### **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 proposing that prior to testing the gas cans, the cans would 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 gas can would be filled with E10, sealed, and soaked for 20 weeks at a temperature of  $28 \pm 5^\circ\text{C}$ . As an alternative, we are proposing that the fuel soak could be performed for 10 weeks at  $43 \pm 5^\circ\text{C}$  to shorten the test time. During this fuel soak, the gas cans would be sealed with the spout attached. This is representative of how the gas cans would be stored in-use. We have established these soak temperatures and durations based on protocols EPA has established to measure permeation from fuel tanks made of HDPE.<sup>26</sup> 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 gas can, we would expect 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 exposure. They represent conditions that are likely to occur in-use for gas cans, 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, representing best available control, and the measured emissions are representative of in-use permeation rates. Fuel slosh, pressure cycling, and ultraviolet (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 proposing to use durability tests that are based on draft recommended SAE practice for evaluating permeation barriers.<sup>27</sup> For slosh testing, the gas can would 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 third durability test is intended to assess potential impacts of ultraviolet (UV) sunlight (0.2  $\mu\text{m}$  - 0.4  $\mu\text{m}$ ) on the durability of a surface treatment. In this test, the gas cans must be exposed to a UV light of at least 0.40 Watt-hour/meter<sup>2</sup> /minute on the gas can surface for 15 hours per day for 30 days. Alternatively, gas cans could 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.<sup>28</sup> While there are obvious differences in the use of gas cans 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 also propose to allow 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 gas cans and therefore that the durability cycles are not needed. Manufacturers would use data collected previously on gas cans 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 would have to be collected under equivalent or more severe conditions as those noted above.

In its recently revised program for gas cans, California included a durability demonstration for spouts. We are proposing 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 proposed 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 would be required to be exposed to fuel by tipping the can between each cycle. Spouts that stick open or leak during these cycles would be considered failed. 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 proposing requirements consistent with California will help manufacturers to avoid duplicate testing.

The order of the durability tests would be optional. However, we would require that the gas can 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 gas can 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 gas can is drained and refilled with fresh fuel, the spout is placed back on the container, and the gas can is tested for diurnal emissions.

#### **7.4.4 Reference Container**

We are proposing the use of a reference container during testing. In cases where the permeation of a gas can is low, and the gas can 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 gas can and create the appearance of a lighter container. Air density can be determined by measuring relative humidity, air temperature, and air pressure.<sup>29</sup>

One testing laboratory presented data to EPA on their experience with variability in weight loss measurements when performing permeation testing on gas cans.<sup>30</sup> 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.<sup>31</sup>

A more direct approach to accounting for the effects of air buoyancy is to use a reference container. In this approach, an identical gas can to that being tested would be tested without fuel in it and used as a reference gas can. Dry sand would be added to this gas can to make up the difference in mass associated with the test cans being half full of fuel. The reference gas can would then be sealed so that the buoyancy effect on the reference gas can would be the same as the test gas cans. The measured weight loss of the test gas can could then be corrected by any measured changes in weight in the reference can. The California Air Resources Board has proposed this approach for measuring gas can emissions, and they refer to the reference gas can as a “trip blank.”<sup>32</sup>

## References for Chapter 7

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<sup>1</sup> [www.arb.ca.gov/msprog/spillcon/reg.htm](http://www.arb.ca.gov/msprog/spillcon/reg.htm), Updated March 26, 2001, Copy of linked data reports available in Docket.

<sup>2</sup> Email from Jim Watson, California Air Resources Board, to Phil Carlson, U.S. EPA, "Early Container Data," August 29, 2002.

<sup>3</sup> "Test Method 513; Determination of Permeation for Spill-Proof Systems," California Air Resources Board, Adopted July 6, 2000.

<sup>4</sup> [www.arb.ca.gov/msprog/spillcon/reg.htm](http://www.arb.ca.gov/msprog/spillcon/reg.htm), Updated March 26, 2001, Copy of linked data reports available in Docket.

<sup>5</sup> Email from Jim Watson, California Air Resources Board, to Phil Carlson, U.S. EPA, "Early Container Data," August 29, 2002.

<sup>6</sup> "Durability Testing of Barrier Treated High-Density Polyethylene Small Off-Road Engine Fuel Tanks," California Air Resources Board, June 21, 2002.

<sup>7</sup> "Durability Testing of Barrier Treated High-Density Polyethylene Small Off-Road Engine Fuel Tanks," California Air Resources Board, March 7, 2003.

<sup>8</sup> Conversation between Mike Samulski, U.S. EPA and Tom Schmoyer, Sulfo Technologies, June 17, 2002.

<sup>9</sup> "Sulfo Data", E-mail from Tom Schmoyer, Sulfotechnologies to Mike Samulski, U.S. EPA, March 17, 2003.

<sup>10</sup> "ADDENDUM TO: Durability Testing of Barrier Treated High-Density Polyethylene Small Off-Road Engine Fuel Tanks," California Air Resources Board, March 27, 2003.

<sup>11</sup> "Resin and Additives - SO3 Compatible," Email from Tom Schmoyer, Sulfo Technologies to Mike Samulski and Glenn Passavant, U.S. EPA, June 19, 2002.

<sup>12</sup> Email from Jim Watson, California Air Resources Board, to Mike Samulski, U.S. EPA, "Attachment to Resin List," August 30, 2002.

<sup>13</sup> Kathios, D., Ziff, R., "Permeation of Gasoline and Gasoline-Alcohol Fuel Blends Through High-Density Polyethylene Fuel Tanks with Different Barrier Technologies," SAE Paper 920164, 1992.

<sup>14</sup> [www.arb.ca.gov/msprog/spillcon/reg.htm](http://www.arb.ca.gov/msprog/spillcon/reg.htm), Updated March 26, 2001, Copy of linked data reports available in Docket.

<sup>15</sup> "Permeation Rates of Blitz Fluorinated High Density Polyethylene Portable Fuel Containers," California Air Resources Board, April 5, 2002.

<sup>16</sup> Email from Jim Watson, California Air Resources Board, to Phil Carlson, U.S. EPA, "Early Container Data," August 29, 2002.

<sup>17</sup> [www.pensteel.co.uk/light/smp/fluorination.htm](http://www.pensteel.co.uk/light/smp/fluorination.htm). A copy of this site, as downloaded on August 13, 2004, is available in Docket.

<sup>18</sup> "Durability Testing of Barrier Treated High-Density Polyethylene Small Off-Road Engine Fuel Tanks," California Air Resources Board, June 21, 2002.

<sup>19</sup> "Durability Testing of Barrier Treated High-Density Polyethylene Small Off-Road Engine Fuel Tanks," California Air Resources Board, March 7, 2003.

<sup>20</sup> Kathios, D., Ziff, R., "Permeation of Gasoline and Gasoline-Alcohol Fuel Blends Through High-Density Polyethylene Fuel Tanks with Different Barrier Technologies," SAE Paper 920164, 1992.

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- <sup>21</sup> “Fluorination Information,” e-mail from Doug McGregor, BMW, to Mike Samulski, US EPA, August 8, 2003.
- <sup>22</sup> “Selar RB Technical Information,” Faxed from David Zang, Dupont, to Mike Samulski, U.S. EPA on May 14, 2002.
- <sup>23</sup> “Fluorination Information,” e-mail from Doug McGregor, BMW, to Mike Samulski, US EPA, August 8, 2003.
- <sup>24</sup> Fead, E., Vengadam, R., Rossi, G., Olejnik, A., Thorn, J., “Speciation of Evaporative Emissions from Plastic Fuel Tanks,” SAE Paper 981376, 1998.
- <sup>25</sup> “Quantification of Permeation and Evaporative Emissions From Portable Fuel Container”, California Air Resources Board, June 2004.
- <sup>26</sup> Final Rule, “Control of Emissions from Nonroad Large Spark-ignition engines, and Recreational Engines (Marine and Land-based)”, 67 FR 68287, November 8, 2002.
- <sup>27</sup> Draft SAE Information Report J1769, “Test Protocol for Evaluation of Long Term Permeation Barrier Durability on Non-Metallic Fuel Tanks,” (Docket A-2000-01, document IV-A-24).
- <sup>28</sup> Final Rule, “Control of Emissions from Nonroad Large Spark-ignition engines, and Recreational Engines (Marine and Land-based)”, 67 FR 68287, November 8, 2002.
- <sup>29</sup> Dickson, A., Goyet, C., “Handbook of Methods for the Analysis of the Various Parameters of the Carbon Dioxide System in Sea Water; Version 2,” Prepared for the U.S. Department of Energy, SOP21 “Applying air buoyancy corrections,” September 29, 1997.
- <sup>30</sup> Testing Services Group, “CARB TM-513: Portable Fuel Container Permeation Testing,” Presented to U.S. EPA on August 18, 2005.
- <sup>31</sup> Testing Services Group, “Technical Brief: Buoyancy Correction for Mass Measurement of Fuel Containers,” TB 50819-1, August 19, 2005.
- <sup>32</sup> California Air Resources Board, “TP-502: Test Procedure for Determining Diurnal Emissions from Portable Fuel Containers,” proposed July 22, 2005.

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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 would 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.<sup>A</sup> 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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<sup>A</sup> 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.<sup>B</sup> 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, in which 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 currently certified by manufacturers (16,867,000 vehicles sold divided by 295 durability groups) to determine an estimate of average number of vehicles sold per durability group (about 57,000 vehicles/durability group).<sup>1, 2</sup> 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 a new cold temperature NMHC standard. During discussions with manufacturers, manufacturers expressed a wide range of concern regarding their testing capabilities. Some manufacturers would 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 6 largest manufacturers that 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 would 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 would be incurred on average three years prior to the start of the program because the facilities would 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

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<sup>B</sup> We estimated costs using \$60 per engineering hour and \$2,500 per test.

\$73,500,000. We projected that the facilities costs would be recovered over 10 years of production 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.<sup>3</sup> 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**

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, our estimated per vehicle cost increase due to the new standards is relatively small. We estimate the average per vehicle cost would 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 are proposing cold temperature standards that we believe are feasible for Tier 2 vehicles. We are also proposing 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 would 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.

### **8.1.4 Annual Total Nationwide Costs**

To estimate annual costs, we distributed the R&D costs over the phase-in schedule shown below and amortized the costs over a 5 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 (HLDV/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 would not expect the phase-in schedule to impact facilities upgrades. Manufacturers would 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	LDV/LLDT	HLD/MDPV	Facilities	
Year	Cost	Cost	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	HLD/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 proposed standards for evaporative emissions, which are equivalent to the California LEV II standards, are technologically feasible now. As discussed earlier in Chapter 5 (*Technological Feasibility*), 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, some manufacturers view the programs as similar in stringency. (See Section VI.C.5 of the proposed rule for further discussion of such test differences -- e.g., test temperatures and fuel volatilities.) Thus, some manufacturers have indicated that they are producing 50-state evaporative systems that meet both sets of standards (manufacturers sent letters indicating this to EPA in 2000).<sup>4,5,6</sup> In addition, a review of recent model year certification results indicates that essentially all manufacturers certify 50-state evaporative emission systems.<sup>7</sup> 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. Therefore, harmonizing with California's LEV-II evaporative emission standards would streamline certification and be an "anti-backsliding" measure -- that is, it would prevent future backsliding as manufacturers pursue cost reductions. It also would codify the approach manufacturers have already indicated they are taking for 50-state evaporative systems.

## References for Chapter 8

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<sup>1</sup> Ward's Automotive Yearbook 2005, Calendar Year 2004 Light-duty Vehicle Sales.

<sup>2</sup> Certification data for the 2005 model year.

<sup>3</sup> 40 CFR Subpart C.

<sup>4</sup> DaimlerChrysler, Letter from Reginald R. Modlin to Margo Oge of U.S. EPA, May 30, 2000. A copy of this letter can be found in Docket No. EPA-HQ-OAR-2005-0036.

<sup>5</sup> Ford, Letter from Kelly M. Brown to Margo Oge of U.S. EPA, May 26, 2000. A copy of this letter can be found in Docket No. EPA-HQ-OAR-2005-0036.

<sup>6</sup> General Motors, Letter from Samuel A. Leonard to Margo Oge of U.S. EPA, May 30, 2000. A copy of this letter can be found in Docket No. EPA-HQ-OAR-2005-0036.

<sup>7</sup> U.S. EPA, Evaporative Emission Certification Results for Model Years 2004 to 2006, Memorandum to Docket EPA-HQ-OAR-2005-0036 from Bryan Manning, February 9, 2006.

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## **Chapter 9: Cost of Proposed Gasoline Benzene Standard and Other Control Options Considered**

This chapter provides a summary of the methodology used and the results obtained from our cost analyses of the proposed benzene standard as well as various other 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 proposed rule followed by the results. We present the results from our energy and supply analyses for our proposed benzene control program. Finally, we summarize the results of other cost estimates for toxics control.

### **9.1 Methodology**

#### **9.1.1 Overview**

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 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.<sup>1</sup> 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 the feasibility section. 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 cases 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 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 technologies which should be used and 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 off 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.<sup>2</sup> 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 control standard.

This strategy results in the optimum selection of benzene control technologies consistent with how the cost of a benzene standard under an ABT program would be expected to affect benzene control investments by the refining industry. For this reason, the refinery-by-refinery cost model was used to estimate the cost for various benzene control standards both with and without ABT programs, and the LP refinery model was used for the other air toxics control programs considered. Because certain 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 used in the refinery-by-refinery cost model is described in the section describing the methodology used with the refinery-by-refinery cost model.

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 evaluated in 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 sort of review was conducted on the model by comparing its cost estimates for benzene control with a benzene control case evaluated with the LP refinery cost model. 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. The peer review comments are summarized later on in this section and appropriate adjustments will be made for the final rule. Waiting to address the peer review comments until the final rule is judged to be acceptable because the changes are not expected to cause a significant difference in the benzene control cost estimates. This judgment is partially based on

our review of the peer review comments, and partially based on the fact that the refinery-by-refinery cost model's benzene control costs agree well with those from the LP refinery cost model. Finally, many of the inputs used in the refinery-by-refinery cost model are from the LP refinery model, a dependable source.

A key assumption associated with the analysis is that the benzene reduction technologies being considered are those which reduce benzene levels from the feed or product streams of the reformer, the unit in the refinery which produces most of the benzene in gasoline.<sup>3</sup> Basing the cost of this program on reformat benzene reduction technologies is reasonable because reformat contains the highest concentrations of benzene and reformat 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 reformat benzene levels. Thus, reducing benzene from reformat would be expected to be the most cost-effective means for achieving benzene control. 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 reformat benzene control at other refineries—reducing the costs of the program. A detailed discussion on the technologies available for benzene control is discussed in Chapter 6 of this Regulatory Impact Analysis.

A number of potential air toxics control programs were considered for this proposed rulemaking. These include the proposed benzene control program and several variants of the benzene standard. 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. We evaluated some of these alternative benzene control standards with a second benzene control standard called a maximum-average (max-avg) standard. The max-avg 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 max-avg standard would require them to meet or exceed the max-avg standard in each refinery before purchasing credits to show compliance with the average standard. For example, a refinery with a gasoline benzene level of 2 volume percent and faced with a 1.3 vol% max-avg 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 volume percent max-avg limit. The addition of a max-avg standard would force several high cost refineries to take additional benzene control steps not required by the 0.62 volume percent average standard alone. This in turn would allow other low-cost refiners who would have been generating credits for sale to these refineries to back off on control. The addition of a max-avg standard would thus tend to increase the cost of a benzene control program over a program without a max-avg standard.

We also evaluated a benzene control standard without an ABT program. This type of benzene control 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 control program without an

ABT program would likely result in a national average benzene level that is lower than the standard.

The air toxics performance standards studied were various extrapolations on the existing RFG, Anti-dumping and MSAT1 standards, based on toxics performance as estimated by the Complex Model. The low RVP programs studied would expand the volume of already existing low RVP programs. The low sulfur program studied would more stringently regulate the sulfur content of gasoline nationwide.

The proposed benzene control program and other benzene control standards evaluated are summarized in Table 9.1-1 and 9.1-2.

**Table 9.1-1. Benzene Control Standards Modeled using Refinery-by-Refinery Model**

Average Std.	Avg.-Max Std.	ABT Program
0.52	None	Yes
0.60	1.3	Yes
0.60	None	Yes
0.62	1.3	Yes
0.62	None	Yes
0.65	1.3	Yes
0.65	None	Yes
0.70	1.3	Yes
0.70	None	Yes
0.73	None	No

**Table 9.1-2. Air Toxics and Other Standards Modeled using LP Refinery Model**

Total Air Toxics with and without Benzene Standards	21.5 Total Toxics Reduction std. on CG <sup>a</sup>
	25% and 35% Total Toxics Reduction std. on CG and RFG, respectively
	0.5 vol% avg. Bz std. on CG and RFG <sup>b</sup>
Low RVP	7.8 maximum RVP std on CG <sup>c</sup>
	7.0 maximum RVP std on CG <sup>d</sup>
Sulfur	10 ppm average std on CG and RFG

<sup>a</sup> The 21.5 percent reduction in total air toxics standard applied to CG is the air toxics standard which was established for RFG in the RFG rulemaking. The reduction is measured relative to average gasoline quality in 1990 (CAA baseline) the quality of which was codified in the Clean Air Act.

<sup>b</sup> This set of air toxics case reduction standards was designed to cost out a maximum total air toxics reduction with a slightly less stringent standard for CG, and proportionally more stringent standard for RFG. The benzene standard was picked to be consistent with the stringency of the total air toxics standard, ensuring benzene content reduction in both CG and RFG.

<sup>c</sup> The 7.8 RVP standard already applies to a part of CG in the U.S. This case modeled a volume of CG lowered to 7.8 RVP equivalent to 50% of the volume of RFG in each PADD.

<sup>d</sup> The 7.0 RVP standard applies to a part of CG in the U.S. This case modeled the same volume affected as the 7.8 RVP standard.

All the refinery modeling case studies were conducted on a summer only basis. This is commonplace for refinery modeling studies since it captures what is generally accepted as the higher cost season for complying with gasoline quality controls. Summertime is also the

appropriate season for studying RVP controls. Studying the costs of gasoline benzene and toxics control only during the summer can lead to somewhat conservative cost estimates.

The cost analysis of the benzene control program includes the participation of California refineries. At the time that the analysis was conducted the decision not to cover California gasoline under the proposed benzene standard had not yet been made. If for the final rule California gasoline is still not covered, the California refineries will not be modeled along with the rest of the U.S. refineries for estimating the cost of the final benzene control program. Not including California refineries in our cost analysis is not expected to have a significant impact on costs since California RFG already averages about the same benzene level as the level we are proposing.

The cost results for the proposed benzene control standard and other air toxics control cases are reported by PADD. This allows one to view the potential impact of the proposed standard on a region-by-region 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 LP Refinery Modeling Methodology**

The LP refinery model was used for estimating the cost for various total air toxics standards, decreasing the RVP of conventional gasoline and lowering the sulfur content of gasoline. Although the benzene control costs considered for this proposed 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 proposal. The information from the LP refinery model used in the refinery-by-refinery model included the 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 output factors from the LP refinery model were 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.<sup>4</sup> 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). At the time that the LP refinery modeling work was being conducted, the air toxics program was assumed to take effect in 2010. 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 2010 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.<sup>5</sup> 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 air toxics programs 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 basecase. At the time that the LP refinery modeling was being conducted, the House and Senate were both considering passing their own Energy Bills. Because no Energy Bill was passed at that time, we modeled a reference case which only contained the state MTBE bans. However, an eventual Energy Bill seemed likely so we also established a reference case with an Energy Bill. For the second reference case, the leading Senate energy bill at that time was assumed to be in effect for

the second reference case. The energy bill modeled included a nationwide ban on MTBE, rescinding the RFG oxygenate standard, and a Renewable Fuels Standard which required 5 billion gallons of ethanol to be blended into gasoline in 2012.<sup>6</sup> Based on the yearly RFS schedule for blending in ethanol, the reference cases modeled the usage of 4.3 billion gallons of ethanol for 2010.

The third step in conducting the LP refinery modeling was to run the various control cases. The control cases are created by inserting the specific fuel control standards into each PADD reference case. The control cases are run with capital costs evaluated at a 10 percent rate of return on investment (ROI) after taxes. The refinery model output for each PADD are 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. For each case modeled, the energy density of each finished gasoline type is reported. The cost of each case is adjusted for changes in energy density using the wholesale gasoline price estimated by the refinery model.

### **9.1.3 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 2003 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 four refineries, we had gasoline blendstock volumes and benzene levels which the refining companies shared with us in our previous discussions with them concerning air toxics control. This specific refinery information provided to us was entered into the refinery-by-refinery model avoiding the need to estimate it.

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 10 percent rate of return on investment (ROI) after taxes, but were adjusted after-the-fact 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 prioritized to meet the various benzene control standards. This provides us a cost estimate as if the program were taking effect in 2003

Finally, we adjusted the cost results from 2003 to 2010 based on the projected increase in volume between those two years.<sup>a</sup> EIA projects gasoline demand for 2010 to be 15 percent greater over 2003.<sup>7</sup> Aggregate total costs are increased by 15 percent to reflect this increased volume. Capital costs are also adjusted higher but by only 9 percent which takes into account the economies of scale of larger capital investments.

### **9.1.3.1 Individual Refinery Gasoline Blendstock Volumes**

Information on the volumes 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.<sup>8 9</sup> Information from these two sources was reviewed for the year 2003, 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, including coking, fluidized catalytic cracking (FCC), hydrocracking, alkylation, dimersol, polymerization, isomerization, reforming and aromatics extraction.

An initial assumption was made that each unit is being operated at the percent of capacity available for that group of refineries based on the basecase conditions in the LP refinery model. The initial assumptions of the percent of capacity utilization that each unit is estimated to be operating by the LP refinery model at is presented in Table 9.1-3.

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<sup>a</sup> For the final rule, the costs will be adjusted to the represent the costs in the year that the benzene control program is projected to start.

**Table 9.1-3. Initial Percent of Refinery Unit Capacity used in Refinery-by-Refinery Cost Model**

	PADD 1	PADD 2	PADD 3	PADD 4 & 5 Outside of CA	CA
Crude	101	100	96	92	101
Coking	89	134	76	90	96
FCC	106	104	94	96	89
Hydrocracker	100	101	80	111	96
Isomerization	89	75	83	102	100
Polymerization	120	117	0	46	0
Alkylation	113	100	96	98	96
Reforming	88	84	82	73	81
Aromatics	53	62	77	0	0

The estimates of refinery unit capacity utilized in Table 9.1-3 are a product of how the LP refinery model models the use of refinery units in each PADD of refineries. Normally, we would expect 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 have no idea 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. Since a number of the average operating characteristics are taken from the LP refinery model, we chose to use the LP refinery model's estimated refinery utilization factors to be internally consistent.

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 9.1-3, 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 9.1-3 shows that the alkylation units in

PADD 1 are estimated to be operating at 113 percent of its listed capacity, thus, alkylate production is 11,300 barrels per day.

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 9.1-3 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.<sup>10</sup> 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 9.1-4, the volume of light straight run naphtha is estimated to be 3 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 1, a portion is designated to be sold into the petrochemicals market. For PADDs 2-5, 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.<sup>11</sup> 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 21 to 29 percent for hydrocracker units depending on the PADD. Table 9.1-4 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 of 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 to 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 in the basecase 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 only 12 refineries in the U.S. 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 40 to 80 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 22 percent relative to the volume of feed due to the conversion of straight chain 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. The severity of reformer operations for California refineries is estimated to be a very low 93 research octane number (RON)<sup>b</sup> reflecting the stringent benzene and aromatics standards

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<sup>b</sup> 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.

which apply there. For the rest of the PADDs, the reformer severity falls within a narrow range of 99 to 100 RON.

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 9.1-3. 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 56 percent.

Some gasoline blendstocks are purchased and blended directly into gasoline. The typically purchased gasoline blendstocks include natural gasoline, alkylate, and oxygenates. 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. 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 9.1-3. This strategy was effective for the refineries in PADD 2 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 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.

The various assumptions associated with estimating gasoline blendstocks and the volumes of purchased and sold blendstocks are summarized in Table 9.1-4.

**Table 9.1-4. Information used with Refinery-by-Refinery Cost Model (2003)**

		PADD 1	PADD 2	PADD 3	PADDs 4, 5	CA
Hydrogen Cost (\$/foeb)		66.3	75.6	63.8	56.6	65.2
Octane Cost (\$/oct-bbl)		0.21	0.21	0.18	0.48	0.73
Gasoline Price (\$/bbl)		31.0	32.7	29.2	32.7	37.2
Light Straight Run Naphtha (% of Crude Oil)		4.5	5.0	4.0	4.5	3.0
Medium and Heavy Straight Run Naphtha (% of Crude Oil)		13.7	16.2	13.4	13.5	9.4
Reformate Severity (RON)		99	100	100	100	93
Average Reformate Yield (vol%)		78	77.5	77.5	76	82
Light Coker Naphtha (% of Unit feed)		5	5	5	5	5
Medium and Heavy Coker Naphtha (% of Unit Feed)		18.4	18.4	18.4	18.4	18.4
Light Hydrocrackate (% of Unit feed)		28.5	28.5	26.3	20.5	20.5
Medium and Heavy Hydrocrackate (% of unit feed)		79	79	69	40.5	40.5
FCC Naphtha (% of feed)		56.3	56.6	56.8	56.4	56.4
Aromatics (% of Unit Capacity)		As necessary	0.62	As necessary	-	-
Inputs	Alkylate Purchased (Kbbl/d)	0	0	0	0	40
	Natural Gasoline (Kbbl/d)	0	37	69	37	0
	Ethanol (Kbbl/d)	0	79	0	8	8
Outputs	Naphtha to Petrochem. (Kbbl/d)	0	6	119	4	4
	Gasoline Blendstocks Kbbl/d)	0	0	52	8	8

### 9.1.3.2 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 reformat, is summarized in Table 9.1-5.

**Table 9.1-5. 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)	10.8
Light Reformate (with complete benzene precursor rerouting)	1.00
Light Reformate (with benzene extraction)	0.10
Light Reformate (with benzene saturation)	0.44
Heavy Reformate – Semi-Regen (High Press.)	1.9-2.4
Cyclical (Medium Press.)	1.75-2.2
Continuous (Low Press.)	0.87-1.1
Heavy Reformate – High Press.	0.02
(with benzene Medium Press.	0.02
Extraction) Low Press.	0.01
Heavy Reformate – High Press.	0.075-0.095
(with benzene Medium Press.	0.07-0.09
Saturation) Low Press	0.035-0.04

### 9.1.3.3 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. 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 2003 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 9.1-6.

**Table 9.1-6. Calibrated Consumption and Production volumes for Crude Oil and Gasoline by PADD (kbbl/day)**

	<b>PADD 1</b>	<b>PADD 2</b>	<b>PADD 3</b>	<b>PADDs 4, 5</b>	<b>CA</b>
Crude Oil Consumed (Kbbl/d)	1489	3227	6880	1228	1858
Gasoline Produced (Kbbl/d)	1017	1805	3389	536	1083

The initial summertime benzene level of each refinery's gasoline estimated with the refinery-by-refinery model was also calibrated against the reported benzene content of summertime gasoline in 2003 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 2003 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.

## **9.2 Cost Inputs for 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. Information was obtained for routing benzene precursors around the reformer, routing that rerouted benzene precursor stream to an isomerization unit, installing two technologies for benzene saturation, and installing benzene extraction.

### **9.2.1 Benzene Precursor Rerouting**

Routing benzene precursors around the reformer requires that the refinery's naphtha splitter distillation column 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 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. 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 modifying the naphtha splitter to facilitate routing benzene precursors around the reformer is summarized in Table 9.2-1.<sup>12</sup> 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.<sup>13</sup>

**Table 9.2-1. Cost Inputs for Rerouting Benzene Precursors**

Capital Costs – onsite and offsite <sup>c</sup> (\$MM)	7.3
Capital Cost Unit Size (bbl/day feedstock)	15,000
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 100 RON)**

Catalyst Cost (\$/bbl)	0.357
Fuel Gas (foeb/bbl)	0.049
Electricity (kwh/bbl)	2.6
Steam (lb/bbl)	75
Hydrogen (foeb/bbl feed)	0.048
Plant Gas (foeb/bbl feed)	0.062
Propane (bbl/bbl feed)	0.061
Isobutane (bbl/bbl feed)	0.021
Butane (bbl/bbl feed)	0.036

## 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 increases the octane by producing branched chain compounds. The isomerized six carbon stream is estimated to have an octane value of  $77.4 (R+M)/2$ . 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 control and not build a new isomerization unit nor increase an existing unit's capacity.<sup>d</sup> 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. Therefore, for some

<sup>c</sup> 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.

<sup>d</sup> 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.

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.<sup>14</sup>

**Table 9.2-3. Cost Inputs for Sending the Rerouted Benzene Precursors to an Isomerization Unit**

Hydrogen (foeb/bbl)	0.002
Natural Gas (foeb/bbl)	0.009
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 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 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, lowering the capital costs. A review of the capital cost inputs of the two benzene saturation technologies confirms this. 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.<sup>15 16 17</sup>

**Table 9.2-4. Cost Inputs for Benzene Saturation**

Inputs	Bensat	CDHydro
Capital Cost – onsite and offsite (\$MM)	10.9	8.7
Capital Cost Unit Size (bbl/day feedstock)	8,000	8,000
Capital Cost Scaling Factor	0.65	0.65
Hydrogen (foeb/bbl)	0.044	0.044
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 proposed 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 reformat using a reformat 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 newly installed benzene extraction unit. The benzene-rich stream off the reformat 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 reformat 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 reformat 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 reformat splitter, a benzene extraction unit and the associated distillation hardware which concentrates the benzene, including a clay treater. The capital costs estimated for this proposed rule, assume 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. We developed an average capital cost for new and revamped extraction units to apply for all refineries eligible for extraction. 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.<sup>e</sup> Utility costs are incurred for operating the various units. Table 9.2-5 contains the capital and utility cost inputs to the refinery-by-refinery cost model for benzene extraction.<sup>18</sup>

**Table 9.2-5. Cost Inputs for Benzene Extraction**

Capital Costs – onsite and offsite (\$MM)	32.9
Capital Cost Unit Size* (bbl/day product)	2000
Capital Cost Scaling Factor	0.65
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 reformat 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 reformat to a neighboring refinery which does extract benzene. For our year 2003 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 reformat 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 unit would process the benzene rich reformat of other refineries to comply with the proposed benzene control standard.

### 9.3 Other Inputs into the Refinery-by-Refinery Cost Model

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<sup>e</sup> 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.

A series of inputs are made to the refinery-by-refinery cost model which are necessary to conduct the cost modeling. These inputs are from various sources including published literature and from the LP refinery model.

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 \$27 dollar per barrel.<sup>19</sup> Subsequent to this analysis, EIA has revised their energy forecasts upward.<sup>20</sup> These new forecasts will be incorporated into the FRM analysis.

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 reduces 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.<sup>21</sup>

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 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 9.3-1 summarizes the various cost factors used in the refinery-by-refinery cost model by PADD.

**Table 9.3-1. Cost Factors by PADD**

	PADD 1	PADD 2	PADD 3	PADDs 4 & 5
Hydrogen \$/foeb	66.34	75.6	63.79	56.56
Octane \$/octane-bbl	0.21	0.21	0.18	0.48
Wholesale Gasoline Price \$/bbl	31.0	32.7	29.18	32.7
Natural Gas \$/foeb	36.02	32.14	22.81	27.07
Electricity \$/kw-hr	0.065	0.044	0.046	0.043
Capital Cost Adjustment Factors	1.25	1.15	1.00	1.40

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 is 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.<sup>22</sup> 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 9.3-2.

**Table 9.3-2. 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 confirms that lowering gasoline benzene levels by extracting it from reformate and selling the concentrated benzene into the chemicals market is a viable way for reducing gasoline benzene levels. This information is used below as the basis for estimating the price impacts for benzene that would be extracted from gasoline to meet the proposed benzene control standard.

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, the most recent year that complete information is available from the CMAI report, are summarized in Table 9.3-3.

**Table 9.3-3. 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 and demand. 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. The U.S. historical prices for benzene, gasoline and the difference between them for the four years prior to 2004 are summarized in Table 9.3-4.

**Table 9.3-4. Historical U.S. Benzene Price**

Year	Benzene Price (\$/bbl)	Gasoline Price (\$/bbl)	Benzene Price above Gasoline Price (\$/bbl)
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

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 2003 consistent with increasing demand as the economies in recession 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.

CMAI used its economic model to project the benzene market in the medium term during the future years from 2004 through 2008. CMAI starts by establishing a basecase which was based on the information on the benzene market in 2003. 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 near future 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. World benzene and U.S. benzene demand are expected to increase annually by 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 higher benzene prices in 2004. As additional benzene production capacity comes on line, benzene prices are expected to come down to more traditional 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 9.3-5 summarizes the projected benzene and gasoline prices obtained from the CMAI report.

**Table 9.3-5. Projected U.S. Benzene Price**

Year	Benzene Price (\$/bbl)	Gasoline Price (\$/bbl)	Benzene Price above Gasoline Price (\$/bbl)
2004	73.3	35.2	38.1
2005	56.2	23.6	32.6
2006	50.1	31.3	18.8
2007	50.4	31.2	19.2
2008	51.2	31.8	19.4

The CMAI model estimates that the price of benzene in 2004 will be \$38 higher than gasoline. As additional benzene production capacity comes on line, the benzene prices are expected to come down to just under \$19 per barrel above gasoline, and then track upwards slightly. The projected prices for 2006 to 2008 are consistent with the historical price for benzene. To select the benzene price to use in our cost analyses, we considered CMAI's projected benzene price and that the benzene prices are trending upward slightly from 2006 to 2008. We therefore rounded the price of benzene to \$20 per barrel higher than gasoline.

As we were conducting our cost analysis in 2004 for various possible air toxics control programs, we learned that benzene prices were significantly higher than the already high prices estimated by CMAI for 2004. Early in 2004, benzene prices were \$40 to \$50 per barrel higher than gasoline. We became concerned that using a benzene price which is \$20 per barrel higher than gasoline might be too low. We decided to conduct a sensitivity analysis at the benzene price level estimated by CMAI for 2004, which is \$38 per barrel higher than gasoline. Sometime during 2005 we found out from CMAI that benzene prices average over \$70 per barrel higher than gasoline for 2004. Thus, even our sensitivity analysis may not bracket the range of benzene prices which could occur considering the very robust demand for benzene.

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 22,000 barrels per day, which is 337 million gallons per year, of benzene would be extracted from gasoline under the proposed benzene control program in 2011.

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 337 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 toluene would remain in the gasoline pool helping to maintain the octane 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.<sup>23 24</sup> For these reasons, we used the projected chemical benzene price of \$20 per barrel higher than gasoline for our principal analysis, and \$38 per barrel for our sensitivity analysis.

## **9.4 Refinery Modeling of Benzene Control Scenarios**

For the proposed benzene control 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 cost effectiveness until the sum of the technologies and refineries chosen results in the U.S. gasoline being produced averaging 0.62 volume percent benzene, giving credit to refineries already below the proposed benzene standard.

For the cases we modeled that involve a maximum-average (max-avg) standard in addition to an average benzene standard, modeling the costs for such cases requires a different modeling methodology. Refineries that the model estimates would be above the max-avg standard are assumed to put in the most cost-effective benzene reduction technology which the model shows them getting below the max-avg standard. The units that the model adds to meet the max-avg standard are assumed to be operated to achieve the maximum possible amount of benzene reduction. The benzene reductions associated with meeting the max-avg standard may or may not be sufficient for meeting the average standard depending on how stringent the max-avg 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.

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, a full sized unit is installed to treat the entire stream being treated, but that 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. This evaluation was conducted in two ways. The first way involved a comparison of the cost output of the refinery-by-refinery cost model with the cost

output of the LP refinery model for the same benzene control case. The second way was through a thorough a peer review process conducted by two refinery industry consulting firms.

We evaluated a stringent nationwide 0.5 volume percent benzene control standard with the LP refinery model that closely matched the 0.52 volume percent standard modeled with the refinery-by-refinery cost model.<sup>f</sup> As expected, the LP refinery cost model produced higher costs than the refinery-by-refinery cost model. The costs are expected to be higher because the LP refinery model inherently averages costs only across the refineries in each PADD, while the refinery-by-refinery cost model averages costs across the entire country through the national ABT program. The LP refinery model projects deeper benzene reductions in PADDs 4 and 5 than the refinery-by-refinery cost model, which results in higher estimated cost of compliance using the LP refinery model. Estimated costs of compliance for PADDs 1 and 3 are roughly the same under either model. Despite estimated benzene control levels which are identical between the two models for PADD 2, the LP refinery model estimates higher costs for PADD 2. 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 0.5 Volume Percent Benzene Control Case**

		PADD 1	PADD 2	PADD 3	PADDs 4 & 5	U.S. Average
Refinery-by-Refinery Cost Model	Cost (cents/gal)	0.10	0.79	0.10	1.20	0.36
	Bz Level (vol%)	0.48	0.50	0.52	0.62	0.52
LP Refinery Cost Model	Cost (cents/gal)	0.13	1.05	0.07	1.75	0.49
	Bz Level (vol%)	0.50	0.50	0.50	0.50	0.50

Peer reviews on the refinery-by-refinery cost model were conducted by Jacobs Engineering and A Second Opinion.<sup>25, 26</sup> 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 reviews agreed with aspects of the refinery modeling and took issue with other aspects. We believe that overall, the two reviews support the refinery-by-refinery cost model and accounting for their comments would not significantly affect the costs estimated by the refinery modeling. Both reviews 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. One reviewer found that the cost inputs for the various technologies were about right, while the other reviewer found that some costs differed from what they expect – both higher and lower than expected. 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

<sup>f</sup> We also evaluated a 0.65 benzene control standard with the LP refinery model, however, the choice of benzene control technologies differed which greatly complicated any comparison with the refinery-by-refinery cost model.

when benzene saturation is applied – removing this modeling method should reduce the cost of the program.

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.

One reviewer commented that using the next increment of octane cost from the LP refinery model might underestimate the cost of making up lost octane since several increments of octane might be necessary, and second and later increments of making up this lost octane could be more expensive. Our analysis of the octane made available from the Renewable Fuels standard mandated by EPAAct reveals that the octane forced into the gasoline pool would make up for the octane loss from this proposed program several times over, and should ensure that many increments of octane recovery could be made available at about the same price.

One comment suggested using a scheme for projecting how refiners would choose a benzene control technology based much more heavily on the level of capital costs associated with each technology rather than on overall costs. The commenter suggested that since refiners are somewhat conservative when it comes to spending money on capital for their refineries, that this might be a better basis. Our analysis already values capital costs higher than other costs by assuming that refiners would choose their technology based on a 10 percent hurdle rate-of-return (ROI) after taxes, then we adjust the costs to a 7 percent ROI before taxes to report the costs. An even higher ROI assumption could be used to more highly value new capital investments.

In summary, the peer reviews generally supported the refinery-by-refinery cost model. We will use the comments to focus our review of the refinery-by-refinery cost model for the final rule on certain specific parts of the model. These include the cost inputs for the various technologies, the cost for octane recovery, and the means for estimating the benzene control technology that would be chosen by refiners, especially whether capital costs should play a larger role.

## **9.6 Refining Costs**

This subsection summarizes the estimated costs of the proposed benzene control program as well as the other air toxics control standards considered for this proposed rulemaking. The estimated cost for the proposed 0.62 volume percent benzene standard with ABT program is summarized first, including the sensitivity cases described above. We next summarize the estimated cost for other variations of the 0.62 volume percent benzene standard which includes an average-maximum standard or which models a benzene control program without an ABT program. We then summarize the estimated costs for other benzene control standards that we considered. Finally we summarize the costs for several total air toxics standards and low RVP and sulfur control programs. Although we included California refineries in the modeling of the

proposed benzene control program, their participation and associated costs were minimal so we therefore are not reporting their costs in the following tables.

### 9.6.1 Cost of the Proposed 0.62 vol% Benzene Standard

The refinery-by-refinery cost model was used to estimate the cost of the proposed 0.62 volume percent average benzene standard under a nationwide 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 control technologies in the refinery-by-refinery cost model is (naturally) affected by the nature of the stringency of the benzene reduction program being modeled. The cost model indicates that extraction is the most cost-effective technology followed by benzene precursor rerouting alone, or precursor rerouting coupled with isomerization. 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 as the means for achieving benzene control. We assume that the ABT program would be fully utilized with credit trading occurring freely within and between refining companies.

The proposed 0.62 benzene standard with ABT program is estimated to cost 0.13 cents per gallon averaged over all gasoline and with capital costs amortized at 7% ROI before taxes. The total capital cost is \$500 million, the total annual cost including amortized capital costs is \$170 million/yr.

The 0.13 cents/gal 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 volume percent. When the costs are averaged only over the portion of U.S gasoline which is expected to be reduced in benzene, the proposed program is expected to cost 0.20 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 \$6 million and \$1 million, respectively. These estimated costs for the proposed benzene standard are summarized in the Table 9.6-1.

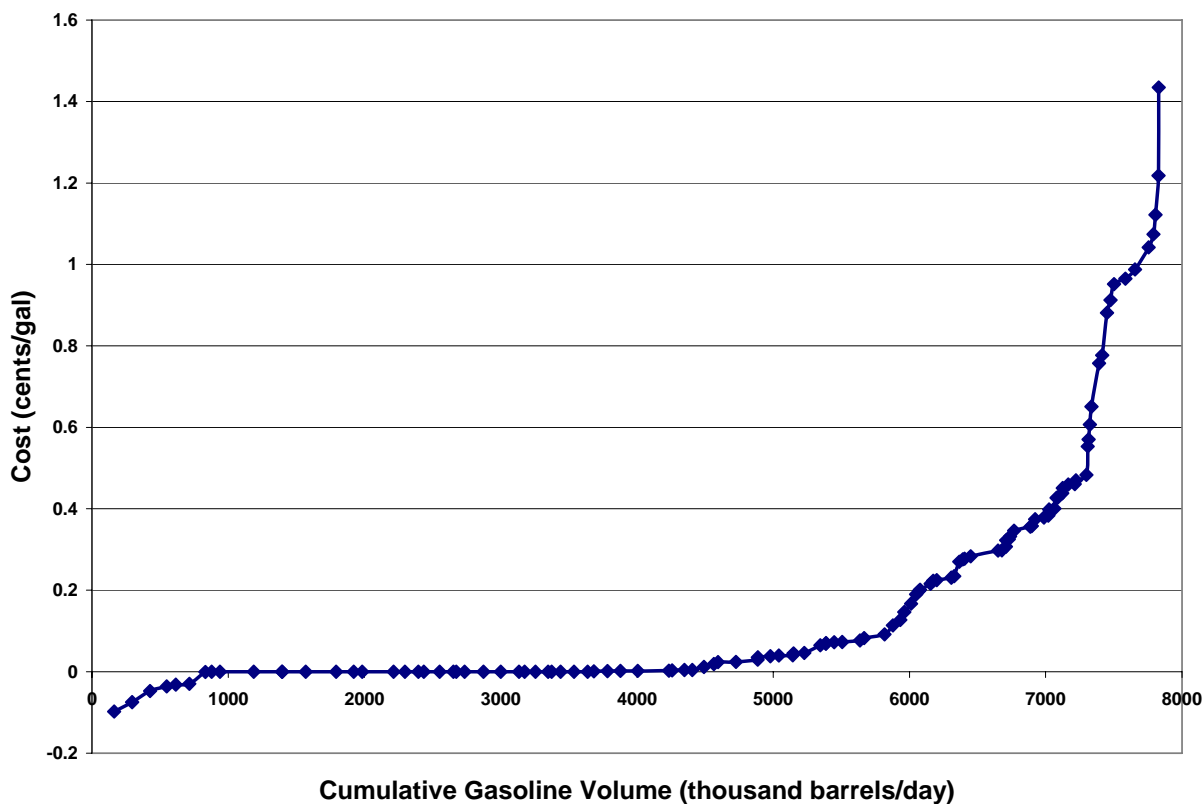
**Table 9.6-1. Estimated Costs of the Proposed 0.62 vol% Average Benzene Standard with ABT Program**  
(2003 dollars, 7% ROI before taxes, benzene priced at \$20/bbl higher than gasoline)

All Refineries	Number of Refineries	115
	Total Capital Cost (\$ million)	500
	Total Annual Cost (\$ million/yr)	170
	Per-Gallon Cost (cents/gallon)	0.13
Refineries Reducing Their Gasoline Benzene Levels	Number of Refineries	88
	Capital Cost per Refinery (\$ million)	6
	Operating Cost per Refinery (\$ million/yr)	1
	Per-Gallon Cost (cents/gal)	0.20

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 proposed standard, or 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. 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.

**Figure 9.6-1. U.S. Refinery Per-Gallon Costs for the Proposed Benzene Control Program (2003 dollars, 7% ROI before Taxes, benzene priced \$20/bbl higher than gasoline)**



As discussed above, a sensitivity case was run assuming that the price of benzene remains high as it was estimated to be in 2004, at \$38/ bbl higher than gasoline. In this case, the cost of the proposed benzene control program decreases to 0.05 cents per gallon. Sensitivity cases were also run for amortizing capital costs at 6 and 10 percent ROI after taxes. These result in per-gallon costs at 0.13 and 0.15 cents per gallon, respectfully. Table 9.6-2 summarizes the per-gallon costs of the ROI sensitivity cases of the proposed benzene control program.

**Table 9.6-2. Alternative Capital Amortization Return on Investment (ROI) for the Proposed Benzene Control Program (benzene \$20/bbl higher than gasoline)**

Capital amortized at 6% ROI after taxes	Capital amortized at 10% ROI after taxes
0.13 cents/gal	0.15 cents/gal

To comply with the proposed benzene standard, we expect that all of the control technologies discussed above would be utilized. Of the 88 refineries expected to take steps to reduce their gasoline benzene levels, 54 are expected to route all of the benzene precursors around the reformer, and 28 of those 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 reformat, 23 would install benzene extraction units or revamp their existing extraction units while the other 11 would install benzene saturation units.

While the estimated per-gallon costs are very low, there is a range in costs depending on the area of the country. 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 rest of the PADDs because extraction is not an option due to lack of benzene markets. The average per-gallon benzene control costs for each PADD are summarized in Table 9.6-3.

**Table 9.6-3. Per-Gallon Costs by PADD for the Proposed 0.62 vol% Benzene Control Program (cents/gal; 2003 dollars; 7% ROI before taxes; benzene priced \$20/bbl higher than gasoline)**

<b>PADD 1</b>	<b>PADD 2</b>	<b>PADD 3</b>	<b>PADD 4</b>	<b>PADD 5 except CA</b>
0.05	0.25	0.05	0.40	0.72

In each PADD, the average costs in Table 9.6-3 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  
Proposed Benzene Control Program  
(2003 dollars, 7% ROI before Taxes, benzene priced \$20/bbl higher than gasoline)**

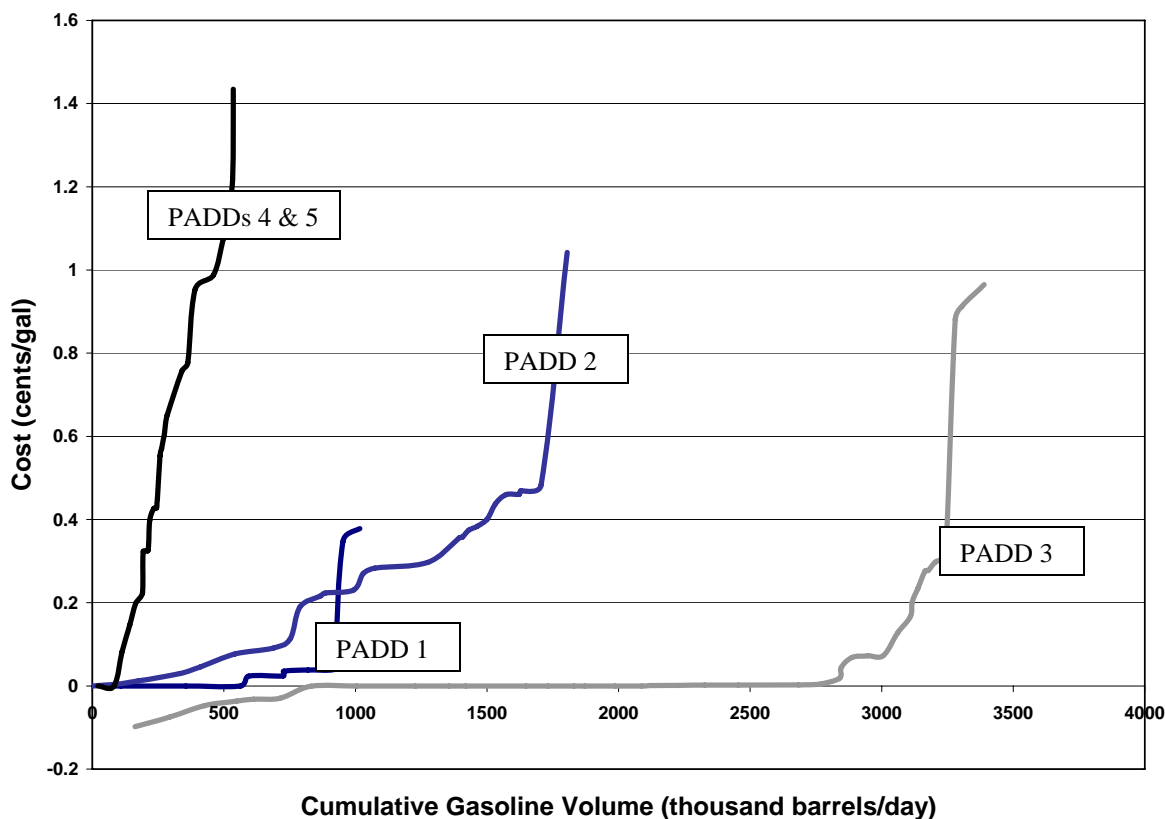


Figure 9.6-2 shows a significant range in costs by the refineries in each PADD. PADD 1 and 3 costs are similar with most costs being incurred through extraction which results in near zero (and in a few cases slightly less than zero) costs, as well as zero costs for refineries which do not need to take any action due to already low benzene levels. The refineries in PADDs 4 and 5 face higher costs, but what differentiates the costs in these two PADDs from the other PADDs is the consistently higher costs across the PADDs. The refinery costs in PADD 2 is more moderate for most of the refineries than those in PADDs 4 and 5, but still more severe than the costs for the refineries in PADDs 1 and 3.

We estimated the stream of total annual compliance costs for the U.S. refining industry complying with the proposed benzene control program from 2011 to 2035. We projected the estimated 2003 total annual program costs to 2011, the proposed start date of the program, using projected gasoline demand by the Energy Information Administration (EIA). The total annual costs for 2012 to 2035 are also projected using the projected growth in demand by EIA. Since the EIA projections end at 2025, we used the annual average growth rate over the years 2020 to 2025 to extrapolate the growth in demand to 2035. The stream of projected gasoline consumption volume and the total annual costs for complying with the proposed benzene control program are summarized in Table 9.6-4.

**Table 9.6-4. Stream of Total Compliance Costs for the  
Proposed Benzene Control Program  
(2003 dollars, 7% ROI before Taxes, Benzene priced \$20/bbl higher than gasoline)**

Year	Gasoline Volume (million gallons)	Total Program Cost (million dollars)
2011	156,020	185.5
2012	158,694	188.7
2013	161,352	191.9
2014	164,069	195.1
2015	166,742	198.3
2016	169,230	201.2
2017	171,728	204.2
2018	174,128	207.1
2019	176,490	209.9
2020	178,787	212.6
2021	181,226	215.5
2022	183,780	218.5
2023	186,504	221.8
2024	189,540	225.4
2025	192,638	229.1
2026	195,787	232.8
2027	198,987	236.6
2028	202,239	240.5
2029	205,545	244.4
2030	208,905	248.4
2031	212,319	252.5
2032	215,790	256.6
2033	219,317	260.8
2034	222,901	265.1
2035	226,545	269.4

## 9.6.2 Cost of Alternative Benzene Control Programs

We used the refinery-by-refinery refinery model to estimate the cost of other potential benzene control standards. This includes analyses of benzene standards which are more and less stringent than the proposal as well as benzene control standards with and without ABT programs. We also evaluated some of these alternative benzene control standards with a second benzene control standard called a maximum-average, or max-avg standard (see Section 9.1.1 above).

Table 9.6-5 contains a summary of the national average per-gallon costs and aggregate capital and total annual costs for average benzene control standards which range from 0.52 to 0.73 and with and without ABT and maximum-average standards. The 0.52 average benzene control standard represents the most stringent benzene control 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 0.73 volume percent benzene, but without the full ABT program. Each refinery would have to average 0.73 volume percent benzene across its own gasoline batches with no ability to average or trade across refineries, or bank credits. This benzene control standard would result in a national average benzene level which would equal the proposed 0.62 volume percent benzene standard with full ABT – thus it is

an interesting case to study. The refinery model also estimates that a number of refineries might not be able to achieve a tighter standard than this without additional benzene control technology beyond reformat benzene control. The refinery-by-refinery cost model projects that 5 refineries would not be able to achieve the 0.73 volume percent benzene standard based on reformat benzene control alone. All of these refineries could achieve the benzene control standard by either treating or reducing their assumed purchases of natural gasoline, a practice that the refiners operating these refineries would probably view as unacceptable.

**Table 9.6-5. Cost of Other Benzene Control Standards**  
(2002 dollars, 7% ROI before taxes and benzene priced at \$20/bbl above gasoline)

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)
0.52	Yes	None	0.52	0.36	490	875
0.60	Yes	1.3	0.60	0.16	215	610
0.60	Yes	None	0.60	0.15	210	540
0.62	Yes	1.3	0.62	0.13	180	590
0.62*	Yes	None	0.62	0.13	170	500
0.65	Yes	1.3	0.65	0.10	145	510
0.65	Yes	None	0.65	0.09	123	460
0.70	Yes	1.3	0.70	0.08	110	475
0.70	Yes	None	0.70	0.06	80	365
0.73	No	None**	0.62	0.25	340	660

\* Proposed Rule

\*\* The 0.73 volume percent benzene standard could also be thought of being an avg-max standard, because without an ABT program, each refinery would have to meet this level with actual production on an annual average basis.

The reduced flexibility of a max-avg benzene standard increases the cost of benzene control over a benzene control program without a max-avg standard. We estimate that the reduced flexibility forces 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.

The 0.73 volume percent benzene control standard without the full ABT program, which results in the same national average gasoline benzene level as the proposed program, is estimated to cost almost two times more than the proposed program. Without any ABT program, this standard offers much less flexibility than the proposed benzene control program. The reason why the national average benzene level for the 0.73 volume percent benzene standard without an ABT program is 0.62 volume percent is that the many refineries with benzene levels below 0.62 volume percent benzene today are assumed to stay at their current levels in the future, which balances out the many refineries which are assumed to come down to 0.73 volume percent benzene in response to the benzene control standard. The lack of flexibility of this benzene control case results in a larger share of benzene reductions occurring through benzene saturation, a more expensive benzene control technology, in lieu of benzene reductions achieved from installing new or revamping existing benzene extraction units or benzene precursor rerouting with and without isomerization.

We plotted the per-gallon costs versus the cumulative volume of gasoline across the refineries producing gasoline for several benzene control programs of interest. Figure 9.6-3 shows the per-gallon costs for the proposed 0.62 volume percent benzene control program and a program with the same standard, but with the addition of a max-avg standard. We also included a plot of the 0.52 volume percent benzene control standard.

**Figure 9.6-3.**

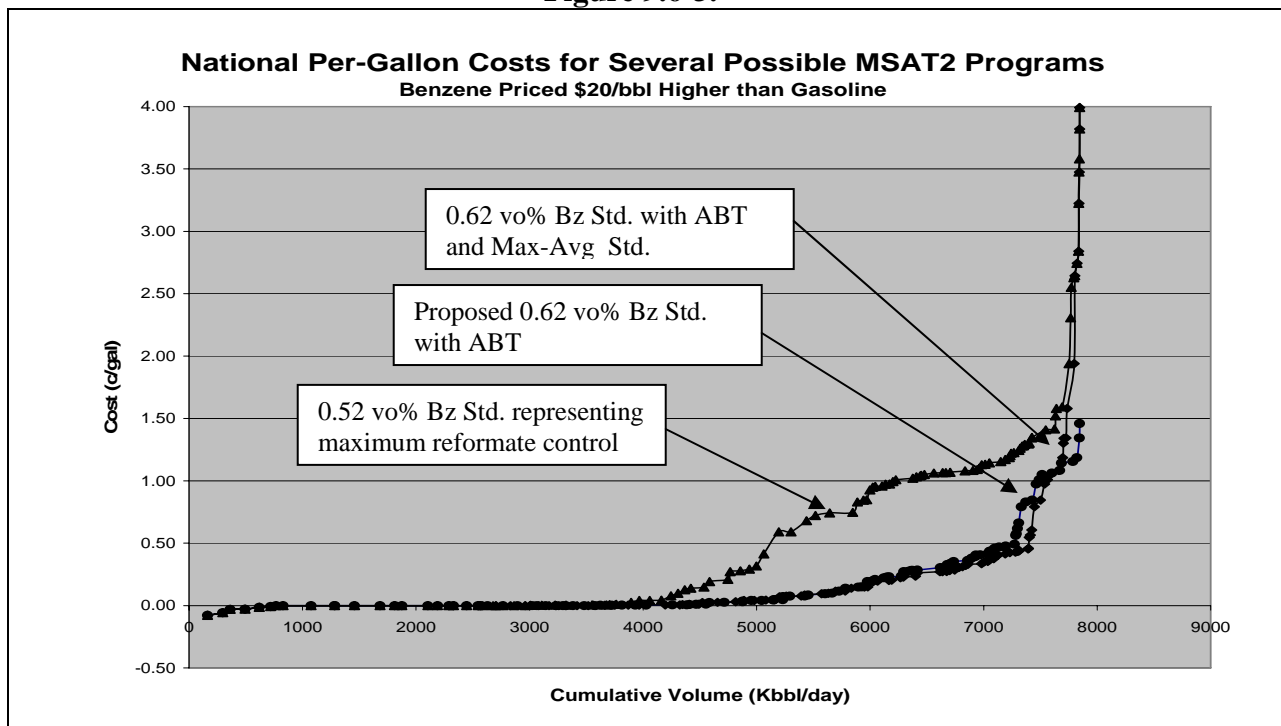


Figure 9.6-3 shows that for roughly half the volume of gasoline, the costs for benzene control are zero or near zero, and for a few extraction refineries even negative. The addition of the max-avg standard forces a small number of refineries to adopt a much more expensive benzene control strategy. Comparing the two programs, the proposed program would cause 9 refineries to exceed 1 cent per-gallon compliance cost compared to the benzene control program with a max-avg standard which would cause 16 refineries to exceed 1 cent per-gallon compliance cost. The 0.52 volume percent benzene standard is much more expensive in this regard causing about 50 refineries to exceed 1 cent per-gallon in compliance costs. The highest cost of compliance under the proposed program would be about 1.5 cents per-gallon, while under the benzene control program with the max-avg standard the highest cost of compliance would be about 4 cents per gallon (same for the 0.52 volume percent control standard).

Table 9.6-6 below summarizes the number refineries which install or adopt each of the four different types of benzene control technologies for:

- the proposed 0.62 volume percent benzene control program with ABT program,

- a 0.62 volume percent benzene control program with a 1.3 volume percent max-avg standard with ABT program, and
- a 0.73 volume percent benzene control standard without an ABT program which results in a 0.62 average benzene level in gasoline.

**Table 9.6-6. Projected Number and Type of Benzene Control Technologies Installed for Different Benzene Control Programs**

	Routing Benzene Precursors Around Reformer	Sending Rerouted Benzene Precursors to Isom Unit	New and Revamped Benzene Extraction Units	Benzene Saturation
Proposed 0.62 avg Bz std with ABT Program	26	28	23	11
0.62 vol% avg Bz std with 1.3 max-avg std and ABT program	20	28	23	16
0.73 avg Bz std, No ABT Program; 0.62 vol% in-use	7	16	17	45

Imposing a max-avg standard or eliminating the ABT program altogether reduces flexibility available to refiners and is projected to result in a different pattern of benzene reduction across the country. Refineries which find it economically advantageous to use the ABT program to realize only minor benzene reductions and purchase credits to show compliance with the average benzene standard are primarily located in PADD 2, PADD 4 and PADD 5. The refineries which generate credits under the ABT program are primarily located in PADDs 1 and 3. Thus, as the flexibility across the different benzene control programs diminishes, benzene levels decrease in PADD 4 and 5 and increase in PADD 3. Table 9.6-7 summarizes the estimated benzene level by PADD for several different benzene control programs that would result in the same nationwide benzene level, but differing gasoline benzene profiles.

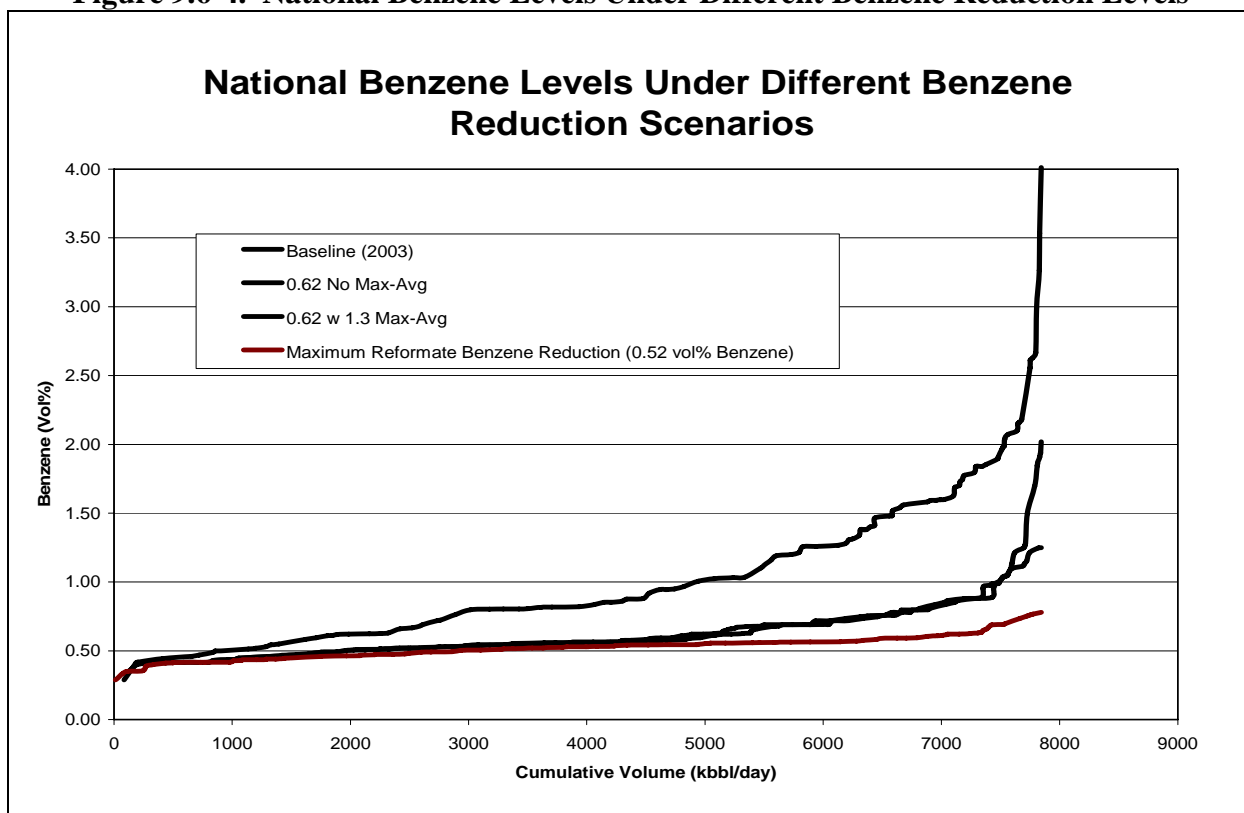
**Table 9.6-7. Estimated Gasoline Benzene Levels by PADD for Several 0.62 volume percent Benzene Control Programs and a 0.52 volume percent Benzene Control Standard with ABT Program Representing Maximum Reformate Control (volume percent benzene)**

	PADD 1	PADD 2	PADD 3	PADD 4	PADD 5 excluding CA	U.S. Average
Current Benzene Levels (summertime)	0.66	1.32	0.86	1.54	1.87	0.97
Proposed 0.62 avg Bz std with ABT Program	0.51	0.73	0.55	0.95	1.04	0.62
0.62 vol% avg Bz std with 1.3 max-avg std and ABT program	0.50	0.75	0.56	0.90	0.88	0.62
0.73 avg Bz std, No ABT Program*	0.49	0.72	0.58	0.71	0.75	0.62
0.52 avg Bz std with ABT (maximum reformate benzene control)	0.48	0.50	0.52	0.56	0.67	0.52

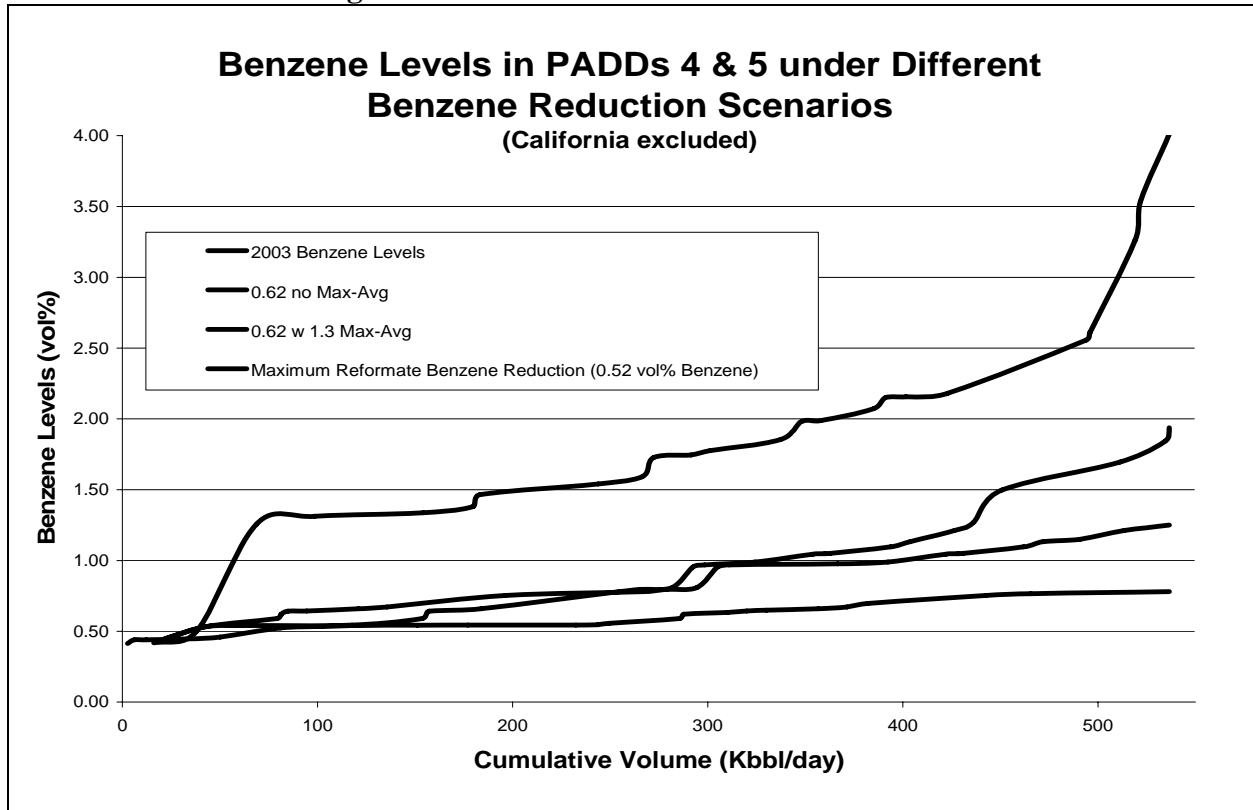
\* The cost analysis shows that 5 refineries would not be able to meet a 0.73 volume percent benzene standard, including three in PADD 5 which results in the modeled PADD-average benzene level to exceed the standard. All these refineries would achieve the 0.73 standard by reducing or eliminating the natural gasoline they are assumed to purchase.

One concern with proposing a benzene control program with a national ABT program is that there may be refineries that could produce gasoline with benzene levels higher than the average standard on an ongoing basis while using credits to comply, thus potentially exposing people using that gasoline to higher benzene emissions. 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 control programs with average national benzene levels of 0.62 volume percent benzene. A review of the refinery-by-refinery output reveals that the benzene levels of the refineries in PADD 4 and PADD 5 (excluding California) are most likely to remain above the standard with a nationwide ABT program in place. The plot of the refinery benzene levels against cumulative gasoline production for all U.S. refineries, and all refineries in PADDs 4 and 5 (excluding California), is contained in Figure 9.6-4, and Figure 9.6-5, respectively.

**Figure 9.6-4. National Benzene Levels Under Different Benzene Reduction Levels**



**Figure 9.6-5. Benzene Levels in PADDs 4 & 5**



All of the benzene control 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.

We also assessed the costs of the various benzene control programs based on the projected 2004 benzene price, which is \$38 per barrel instead of the \$20 per barrel upon which the proposed program cost estimates are based. Table 9.6-8 contains a summary of costs for the proposed and other benzene control standards based on benzene priced \$38 per barrel above gasoline.

**Table 9.6-8. Cost of Other Benzene Control Standards**  
**(2000 dollars, 7% ROI before taxes and benzene priced at \$38/bbl above gasoline)**

Average Benzene Std. (vol %)	ABT Program	Avg.-Max Std. (vol %)	Actual In-Use Benzene Level (vol %)	Per-Gallon Cost (cents/gal)	Total Annual Cost (\$ million/yr)	Aggregate Capital Cost (\$ million)
0.52	Yes	None	0.52	0.28	380	870
0.60	Yes	1.3	0.60	0.09	125	630
0.60	Yes	None	0.60	0.07	96	530
0.62	Yes	1.3	0.62	0.05	66	580
0.62*	Yes	None	0.62	0.05	64	500
0.65	Yes	1.3	0.65	0.03	35	560
0.65	Yes	None	0.65	0.01	15	460
0.70	Yes	1.3	0.70	0.00	6	530
0.70	Yes	None	0.70	-0.02	-26	415
0.73	No	None	0.62	0.19	260	660

\* Proposed Rule

### 9.6.3 Costs Used to Estimate Price Impacts of the Proposed Benzene Standard

In Chapter 13 of the RIA, we estimate the increase in gasoline prices for the proposed benzene control standard. 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 principals 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. Table 9.6-9 summarizes the maximum total and variable costs and the average per-gallon consumption costs for each PADD for estimating the price impacts of the proposed benzene control program.

**Table 9.6-9. Summary of Potential Price Increases by PADD for the Proposed Benzene Control Program Based on Three Methods, Cents per Gallon  
(2002 dollars, 7% ROI before taxes)**

Price Estimating Methodology	PADD 1	PADD 2	PADD 3	PADD 4	PADD 5 (excluding CA)	CA
Max-Total Cost (cents/gal)	0.41	1.15	1.06	1.46	1.14	0.15
Max-Variable Cost (cents/gal)	0.35	1.07	0.98	1.46	1.14	0.08
Average Cost for Gasoline Consumed (cents/gal)	0.05	0.20	0.05	0.36	0.39	0.15

#### **9.6.4 Projected Fuel Supply and Energy of the Proposed Benzene Program**

EPA has evaluated the potential impact on U.S. fuel supply of the proposed gasoline benzene control 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 reformat stream, usually for sale into the petrochemical market. In extracting benzene, the volume of reformat available for gasoline production is reduced.

We estimate that in response to the proposed program, refiners would extract about 21,700 barrels of benzene per day in 2010. Because benzene has a slightly higher energy density than gasoline (about 7 percent higher), the projected extracted benzene is equivalent to about 23,500 barrels per day of gasoline, or about 0.2 percent of U.S. gasoline production. However, for two main reasons the net effect on gasoline supply of the rule will be far less, potentially zero.

First, gasoline volume reduced through benzene extraction would be largely made up through other processes that otherwise would produce this benzene. As shown in Table 9.3-2 of this RIA, about 41 percent of benzene supply for the petrochemical market is already extracted from the refinery reformat stream. Another 21 percent comes from a process that uses toluene as a feedstock. Both of reformat and toluene are components of gasoline, and so a large fraction of benzene on the market would be supplied directly from gasoline production even in the absence of the proposed program. Another approximately 25 percent of benzene comes from extraction from pyrolysis gasoline, which results from ethylene production for such things as plastics manufacture. The primary feedstock for pyrolysis gasoline is atmospheric gas oil which, although not directly a gasoline feedstock, would otherwise be processed in an FCC unit and mainly produce gasoline. Thus, nearly 90 percent of benzene is produced from gasoline blendstocks or from intermediate streams refineries normally use to produce gasoline. The reduced volume of gasoline from benzene extraction would largely be made up by increased production from processes currently used to produce benzene. Thus, overall, there would be little or no net reduction in gasoline.

Second, this increase in extraction of benzene from gasoline is expected to occur with or without the proposed benzene standard. Using CMAI's estimate of a 2.4 percent annual growth in benzene demand, we would expect that demand for benzene would increase by 650 million gallons from 2006 to 2011. This increased demand is expected to come from gasoline and crude oil, since roughly 90% of benzene is produced today from gasoline feedstocks, and 95% from crude oil. This compares with the projected new supply of benzene from extraction to meet the proposed standard of about 337 million gallons per year. Because the industry would be using the ABT program to effectively phase in the use of extraction over a period of several years, the amount of benzene extracted from benzene in any given year could easily be less than the increased annual demand, resulting in no net impact of the rule.

#### *Projected Energy Impacts of the Proposed 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 proposed benzene control program. 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 2010, 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 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 (2010)**  
**(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)
Total Benzene Control-Related	0.4	3	8	3	14
Light Naphtha Splitting	-0.1	1.3	-1.0	-0.1	0
Reforming	0.1	-1.9	3.1	0.1	1
Isomerization	0	1.5	0	0.3	2
Benzene Saturation	0	0	0.3	1.1	1
Benzene Extraction	0.4	0	5.2	0	6
Hydrogen Production	0	1.6	0.3	1.9	4
All Other	0	-1	3	0	3
<b>Net Process Energy Change</b>	<b>0.4</b>	<b>2</b>	<b>11</b>	<b>3</b>	<b>17</b>
<i>% Change in Process Energy</i>	<i>0.4</i>	<i>0.6</i>	<i>1.3</i>	<i>2.8</i>	<i>1.2</i>
Non-Process Energy Change	0.8	1	2	2	6
<b>Net Total Energy Change</b>	<b>1.2</b>	<b>3</b>	<b>13</b>	<b>5</b>	<b>23</b>
<i>% Change in Total Energy</i>	<i>0.07</i>	<i>0.08</i>	<i>0.14</i>	<i>0.28</i>	<i>0.13</i>

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 (17 of the total increase of 23 Kfoeb/d). This process energy increase would represent about one percent of all energy used in refinery processes. When all energy involved in producing gasoline is considered, including the energy in crude oil and other feedstocks, we project that the proposed benzene control program would increase overall energy use by refineries by about one tenth of one percent.

Of the nationwide increase in process energy, most would be due to processes directly related to benzene control (14 of 17 Kfoeb/d). Benzene extraction would be the largest contributor to this process energy increase (6 of 14 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 proposed benzene control 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 proposed program. (Projected increases in energy use due to the other benzene-related processes would be appropriately attributed to the proposed 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 proposed 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 more than half of the nationwide

increase in energy use, both due to the emphasis on extraction by refiners there as well as the large volume of gasoline produced in that region.

### **9.6.5 Costs of Other Air Toxics Control Programs**

We used the linear program (LP) refinery model to estimate the cost of total air toxics control standards and total air toxics standards coupled with benzene standards. Use of the LP refinery model is necessary to express the wide-ranging impacts of one fuel change on others. This is less important if the fuel change has limited ripple effects (eg. benzene) but is critical for fuel changes expected to have significant ripple effects (eg. aromatics, sulfur, RVP).

The total air toxics standards modeled included (percent reductions in air toxics emissions are projected using the Complex Model):

- a minimum 21.5 percent reduction in total air toxics applied to conventional gasoline for each PADD,
- a minimum 25% total air toxics reduction applied to conventional gasoline for each PADD, and a minimum 35% total air toxics reduction applied to reformulated gasoline for each PADD and a 0.5 vol% average benzene standard applied to both conventional and reformulated gasoline.

We also evaluated the cost of several ozone/total air toxics control programs which would reduce the Reid vapor pressure (RVP) of conventional gasoline, and would further reduce the sulfur content of all gasoline. These ozone/air toxics control programs modeled include:

- a 7.8 RVP standard applied to a portion of the conventional gasoline pool, the volume of which is equivalent to 50% of the volume of reformulated gasoline consumed in each PADD,
- a 7.0 RVP standard applied to a portion of the conventional gasoline pool, the volume of which is equivalent to 50% of the volume of reformulated gasoline consumed in each PADD, and
- a 10 ppm sulfur standard applied to all U.S. gasoline.

As discussed in the preamble for this rule (section VII.C.1), we considered addressing MSATs in several ways other than reducing benzene emissions. Our decision to address MSAT emissions through gasoline benzene content reductions was not based exclusively on an analysis of costs, but strongly considered other factors. We discussed our reasoning for deciding not to propose to address MSAT emissions through a total toxics performance standard, as well as through further reductions in gasoline sulfur content and gasoline volatility.

For example, our experience with past toxics control programs has shown that, because reducing gasoline benzene content is by far the least expensive approach, we believe that regardless of the form of the standard, refiners would almost exclusively respond to a standard of equivalent stringency by reducing gasoline benzene. At the same time, a toxics performance

standard would introduce complexities and uncertainties that we believe would be unnecessary and could prove to be costly in the future. Regarding the value of controlling gasoline sulfur and volatility for MSAT purposes, sufficient data about the potential impact of such fuel changes on the toxics emissions of today's generation of vehicles does not yet exist.

Although we did not base these decisions on cost factors, we present for general information purposes the results of several limited modeling exercises that may be of interest. Table 9.6-11 presents LP modeling runs of two hypothetical toxics performance and benzene content standards. As discussed above in Section 9.1.1, there are strengths and weaknesses to the use of the LP model in evaluating fuel control programs. There are also important similarities and differences between EPA's refinery-by-refinery model (used to evaluate the proposed benzene control program) and the LP model (used in the case of other programs). We do not draw specific conclusions from these modeling results, but clarify some of the results below.

Table 9.6-11 contains a summary of the national average per-gallon costs and aggregate capital and total annual costs for the various total air toxics standards which we modeled. Much more information for these LP refinery modeling cases are contained in submissions to the docket.

**Table 9.6-11. Detailed Cost Information by PADD for Air Toxics, Low RVP and Sulfur Control Cases**  
**(2000 dollars, 7% ROI before taxes and benzene priced \$20/bbl above gasoline)**

		21.5% Tox Std CG	25% Tox Std CG 35% Tox Std RFG; 0.5 vol% Bz std for RFG & CG	7.8 RVP	7.0 RVP	10 ppm Sulfur CG & RFG
PADD 1	Volume (kbbbl/day)	428	1067	64	64	1067
	Capital Cost (\$MM)	-7	260	-27	-65	-15
	Total Annual Cost (\$MM/yr)	33	190	8	14	145
	Per-Gallon (cents/gal)	0.50	1.17	0.86	1.45	0.90
PADD 2	Volume (Kbbbl/day)	1864	2169	206	206	1864
	Capital Cost (\$MM)	480	560	15	37	236
	Total Annual Cost (\$MM/yr)	240	300	14	17	229
	Per-Gallon Cost (cents/gal)	0.84	0.90	0.45	0.54	0.69
PADD 3	Volume (Kbbbl/day)	3399	4198	612	612	4198
	Capital Cost (\$MM)	580	1840	133	222	574
	Total Annual Cost (\$MM/yr)	170	850	9	22	201
	Per-Gallon Cost (cents/gal)	0.33	1.32	0.10	0.24	0.31
PADD 4 & 5	Volume (Kbbbl/day)	724	724	-	-	724
	Capital Cost (\$MM)	185	300	-	-	530
	Total Annual Cost (\$MM/yr)	130	175	-	-	66
	Per-Gallon Cost (cents/gal)	0.51	1.60	-	-	0.06
Total and Average Costs	Volume (Kbbbl/day)	6415	8158	882	882	8158
	Capital Cost (\$MM)	1240	2960	121	184	1325
	Total Annual Cost (\$MM/yr)	570	1520	32	54	643
	Per-Gallon Cost (cents/gal)	0.58	1.21	0.23	0.40	0.51
Total Air Toxics Reduction Compared to Clean Air Act Baseline (percent) See Note A		26.7	29.7	See Note B	See Note B	See Note B

Note A – Volume-weighted toxics reduction for CG and RFG.

Note B – The potential for air toxics emissions reductions with additional RVP and gasoline sulfur controls is uncertain, therefore no estimates are provided for these control programs. While the tendency is for these programs to provide some sort of reduction in air toxics emissions, without additional emissions testing, the VOC and toxics emissions impacts of these programs would need to be based on older correlations between fuel quality and emissions which may no longer apply as vehicle technology has changed. In addition, the reductions may be partially or completely offset by the means which refiners adjust the fuel quality secondarily (i.e., recover octane loss).

The projected costs for the total air toxics control programs presented in Table 9.6-11 are much higher than those for the proposed benzene control program. To understand the reasons for this difference, we compared the 21.5 percent total air toxics reduction case (since it is closest scenario in the existing modeling to the proposed benzene control program) with the proposed

benzene control program case. There are three primary reasons why the 21.5 total air toxics reduction case is more costly than the proposed benzene control standard.

The primary reason why the 21.5 percent reduction case is higher in cost is because when the contractor was setting up the LP refinery modeling work, it established the types of benzene control technologies that could be used for the total air toxics control cases, and it specified that benzene saturation be the primary technology used.<sup>g</sup> Since benzene control is the primary means picked by the refinery model for controlling total air toxics, benzene saturation provides a significant portion of the total air toxics control costs for the 21.5 percent toxics reduction case. However, for nearly the same level of total air toxics control, the refinery-by-refinery cost model, to achieve benzene control, relies mostly on benzene precursor rerouting with or without isomerization, and secondarily relies on extraction. As a result, benzene saturation plays a very small role in achieving benzene control in the refinery-by-refinery cost model. Yet benzene saturation costs average about 5 times higher than either benzene precursor rerouting or extraction for the average refinery (the difference is much less if only large refineries rely on benzene saturation). The reason why different benzene control strategies were relied upon for the two refinery modeling studies is that the total air toxics control cases modeled with the LP refinery model were completed early on in the development of the program and the choice of benzene control technologies was not a focal point of the cost analysis at that time.

Another reason why our modeling projects the 21.5 total air toxics reduction case to be higher in cost than the proposed benzene control standard is that it is a more severe toxics control case. RFG is assumed to maintain its MSAT1 performance, and CG is assumed to achieve 21.5 total air toxics reduction in each PADD. As a result, the refinery modeling of the 21.5 percent reduction case projects that all gasoline produced by U.S. refineries would achieve on average a 26.7 percent reduction in total air toxics compared to an estimated 25.1 percent reduction for the proposed benzene control case.<sup>h</sup> It is costlier to achieve a higher level of total air toxics control.

Finally, while the LP refinery modeling does tend to optimize the total air toxics reduction costs across the refineries in each PADD (partially emulating an ABT program within each PADD), it does not optimize total air toxic control costs nationwide. Thus, this restriction in program cost optimization increases the projected compliance cost compared to the proposed benzene control case which optimizes benzene control costs nationwide.

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g It is typical for the contractor to limit or specify certain control technologies in LP refinery modeling to prevent the LP refinery model from choosing control technologies that are obviously unreasonable choices for a subset of refineries affected by a fuel quality control standard.

h To estimate the total air toxics emission reductions for the 21.5 percent toxics reduction case and proposed benzene control case, we needed to insert the relevant gasoline qualities (i.e., RVP, volume percent benzene, aromatics, olefins, percent evaporated at 200 and 300 F, and RVP) into the Complex Model to estimate the total air toxics emission reductions. This is easily obtainable from the LP refinery modeling reports since the necessary gasoline qualities are estimated for the control cases in each PADD. Since the refinery-by-refinery cost model does not estimate these various gasoline qualities, the reference case gasoline qualities for the LP refinery modeling reference cases were used for most of the gasoline qualities, and we then substituted the benzene levels from the refinery-by-refinery model output to estimate the final total air toxics reductions for the proposed benzene control standard.

The other total air toxics control case is even more stringent than the 21.5 percent reduction in total air toxics case and therefore achieves even deeper reductions in air toxics emissions at a higher cost, but was developed using the same assumptions. Therefore, these results can best be compared among the two air toxics control cases, but not relative to the proposed benzene control case.

## References for Chapter 9

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<sup>1</sup> Refinery Modeling: Legislative and Regulatory Developments: Effects on Gasoline Supply, Prepared for U.S. Environmental Protection Agency by Abt Associates Inc under subcontract from ICF Incorporated, January 14, 2003; Appendices A, B and D.

<sup>2</sup> Evaluation of Refinery Gasoline Benzene Reduction Options – Part 2, Prepared for U.S. Environmental Protection Agency by Abt Associates Inc. under contract from ICF Consulting Inc., November 30, 2004.

<sup>3</sup> Keesom, William H., et al, Benzene Reduction Alternatives, Technical Paper presented to the 1991 National Petroleum Refiners Association Annual Meeting.

<sup>4</sup> Worldwide Refining/Worldwide Production, Oil and Gas Journal, Volume 98.51, December 18, 2000.

<sup>5</sup> Annual Energy Outlook 2002, Energy Information Administration, Department of Energy.

<sup>6</sup> Senate Bill S.791, 108<sup>th</sup> Congress, April 3, 2003.

<sup>7</sup> Annual Energy Outlook 2005, Energy Information Administration, Department of Energy.

<sup>8</sup> Worldwide Report , Oil and Gas Journal, [www.ogjonline.com](http://www.ogjonline.com), December 22, 2003.

<sup>9</sup> Capacity of Operable Petroleum Refineries by State as of January 1, 2003, Table 38 of Petroleum Supply Annual 2002, Volume 1, Energy Information Administration, Department of Energy.

<sup>10</sup> Inputs of Crude Oil and Petroleum Products by Country of Origin, 2003, Tables 22 – 25, Petroleum Supply Annual 2003 Volume 1, Energy Information Administration, Department of Energy.

<sup>11</sup> Refinery Net Production of Finished Petroleum Products by PAD, and Refining Districts, 2003, Petroleum Supply Annual, Table 17, Petroleum Supply Annual 2003, Volume 1, Energy Information Administration, Department of Energy.

<sup>12</sup> Information in the LP refinery model from literature and provided by vendors of refining technologies.

<sup>13</sup> Information in the LP refinery model from literature and provided by vendors of refining technologies.

<sup>14</sup> Information in the LP refinery model from literature and provided by vendors of refining technologies.

<sup>15</sup> Information in the LP refinery model from literature and provided by vendors of refining technologies including new information.

<sup>16</sup> Rock, Kerry L., Manager CDTECH, Low Cost Benzene Reduction for RFG, Technical Paper presented at the 1995 National Petroleum Refiners Association Annual Meeting.

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<sup>19</sup> Annual Energy Outlook 2005, Energy Information Administration, Department of Energy.

<sup>20</sup> Annual Energy Outlook 2006 (early release), Energy Information Administration,

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## CHAPTER 10: Gas Can Costs

This chapter presents a detailed analysis of the projected average gas can 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 gas cans (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 gas cans.

### 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 gas can manufacturers' overhead and profit.<sup>1</sup> 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 gas cans and also an average per container cost based on the approximate sales weighting of the three gas can sizes.<sup>A</sup> All costs are in 2003 dollars.

We are not projecting any additional R&D costs associated with the new EPA gas can standards. Manufacturers have developed and are continuing to develop control technologies in response to the California (and other state) programs. EPA's program would be 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 would 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 would not incur significant new R&D costs due to an EPA program.

We estimate that tooling and certification costs would 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*

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<sup>A</sup> Gas can 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 gas can design with a material composition of 3% EVOH at \$3.50/lb, 4% adhesive layer at \$1/lb and the remainder HDPE.<sup>2</sup> 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.<sup>B</sup>

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 gas cans by blending in a low permeation material such as ethylene vinyl alcohol (EVOH) with the HDPE. This is typically known by its trade name, Sellar. The EVOH in the plastic forms non-continuous barrier platelets in the gas can 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 gas cans 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 gas can 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.<sup>3</sup> We estimate that gas can 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 gas cans; we estimated that shipping, handling and overhead costs would be an additional \$0.30 per gas can.<sup>4</sup>

### **10.3 Spout Costs**

Manufacturers would 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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<sup>B</sup> 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 gas can 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 gas can 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, gas can manufacturers will perform durability and permeation testing for certification. They will be able to carry over this data in future years and to gas cans that are made of similar materials and have the same permeation control strategy regardless of gas can size.

Manufacturers would need to run certification testing for their gas cans 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 would 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 gas can certification cost, we calculated a total industry cost for certification of \$62,500 and spread this cost over industry-wide sales of 22,000,000 units. As with other fixed costs, we amortized the cost over 5 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 gas cans. 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 Gas Can**

	1 gallon	2 gallon	5 gallon
Variable costs			
- Permeation Barrier	\$0.22	\$0.28	\$0.44
- Spout	\$0.85	\$0.85	\$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 gas can 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 Gas Cans Complying with State Programs

The above costs are for currently uncontrolled gas cans. Some states have adopted gas can programs, based on the original California program which took effect in 2001.<sup>c</sup> 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.

<sup>c</sup> Delaware, Maine, Maryland, Pennsylvania, New York, Connecticut, Massachusetts, New Jersey, Rhode Island, Vermont, Virginia, Washington DC, and Texas

## 10.7 Fuel Savings

The emissions reductions due to reduced evaporative losses and reduced spills from gas cans 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 gas cans in use we can estimate the annual tons reduction per gas can. In 2015, after the program is fully implemented, we estimated that there would be 88,023,896 gas cans in use nationwide and that those cans would be responsible for about 182,933 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 6 lbs/gallon (for lighter hydrocarbons which evaporate first). We used an average life of 5 years for gas cans and used a discount rate of seven percent to estimate total average undiscounted and discounted fuel savings per gas can, provided below. We calculated the savings using \$1.52 per gallon of gasoline.<sup>5</sup> These savings would offset the cost of the gas can controls.

**Table 10.7-1. Average Fuel Savings Over Life of Gas Can**

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 gas can 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 gas cans are sold and fuel savings occurring over the life of the gas can. To project annual sales into the future, we started with an estimated 22 million gas cans sold nationwide in 2002 and then grew sales by 2 percent per year.<sup>6</sup> The resulting sales estimates for select years are shown in Table 10.8-1 below. To estimate sales in states with and without existing gas can programs, we projected that 39 percent of overall sales would be in states with existing gas can programs. This estimate is based on current estimated gas can populations by state provided in Chapter 2 of the RIA.

**Table 10.8-1. Projected Annual Gas Can Sales**

	2009	2015	2020	2030
Projected sales	25,271,085	28,459,346	31,421,417	38,302,533

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 gas cans 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 \$50 million and then drop to \$28 million in 2014 when the fixed costs have been

recovered. Fuel savings start out at about \$14 million per year and reach \$91 million in 2014. After 2014, increases in costs and savings are due to gas can 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 \$90 million.

**Table 10.8-2. Annual Nationwide Gas Can Costs and Fuel Savings**

Calendar Year	Variable Costs	Fixed Costs	Total Costs	Fuel Savings	Net Cost
2008	0	0	0	0	0
2009	\$ 25,548,976	\$ 23,573,284	\$49,122,261	\$14,381,149	\$34,741,111
2010	\$ 26,059,956	\$ 23,573,284	\$49,633,240	\$29,795,152	\$19,838,089
2011	\$ 26,581,155	\$ 23,573,284	\$50,154,439	\$45,209,154	\$4,945,285
2012	\$ 27,112,778	\$ 23,573,284	\$50,686,062	\$60,623,156	-\$9,937,094
2013	\$ 27,655,034	\$ 23,573,284	\$51,228,318	\$76,037,159	-\$24,808,841
2014	\$ 28,208,134	\$ -	\$28,208,134	\$91,451,161	-\$63,243,027
2015	\$ 28,772,297		\$28,772,297	\$92,686,097	-\$63,913,800
2016	\$ 29,347,743		\$29,347,743	\$93,921,033	-\$64,573,290
2017	\$ 29,934,698		\$29,934,698	\$95,155,969	-\$65,221,271
2018	\$ 30,533,392		\$30,533,392	\$96,390,905	-\$65,857,513
2019	\$ 31,144,060		\$31,144,060	\$97,625,841	-\$66,481,782
2020	\$ 31,766,941		\$31,766,941	\$98,860,777	-\$67,093,836
2021	\$ 32,402,280		\$32,402,280	\$100,095,713	-\$67,693,434
2022	\$ 33,050,325		\$33,050,325	\$101,330,649	-\$68,280,324
2023	\$ 33,711,332		\$33,711,332	\$102,565,585	-\$68,854,254
2024	\$ 34,385,558		\$34,385,558	\$103,800,521	-\$69,414,963
2025	\$ 35,073,270		\$35,073,270	\$105,035,457	-\$69,962,188
2026	\$ 35,774,735		\$35,774,735	\$106,270,393	-\$70,495,658
2027	\$ 36,490,230		\$36,490,230	\$107,505,329	-\$71,015,100
2028	\$ 37,220,034		\$37,220,034	\$108,740,265	-\$71,520,231
2029	\$ 37,964,435		\$37,964,435	\$109,975,201	-\$72,010,766
2030	\$ 38,723,724		\$38,723,724	\$111,210,137	-\$72,486,414
2031	\$ 39,498,198		\$39,498,198	\$112,445,073	-\$72,946,875
2032	\$ 40,288,162		\$40,288,162	\$113,680,009	-\$73,391,847
2033	\$ 41,093,925		\$41,093,925	\$114,914,945	-\$73,821,020
2034	\$ 41,915,804		\$41,915,804	\$116,149,881	-\$74,234,077
2035	\$ 42,754,120		\$42,754,120	\$117,384,817	-\$74,630,697

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<sup>1</sup> . "Update of EPA's Motor Vehicle Emission Control Equipment Retail Price Equivalent (RPE) Calculation Formula," Jack Faucett Associates, Report No. JACKFAU-85-322-3, September 1985.

<sup>2</sup> "Plastic News," Resin Pricing for November 8, 2004, [www.plasticsnews.com](http://www.plasticsnews.com).

<sup>3</sup> "Information on Costs and Effectiveness of Fluorination Received from Fluoroseal," Memorandum from Mike Samulski to Docket A-2000-1, March 27, 2002.

<sup>4</sup> "Shipping Costs," Memorandum from Glenn Passavant, U.S. EPA to Docket A-2000-01, March 27, 2002.

<sup>5</sup> Energy Information Administration, Annual Energy Outlook 2005, Table 12, Petroleum Product Prices, January 2005, DOE/EIA-0383(2005). EIA projected average post-tax gasoline costs for 2010.

<sup>6</sup> "Characterizing Gas Can Markets: A Profile," RTI International, Final Report, August 2004.

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## **Chapter 11: Cost per Ton of Emissions Reduced**

We have calculated the cost per ton for the proposed 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 gas cans in use, and the later period when there is nearly complete turnover to compliant vehicles and gas cans. For the proposed fuel benzene standards, proposed to 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, gas cans, 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 proposed 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 gas cans 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 gas cans separately. In Section, 11.4, we present the cost per ton estimates for the combined proposal.

### **11.1 Cost per Ton for Vehicle Standards**

We are proposing a new cold temperature NMHC standard for light-duty vehicles, including medium-duty passenger vehicles. The new standard would 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 proposed 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 proposed NMHC standard. We have estimated NMHC, total MSATs, benzene, and PM emissions reductions associated with the proposed 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 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	Benzene Reduction	MSAT Reduction	PM Reduction
2009	\$0	0	0	0	0
2010	\$11,118,971	145,934	7,799	49,607	3,211
2011	\$11,772,829	180,722	9,611	61,363	3,976
2012	\$12,535,232	215,510	11,423	73,118	4,741
2013	\$13,297,635	250,298	13,235	84,874	5,507
2014	\$13,406,181	285,086	15,047	96,629	6,272
2015	\$12,860,869	319,874	16,859	108,385	7,037
2016	\$12,207,011	363,196	19,108	123,010	7,990
2017	\$11,444,608	406,518	21,357	137,634	8,943
2018	\$10,682,205	449,840	23,606	152,259	9,897
2019	\$10,573,659	493,163	25,856	166,883	10,850
2020	\$0	536,485	28,105	181,508	11,803
2021	\$0	574,180	30,063	194,246	12,632
2022	\$0	611,876	32,022	206,984	13,462
2023	\$0	649,571	33,980	219,722	14,291
2024	\$0	687,267	35,939	232,460	15,120
2025	\$0	724,962	37,897	245,198	15,950
2026	\$0	762,658	39,856	257,935	16,779
2027	\$0	800,353	41,814	270,673	17,608
2028	\$0	838,049	43,773	283,411	18,437
2029	\$0	875,744	45,731	296,149	19,267
2030	\$0	913,440	47,690	308,887	20,096

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)**

	<b>Discounted Lifetime Cost per ton at 3%</b>	<b>Discounted Lifetime Cost per ton at 7%</b>	<b>Long-Term Cost per Ton in 2030</b>
NMHC	\$14	\$18	\$0
Benzene	\$260	\$340	\$0
Total MSATs	\$40	\$53	\$0
Direct PM	\$620	\$820	\$0

## **11.2 Cost Per Ton for Fuel Benzene Standard**

We are proposing a new benzene fuel content standard which would go into effect in 2011. We have estimated the costs and benzene reductions for the proposed 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 proposed 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 gas cans and gasoline distribution.

**Table 11.2-1 Aggregate Annualized Fuels Costs and Benzene Reductions**

Calendar Year	Cost	Benzene Reduction
2009	\$0	0
2010	\$0	0
2011	\$185,533,322	19,125
2012	\$188,712,850	18,852
2013	\$191,873,334	18,578
2014	\$195,104,654	18,305
2015	\$198,282,728	18,031
2016	\$201,242,062	18,054
2017	\$204,211,773	18,077
2018	\$207,066,724	18,099
2019	\$209,874,973	18,122
2020	\$212,606,389	18,145
2021	\$215,507,081	18,358
2022	\$218,543,629	18,570
2023	\$221,783,781	18,783
2024	\$225,393,594	18,996
2025	\$229,077,715	19,209
2026	\$232,821,990	19,421
2027	\$236,627,466	19,634
2028	\$240,495,142	19,847
2029	\$244,426,035	20,059
2030	\$248,421,178	20,272

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	\$11,700	\$11,900	\$12,300

### 11.3 Cost Per Ton for Gas Cans

We are proposing an HC standard for gas cans that would go into effect beginning in 2009. The estimated costs for the standard, and fuel savings, are presented in Chapter 10 and the emissions reductions are provided in Chapter 2. The new HC standard would also reduce VOC-based toxics including benzene. The stream of annualized costs, fuel savings, and emissions reduction estimates for HC, benzene, and total MSATs for gas cans are provided in Table 11.3-1.

**Table 11.3-1 Aggregate Annualized Gas Can Costs and Emissions Reductions**

Calendar Year	Cost	Fuel Savings	HC Reduction	Benzene Reduction	MSAT Reduction
2009	\$49,122,261	\$14,381,149	28,384	233	3,561
2010	\$49,633,240	\$29,795,152	58,806	480	7,375
2011	\$50,154,439	\$45,209,154	89,229	727	11,189
2012	\$50,686,062	\$60,623,156	119,651	974	15,002
2013	\$51,228,318	\$76,037,159	150,073	1,221	18,816
2014	\$28,208,134	\$91,451,161	180,496	1,468	22,630
2015	\$28,772,297	\$92,686,097	182,933	1,488	22,935
2016	\$29,347,743	\$93,921,033	185,370	1,508	23,241
2017	\$29,934,698	\$95,155,969	187,808	1,527	23,546
2018	\$30,533,392	\$96,390,905	190,245	1,547	23,852
2019	\$31,144,060	\$97,625,841	192,683	1,567	24,157
2020	\$31,766,941	\$98,860,777	195,120	1,588	24,475
2021	\$32,402,280	\$100,095,713	197,557	1,608	24,794
2022	\$33,050,325	\$101,330,649	199,995	1,629	25,112
2023	\$33,711,332	\$102,565,585	202,432	1,649	25,431
2024	\$34,385,558	\$103,800,521	204,869	1,670	25,749
2025	\$35,073,270	\$105,035,457	207,307	1,690	26,067
2026	\$35,774,735	\$106,270,393	209,744	1,711	26,386
2027	\$36,490,230	\$107,505,329	212,182	1,731	26,704
2028	\$37,220,034	\$108,740,265	214,619	1,752	27,023
2029	\$37,964,435	\$109,975,201	217,056	1,772	27,341
2030	\$38,723,724	\$111,210,137	219,494	1,792	27,648

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 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. Gas Can Aggregate Cost per Ton and Long-Term Annual Cost Per Ton (\$2003)**

	<b>Discounted Lifetime Cost per ton at 3%</b>	<b>Discounted Lifetime Cost per ton at 7%</b>	<b>Long-Term Cost per Ton in 2030</b>
HC without fuel savings	\$230	\$250	\$180
HC with fuel savings	\$0	\$0	\$0
Total MSATs without fuel savings	\$1,800	\$2,000	\$1,400
Total MSATs with fuel savings	\$0	\$0	\$0
Benzene without fuel savings	\$27,800	\$30,900	\$21,600
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 gas cans, including fuel savings. For MSAT and benzene reductions, we have accounted for the interaction between reduced fuel benzene content due to a new standard and the reductions in benzene that would be provided by the vehicle and gas can proposed 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 gas cans, including fuel savings. Tables 11.4-1 and 11.4-2 provide the streams of costs and emissions reductions 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	MSAT Reduction
2009	\$34,741,111	233	3561
2010	\$30,957,060	8,279	56,982
2011	\$202,251,436	28,188	90,402
2012	\$191,310,988	29,856	105,580
2013	\$180,362,128	31,523	120,757
2014	\$145,267,808	33,191	135,935
2015	\$147,229,797	34,858	147,832
2016	\$148,875,783	36,935	162,569
2017	\$150,435,109	39,011	177,307
2018	\$151,891,416	41,088	192,045
2019	\$153,966,851	43,164	206,782
2020	\$145,512,553	45,241	221,532
2021	\$147,813,647	47,245	234,614
2022	\$150,263,305	49,249	247,695
2023	\$152,929,527	51,253	260,776
2024	\$155,978,631	53,257	273,858
2025	\$159,115,527	55,262	286,939
2026	\$162,326,332	57,266	300,021
2027	\$165,612,366	59,270	313,102
2028	\$168,974,910	61,274	326,183
2029	\$172,415,268	63,278	339,265
2030	\$175,934,765	65,282	352,335

\* includes fuels, vehicles, and gas cans

**Table 11.4-2 Aggregate Annualized Overall Costs and HC Emissions Reductions\***

Calendar Year	Cost Including Fuel Savings	HC Reduction
2009	\$34,741,111	28,384
2010	\$30,957,060	204,740
2011	\$16,718,114	269,951
2012	\$2,598,138	335,161
2013	-\$11,511,206	400,371
2014	-\$49,836,846	465,582
2015	-\$51,052,931	502,807
2016	-\$52,366,279	548,566
2017	-\$53,776,663	594,326
2018	-\$55,175,309	640,086
2019	-\$55,908,122	685,845
2020	-\$67,093,836	731,605
2021	-\$67,693,434	771,738
2022	-\$68,280,324	811,870
2023	-\$68,854,254	852,003
2024	-\$69,414,963	892,136
2025	-\$69,962,188	932,269
2026	-\$70,495,658	972,402
2027	-\$71,015,100	1,012,535
2028	-\$71,520,231	1,052,668
2029	-\$72,010,766	1,092,801
2030	-\$72,486,414	1,132,934

\* 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 fuel savings from gas cans offsets the combined costs of the proposed vehicle and gas can 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 gas cans combined	\$3,700	\$4,000	\$2,700

Total MSATs for fuels, vehicles, and gas cans combined	\$770	\$850	\$500
HC for vehicles and gas cans combined	\$0	\$0	\$0

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## Chapter 12: Cost-Benefit Analysis

### 12.1 Overview

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 proposed standards. In terms of emission benefits, we expect to see significant reductions in mobile source air toxics (MSATs) from the proposed vehicle, fuel and gas can standards, reductions in VOCs (an ozone precursor) from the proposed cold temperature vehicle and gas can standards, and reductions in direct PM<sub>2.5</sub> from the proposed cold temperature vehicle standards. When translating emission benefits to health effects and monetized values, however, we only quantify the PM-related benefits associated with the proposed cold temperature vehicle standards.

We demonstrate that the proposed standards would 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 due to the VOC emission reductions expected to occur as a result of the proposed standards. We describe in more detail below why these benefits are not quantified.

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 proposed cold temperature standards? (2) what is the monetary value of the changes in effects attributable to the proposed 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.

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).<sup>1,2</sup> 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 proposed cold temperature vehicle standards on the national direct PM emissions inventory for two future years (2020 and 2030).<sup>A</sup>
- 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<sub>2.5</sub>. Potential human health effects

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<sup>A</sup> 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.

associated with PM<sub>2.5</sub> 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.

Other standards we are currently proposing, such as the cold temperature vehicle and gas can standards, would 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 suggest ozone may have an effect on daily premature mortality rates 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 would 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 would, however, likely be benefits associated with VOC emission reductions associated with the proposed gas can standards. In Chapter 3, we discuss that the ozone modeling conducted for the proposed gas can 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 would likely lead to negligible monetized benefits. We therefore do not estimate ozone benefits for the gas can 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 proposed standards and will discuss them qualitatively within this chapter.

Table 12.1-1 summarizes the annual monetized health and welfare benefits associated with the proposed cold temperature standards for two years, 2020 and 2030, assuming a background PM threshold of 3 µg/m<sup>3</sup> in the calculation of PM mortality. EPA's consistent approach has 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 (down to background). This approach has 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<sub>2.5</sub> 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." We consider the impact of a threshold in the PM-mortality concentration response function in Section 12.6.1.1 of the RIA. 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 12.1-1. Estimated Monetized PM-Related Health Benefits of the Proposed Mobile Source Air Toxics Standards: Cold Temperature Controls**

	Total Benefits <sup>a, b, c</sup> (billions 2003\$)	
	2020	2030
Using a 3% discount rate	\$3.4 + B	\$6.5 + B
Using a 7% discount rate	\$3.1 + B	\$5.9 + B

- <sup>a</sup> 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<sup>3</sup>). 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 12.6.1.1 of the RIA.
- <sup>b</sup> 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 13-2 of the RIA.
- <sup>c</sup> Results reflect the use of two different discount rates: 3 and 7 percent, which are recommended by EPA’s *Guidelines for Preparing Economic Analyses*<sup>3</sup> and OMB Circular A-4. Results are rounded to three significant digits for ease of presentation and computation.

This chapter specifically assesses the PM-related benefits of the proposed cold temperature vehicle standards. However, we note that there would be significant reduction in emissions of air toxics (including benzene, 1,3-butadiene, formaldehyde, acetaldehyde, acrolein, naphthalene, and other air toxic pollutants) with the proposed standards in place. 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 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.<sup>4</sup> 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. For benzene, the cancer unit risk estimate is based on only one endpoint, acute nonlymphocytic leukemia; however, as discussed in Chapter 1, there is a causal relationship between benzene and other leukemias. There are additional 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 as part of a case study being done for benzene as part of the ongoing update to the Section 812 retrospective and prospective studies.<sup>B</sup>

**Table 12.1-2. Human Health and Welfare Effects of Pollutants Affected by the Proposed Standards**

<b>Pollutant/Effect</b>	<b>Quantified and Monetized in Base Estimates<sup>a</sup></b>	<b>Unquantified Effects - Changes in:</b>
PM/Health <sup>b</sup>	Premature mortality based on cohort study estimates <sup>c</sup> 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 <sup>d</sup> Subchronic bronchitis cases Low birth weight Pulmonary function Chronic respiratory diseases other than chronic bronchitis Nonasthma respiratory emergency room visits UVb exposure (+/-) <sup>e</sup>
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 (+/-) <sup>e</sup>

<sup>B</sup> 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 <sup>a</sup>	Unquantified Effects - Changes in:
Ozone/Health <sup>f</sup>		Premature mortality: short term exposures <sup>g</sup> 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 (+/-) <sup>e</sup>
Ozone/Welfare		Decreased outdoor worker productivity Yields for: <ul style="list-style-type: none"> <li>- Commercial forests</li> <li>- Fruits and vegetables, and</li> <li>- Other commercial and noncommercial crops</li> </ul> Damage to urban ornamental plants Recreational demand from damaged forest aesthetics Ecosystem functions UVb exposure (+/-) <sup>e</sup>
MSAT Health		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)
MSAT Welfare		Direct toxic effects to animals Bioaccumulation in the food chain Damage to ecosystem function Odor

<sup>a</sup> Primary quantified and monetized effects are those included when determining the primary estimate of total monetized benefits of the proposed standards.

<sup>b</sup> 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.

<sup>c</sup> 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).<sup>5</sup>

<sup>d</sup> 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.

<sup>e</sup> May result in benefits or disbenefits. See Section 12.5.3. for more details.

<sup>f</sup> 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.

<sup>g</sup> 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 primary benefits analyses.

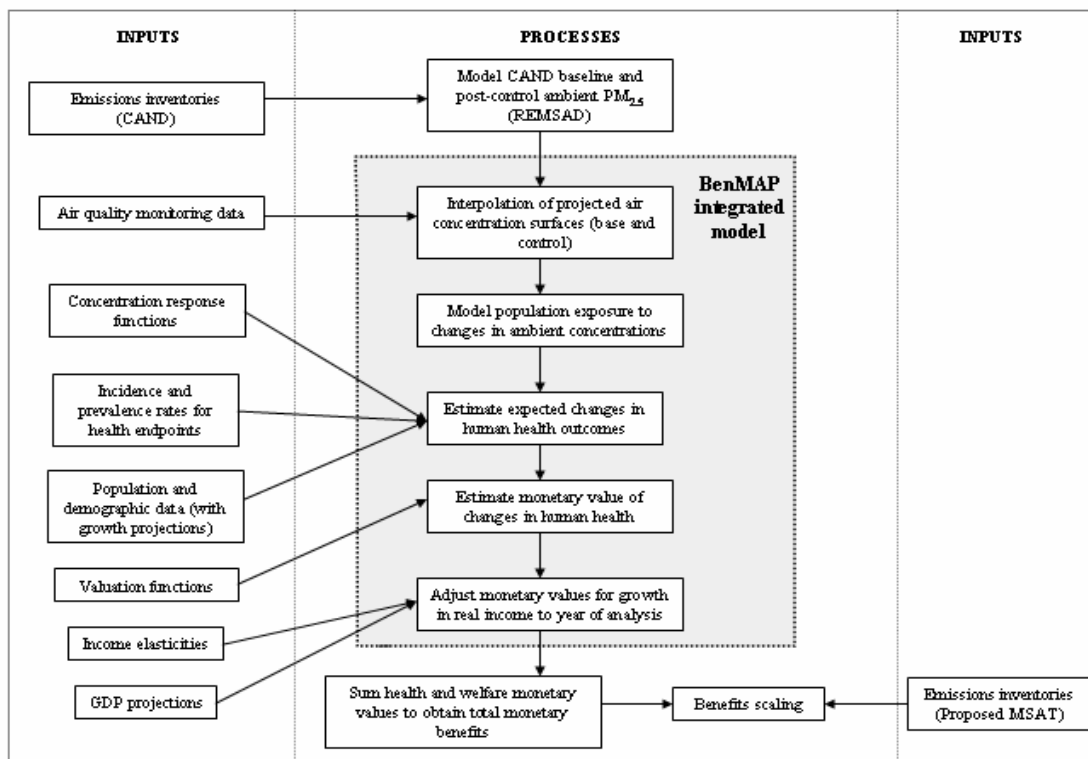
Figure 12.1-1 illustrates the major steps in this PM benefits analysis. Given the change in direct PM emissions modeled for the proposed cold temperature vehicle standards, we use a benefits transfer approach to scale PM benefits estimated for the CAND analysis (see Section 12.2 for a description of the scaling approach). For the CAND analysis, EPA ran a sophisticated photochemical air quality model 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 for use in estimating health effects. Changes in population exposure to ambient air pollution were then input to impact functions<sup>c</sup> to generate changes in the incidence of health effects. The resulting effects changes 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 would occur as a result of the proposed cold temperature standards.

Benefits estimates calculated for the CAND analysis, and scaled for the proposed 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 estimates. Interested parties may wish to consult the webpage <http://www.epa.gov/ttn/ecas/benmodels.html> for more information.

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<sup>c</sup> 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.

**Figure 12.1-1. Key Steps in Air Quality Modeling Based Benefits Analysis**



All of the benefit estimates for the proposed 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 in the “section 812 studies.”<sup>D</sup> By adopting the major design elements, models, and assumptions developed for the CAIR rule and other recent RIAs (such as the CAND rule), 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.<sup>E</sup>

These methods incorporate guidance from the National Academy of Sciences (NAS) (2002) report on its review of the Agency’s methodology for analyzing the health benefits of measures taken to reduce air pollution. EPA has been updating its methods to address the NAS

<sup>D</sup> The section 812 studies include: (1) U.S. EPA, Report to Congress: The Benefits and Costs of the Clean Air Act, 1970 to 1990, October 1997 (also known as the “Section 812 Retrospective Report”); and (2) the first in the ongoing series of prospective studies estimating the total costs and benefits of the Clean Air Act (see EPA report number: EPA-410-R-99-001, November 1999). See Docket A-99-06, Document II-A-21.

<sup>E</sup> Interested parties may want to consult the webpage: <http://www.epa.gov/science1> regarding components of the 812 prospective analytical blueprint.

comments; the analysis in the final CAIR rule included our most recent updates.<sup>F</sup> Our analysis of the proposed rule incorporates this most recent work when it is analytically feasible.

This chapter is organized as follows. In Section 12.2, we provide an overview of the air quality impacts modeled for the proposed standards that are used as inputs to the benefits analysis. In 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 presents the health-based cost-effectiveness analysis for the proposed standards. Finally, in Section 12.8, we present a comparison of the costs and benefits associated with the proposed 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 proposed 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<sub>2.5</sub> related to direct PM emission reductions estimated to occur due to the proposed cold temperature vehicle standards. We do this by scaling the modeled relationship between emissions and ambient PM concentrations observed for the CAND analysis.<sup>G</sup>

### **12.2.1 PM Air Quality Impact Estimation**

To estimate PM<sub>2.5</sub> benefits from the proposed 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<sub>2.5</sub> concentrations modeled for the Clean Air Nonroad Diesel (CAND) proposal.<sup>G</sup> For a given future year, we first calculate the ratio between CAND direct PM<sub>2.5</sub> emission reductions and direct PM<sub>2.5</sub> emission reductions associated with the proposed standards (proposed emission reductions/CAND emission reductions, displayed in Table 12.2-1). We multiply this ratio by the percent that direct PM<sub>2.5</sub> contributes towards population-weighted reductions in total PM<sub>2.5</sub> 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<sub>2.5</sub> (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

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<sup>F</sup> See Chapter 4 of the Final Clean Air Interstate Rule RIA ([www.epa.gov/cair](http://www.epa.gov/cair)) for a discussion of EPA's ongoing efforts to address the NAS recommendations in its regulatory analyses.

<sup>G</sup> See 68 FR 28327, May 23, 2003.

emission reductions between the modeled CAND control option and the proposed standards.<sup>H</sup> This benefits transfer method is consistent with the approach used in other recent mobile and stationary source rules.<sup>I</sup> We refer the reader to the final CAND RIA for more details on this benefits transfer approach.<sup>7</sup>

**Table 12.2-1. Comparison of 48-state Cold Temperature Emission Reductions in 2020 and 2030 Between the CAND and Proposed Cold Temperature Standards**

Emissions Species	Reduction from Baseline (tons)		Ratio of Reductions (MSAT/ CAND)
	CAND Modeling Inputs <sup>a</sup>	Cold Temperature Emissions Changes <sup>b</sup>	
<b>2020</b>			
Direct PM <sub>2.5</sub>	98,121	11,803	0.120
<b>2030</b>			
Direct PM <sub>2.5</sub>	138,208	20,096	0.145

<sup>a</sup> 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.

<sup>b</sup> 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<sub>2.5</sub> 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 <sub>2.5</sub>	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.

<sup>H</sup> Note that while the proposed regulations also control VOCs, which contribute to PM formation, the benefits transfer scaling approach only scales benefits based on NO<sub>x</sub>, SO<sub>2</sub>, 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.

<sup>I</sup> 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 (documentation forthcoming).

**Table 12.2-3. Calculation of PM<sub>2.5</sub> Benefits Apportionment Factor for Proposed Cold Temperature-Related Direct PM Emission Reductions**

	2020			2030		
	Ratio of Emission Reductions <sup>a</sup> (1)	% of Total Ambient Change <sup>b</sup> (2)	Benefits Apportionment Factor (1*2) (3)	Ratio of Emission Reductions <sup>a</sup> (3)	% of Total Ambient Change <sup>b</sup> (4)	Benefits Apportionment Factor (3*4) (5)
Direct PM Emissions	0.120	0.644	0.077	0.145	0.627	0.091

<sup>a</sup> Calculated by dividing cold temperature vehicle emission reductions by CAND emission reductions. See Table 12.2-1.

<sup>b</sup> 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 ozone-related and PM<sub>2.5</sub>-related benefits since the analysis for the CAIR and CAND rules include the following:

- Use of an updated dataset projecting county-level age-specific mortality rates for future scenarios (1997-2050). 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.<sup>8</sup> This approach is different than the fixed 1996-1998 CDC mortality rate data used in the CAND analysis, and the scaled benefits analysis of the proposed standards has 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<sub>2.5</sub>, and 20 percent occurring evenly over the years 6 to 20 after the reduction in PM<sub>2.5</sub>. 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 proposed 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**

Endpoint	Pollutant	Study	Study Population
<b>Premature Mortality</b>			
Premature mortality —cohort study, all-cause	PM <sub>2.5</sub>	Pope et al. (2002) <sup>9</sup>	>29 years
Premature mortality — all-cause	PM <sub>2.5</sub>	Woodruff et al. (1997) <sup>10</sup>	Infant (<1 year)
<b>Chronic Illness</b>			
Chronic bronchitis	PM <sub>2.5</sub>	Abbey et al. (1995) <sup>11</sup>	>26 years
Nonfatal heart attacks	PM <sub>2.5</sub>	Peters et al. (2001) <sup>12</sup>	Adults
<b>Hospital Admissions</b>			
Respiratory	PM <sub>2.5</sub>	Pooled estimate: Moolgavkar (2003) <sup>13</sup> —ICD 490-496 (COPD) Ito (2003) <sup>14</sup> —ICD 490-496 (COPD)	>64 years
	PM <sub>2.5</sub>	Moolgavkar (2000) <sup>15</sup> —ICD 490-496 (COPD)	20–64 years
	PM <sub>2.5</sub>	Ito (2003)—ICD 480-486 (pneumonia)	>64 years
	PM <sub>2.5</sub>	Sheppard (2003) <sup>16</sup> —ICD 493 (asthma)	<65 years
	PM <sub>2.5</sub>	Pooled estimate: Moolgavkar (2003)—ICD 390-429 (all cardiovascular) Ito (2003)—ICD 410-414, 427-428 (ischemic heart disease, dysrhythmia, heart failure)	>64 years
Cardiovascular	PM <sub>2.5</sub>	Moolgavkar (2000)—ICD 390-429 (all cardiovascular)	20–64 years
	PM <sub>2.5</sub>	Norris et al. (1999) <sup>17</sup>	0–18 years
<b>Other Health Endpoints</b>			
Acute bronchitis	PM <sub>2.5</sub>	Dockery et al. (1996) <sup>18</sup>	8–12 years
Upper respiratory symptoms	PM <sub>2.5</sub>	Pope et al. (1991) <sup>19</sup>	Asthmatics, 9–11 years
Lower respiratory symptoms	PM <sub>2.5</sub>	Schwartz and Neas (2000) <sup>20</sup>	7–14 years
Asthma exacerbations	PM <sub>2.5</sub>	Pooled estimate: Ostro et al. (2001) <sup>21</sup> (cough, wheeze and shortness of breath) Vedal et al. (1998) <sup>22</sup> (cough)	6–18 years <sup>a</sup>
Work loss days	PM <sub>2.5</sub>	Ostro (1987) <sup>23</sup>	18–65 years
MRADs	PM <sub>2.5</sub>	Ostro and Rothschild (1989) <sup>24</sup>	18–65 years

<sup>a</sup> 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\$)<sup>a</sup>**

Health Endpoint	Central Estimate of Value Per Statistical Incidence			Derivation of Estimates
	1990 Income Level	2020 Income Level <sup>b</sup>	2030 Income Level <sup>b</sup>	
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) <sup>25</sup> meta-analysis and \$10 million represents the upper end of the interquartile range from the Viscusi and Aldy (2003) <sup>26</sup> 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] <sup>27</sup> ) 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). <sup>28</sup> Direct medical costs are based on simple average of estimates from Russell et al. (1998) <sup>29</sup> and Wittels et al. (1990). <sup>30</sup>
<u>3% discount rate</u>				<u>Lost earnings:</u>
Age 0–24	\$66,902	\$66,902	\$66,902	Cropper and Krupnick (1990). Present discounted value of 5 years of lost earnings:
Age 25–44	\$74,676	\$74,676	\$74,676	<u>age of onset:</u> <u>at 3%</u> <u>at 7%</u>
Age 45–54	\$78,834	\$78,834	\$78,834	25-44      \$8,774      \$7,855
Age 55–65	\$140,649	\$140,649	\$140,649	45-54      \$12,932      \$11,578
Age 66 and over	\$66,902	\$66,902	\$66,902	55-65      \$74,746      \$66,920
<u>7% discount rate</u>				<u>Direct medical expenses:</u> An average of:
Age 0–24	\$65,293	\$65,293	\$65,293	1. Wittels et al. (1990) (\$102,658—no discounting)
Age 25–44	\$73,149	\$73,149	\$73,149	2. Russell et al. (1998), 5-year period (\$22,331 at 3% discount rate; \$21,113 at 7% discount rate)
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\$)<sup>a</sup> (continued)**

Health Endpoint	Central Estimate of Value Per Statistical Incidence			Derivation of Estimates
	1990 Income Level	2020 Income Level <sup>b</sup>	2030 Income Level <sup>b</sup>	
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) <sup>31</sup> (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) <sup>32</sup> and (2) \$260.67, from Stanford et al. (1999). <sup>33</sup>

(continued)

**Table 12.3-2. Unit Values Used for Economic Valuation of Health Endpoints (2000\$)<sup>a</sup> (continued)**

Health Endpoint	Central Estimate of Value Per Statistical Incidence			Derivation of Estimates
	1990 Income Level	2020 Income Level <sup>b</sup>	2030 Income Level <sup>b</sup>	
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) <sup>34</sup> 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). <sup>35</sup> 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). <sup>36</sup>

(continued)

**Table 12.3-2. Unit Values Used for Economic Valuation of Health Endpoints (2000\$)<sup>a</sup> (continued)**

Health Endpoint	Central Estimate of Value Per Statistical Incidence			Derivation of Estimates
	1990 Income Level	2020 Income Level <sup>b</sup>	2030 Income Level <sup>b</sup>	
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). <sup>37</sup>

<sup>a</sup> Although the unit values presented in this table are in year 2000 dollars, all monetized annual benefit estimates associated with the proposed 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.<sup>38</sup> 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.

<sup>b</sup> 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 proposed standards, however, we are unable to quantitatively characterize these impacts because of limited data availability; we are not quantifying ozone benefits related to the proposed 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.

Similar to Kunzli et al. (2000)<sup>39</sup> and other recent health impact analyses, our estimates are based on the best available methods of benefits transfer. Benefits transfer is the science and art of adapting primary research from similar contexts to obtain the most accurate measure of benefits for the environmental quality change under analysis. Adjustments are made for the level of environmental quality change, the sociodemographic and economic characteristics of the affected population, and other factors to improve the accuracy and robustness of benefits estimates.

## **12.4 Benefits Analysis Results for the Proposed Cold Temperature Vehicle Standards**

Applying the impact and valuation functions described previously in this chapter to the estimated changes in PM<sub>2.5</sub> associated with the proposed 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 Proposed Cold Temperature Standards<sup>a</sup>**

<b>Health Effect</b>	<b>2020</b>	<b>2030</b>
<b>PM-Related Endpoints</b>		
Premature Mortality <sup>b,c</sup>		
Adult, age 30+ and Infant, age <1 year	480	910
Chronic bronchitis (adult, age 26 and over)	330	590
Nonfatal myocardial infarction (adults, age 18 and older)	820	1,600
Hospital admissions—respiratory (all ages) <sup>d</sup>	260	540
Hospital admissions—cardiovascular (adults, age >18) <sup>e</sup>	220	400
Emergency room visits for asthma (age 18 years and younger)	360	630
Acute bronchitis (children, age 8–12)	790	1,400
Lower respiratory symptoms (children, age 7–14)	9,400	17,000
Upper respiratory symptoms (asthmatic children, age 9–18)	7,100	13,000
Asthma exacerbation (asthmatic children, age 6–18)	12,000	21,000
Work loss days (adults, age 18–65)	63,000	110,000
Minor restricted-activity days (adults, age 18–65)	370,000	620,000

<sup>a</sup> Incidences are rounded to two significant digits. PM estimates represent benefits from the proposed rule nationwide.

<sup>b</sup> PM premature mortality impacts for adults are based on application of the effect estimate derived from the Pope et al (2002) cohort study.<sup>40</sup> Infant premature mortality based upon studies by Woodruff, et al 1997.<sup>41</sup>

<sup>c</sup> PM-related mortality benefits estimated using an assumed PM threshold at background levels (3 µg/m<sup>3</sup>). 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 12.6.1.1 of the RIA.

<sup>d</sup> Respiratory hospital admissions for PM include admissions for COPD, pneumonia, and asthma.

<sup>e</sup> 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\$)<sup>a,b</sup>**

<b>PM-Related Health Effect</b>	<b>2020 Estimated Value of Reductions</b>	<b>2030 Estimated Value of Reductions</b>
Premature mortality <sup>c,d,e</sup>		
Adult, age 30+ and Infant, < 1 year		
3% discount rate	\$3,100	\$6,000
7% discount rate	\$2,800	\$5,400
Chronic bronchitis (adults, 26 and over)	\$150	\$270
Non-fatal acute myocardial infarctions		
3% discount rate	\$80	\$150
7% discount rate	\$77	\$150
Hospital admissions for respiratory causes	\$4.8	\$10
Hospital admissions for cardiovascular causes	\$5.1	\$9.4
Emergency room visits for asthma	\$0.12	\$0.21
Acute bronchitis (children, age 8–12)	\$0.32	\$0.58
Lower respiratory symptoms (children, 7–14)	\$0.17	\$0.30
Upper respiratory symptoms (asthma, 9–11)	\$0.20	\$0.37
Asthma exacerbations	\$0.57	\$1.0
Work loss days	\$9.2	\$14
Minor restricted-activity days (MRADs)	\$21	\$36
Monetized Total <sup>f</sup>		
Base Estimate:		
3% discount rate	\$3,400+ B	\$6,500+ B
7% discount rate	\$3,100+ B	\$5,900+ B

<sup>a</sup> Monetary benefits are rounded to two significant digits for ease of presentation and computation. PM benefits are nationwide.

<sup>b</sup> Monetary benefits adjusted to account for growth in real GDP per capita between 1990 and the analysis year (2020 or 2030)

<sup>c</sup> PM-related mortality benefits estimated using an assumed PM threshold at background levels (3 µg/m<sup>3</sup>). 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 12.6.1.1 of the RIA.

<sup>d</sup> 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).<sup>42,43</sup>

<sup>e</sup> Adult premature mortality estimates based upon studies by Pope, et al 2002.<sup>44</sup> Infant premature mortality based upon Woodruff et al 1997.<sup>45</sup>

<sup>f</sup> B represents the monetary value of health and welfare benefits and disbenefits not monetized. A detailed listing is provided in Table 12-2.

In addition to omitted benefits categories such as air toxics, ozone, and various welfare effects, not all known PM-related health and welfare effects could be quantified or monetized. 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 proposed 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 proposed cold temperature vehicle standards would result in 480 avoided premature deaths annually in 2020 and 910 avoided premature deaths annually in 2030. The increase in annual benefits from 2020 to 2030 reflects additional emission reductions from the proposed 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 proposed cold temperature vehicle standards is \$3.4 billion using a 3 percent discount rate and \$3.1 billion using a 7 percent discount rate. In 2030, the monetized benefits are estimated at \$6.5 billion using a 3 percent discount rate and \$5.9 billion using a 7 percent discount rate. The monetized benefit associated with reductions in the risk of premature mortality, which accounts for \$3.1 billion in 2020 and \$6.0 billion in 2030 (assuming a 3 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). As such, the true value of these effects may be higher than that reported in Table 12-9.

## **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 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. We will explore how to monetize these welfare effects using the available tools for the analysis of the final standards.

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.

### **12.5.1 Human Health Impact Assessment**

In addition to the PM 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 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. The inability to quantify these effects lends a downward bias to the monetized benefits presented in this analysis.

Other standards we are currently proposing, such as the gas can standards, would 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 proposed gas can 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 do not contribute significantly to the monetized benefits; thus, their omission will not materially affect the conclusions of the benefits analysis.

Over the past several years, EPA has consulted with the Science Advisory Board regarding evidence for an independent ozone mortality effect. Because of new studies and the recommendations from the SAB, EPA sponsored three independent meta-analyses of the ozone-mortality epidemiology literature to inform a determination on including this important health

endpoint. The three meta-analyses were published in the journal *Epidemiology* in July 2005.<sup>46,47,48</sup> These meta-analyses, as well as another major study in the *Journal of the American Medical Association*,<sup>49</sup> reported that on average, short-term changes in ozone are significantly associated with premature mortality, and that the significance of the association is robust to adjustment for particulate matter. The JAMA study used the extensive National Morbidity, Mortality, and Air Pollution Study database to examine associations between ozone and premature mortality in 95 U.S. urban communities.

The Agency believes that publication of these studies significantly enhances the scientific defensibility of benefits estimates for ozone that include the benefits of premature mortality reductions. In the future we plan to examine a variety of ozone mortality quantification methods, including approaches that provide information on relative probability of different benefits levels. Using effect estimates similar to those found in these new studies, EPA estimates that the monetary value of the ozone-related premature mortality benefits could be substantial.

### **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 caused by the reduction in emissions from the proposed standards would 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.<sup>50</sup>

#### **12.5.2.2 Agricultural, Forestry and other Vegetation-Related 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).<sup>51</sup> Changes in ground-level ozone would result from the proposed standards are expected to affect crop and forest yields throughout the affected area.

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 proposed 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.”<sup>54</sup> In addition, economic studies have shown a relationship between observed ozone levels and crop yields.<sup>52</sup>

#### 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).<sup>54,53</sup> In our previous analysis of the HD 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 of resource limitations, we were not able to quantify such impacts for this analysis.

#### 12.5.2.2.3 Other Vegetation Effects

An additional welfare benefit expected to accrue as a result of reductions in ambient ozone concentrations in the United States is the economic value the public receives from reduced aesthetic injury to forests. There is sufficient scientific information available to reliably establish that ambient ozone levels cause visible injury to foliage and impair the growth of some sensitive plant species (EPA, 1996).<sup>54</sup> However, present analytic tools and resources preclude EPA from quantifying the benefits of improved forest aesthetics.

Urban ornamentals (floriculture and nursery crops) represent an additional vegetation category likely to experience some degree of negative effects associated with exposure to ambient ozone levels and likely to affect large economic sectors. 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 economic benefits analysis has been conducted. The farm production value of ornamental crops was estimated at over \$14 billion in 2003 (USDA, 2004).<sup>54</sup> This is therefore a potentially important welfare effects category. However, information and valuation 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.

#### 12.5.2.3 Benefits from Reductions in Materials Damage

The proposed 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<sub>2.5</sub> 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).<sup>55</sup>

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)<sup>56</sup> 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 proposed 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.<sup>57</sup> 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.<sup>58</sup> 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 proposed 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 key sources of uncertainty in each stage of the benefits analysis are the following:

- The exclusion of potentially substantial benefit categories (such as health, odor, and ecological benefits of reduction in air toxics, ozone, and PM);
- Errors in measurement and projection for variables such as population growth;
- Uncertainties in the estimation of future year emissions inventories and air quality, including uncertainties in the estimated reductions in PM emissions resulting from the cold temperature standard for light-duty vehicles;
- Uncertainties associated with the scaling of the PM results of the modeled benefits analysis to the proposed standards, especially regarding the assumption of similarity in geographic distribution between emissions and human populations and years of analysis;
- Uncertainty in the estimated relationships of health and welfare effects to changes in pollutant concentrations including the shape of the C-R function, the size of the effect estimates, and the relative toxicity of the many components of the PM mixture;
- Uncertainties in exposure estimation; and
- Uncertainties associated with the effect of potential future actions to limit emissions.

The NRC report on estimating public health benefits of air pollution regulations recommended that EPA begin to move the assessment of uncertainties from its ancillary analyses into its primary analyses by conducting probabilistic, multiple-source uncertainty analyses (NRC, 2002).<sup>59</sup> The probability distributions required for these analyses should be based on available data and expert judgment.

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 for individual health endpoints are provided in the CAIR RIA (Appendix B; EPA, 2005).<sup>60</sup> It is likely that these

distributions do not capture the full range of benefits, and in fact are likely to understate the uncertainty, especially on the high end of the range due to omission of potentially significant benefit categories. We estimate them here as an illustration of EPA's traditional approach towards characterizing uncertainty using probabilistic, statistical error-based distributions. Results and discussion of the Monte Carlo approach can be found in Appendix 12.A.

In addition to the Monte Carlo approach to characterizing statistical sources of uncertainty, we also supplement our primary estimates of benefits with a series of sensitivity calculations that use other sources of health effect estimates and valuation data for key benefits categories. The supplemental estimates examine sensitivity to both valuation issues (e.g., the type of lag structure used for the valuation of PM-related premature mortality) and physical effects issues (e.g., alternative health impact functions for PM-related premature mortality). The results of these supplemental calculations are presented in Appendix 12.B.

### **12.6.1 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 mortality health impact function relationship and valuation. Use of the Pope et al., 2002-derived mortality function to support this analysis is associated with uncertainty resulting from: (a) potential of the study to incompletely capture short-term exposure-related mortality effects, (b) potential mismatch 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<sub>2.5</sub> 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 both the CAND RIA and the CAIR RIA, EPA has used two methods to quantify uncertainties in the mortality function, including: the statistical uncertainty derived from the standard errors reported in the Pope et al., 2002 study, and the use of results of a pilot expert elicitation conducted in 2004 to investigate other uncertainties in the mortality estimate. Because this analysis utilizes the PM scaling benefits transfer approach to estimate mortality incidence for the proposed standard, we can not quantify the PM mortality uncertainty to the same extent as was done for the CAIR or CAND analyses. However, in a similar fashion to the analysis conducted for the Clean Air Visibility Rule (CAVR),<sup>61</sup> we can scale the results of the CAND mortality uncertainty analysis to the direct PM emission changes modeled for the proposed cold temperature standards.

In the benefit analysis of the CAND 2030 emission control standards, the statistical uncertainty represented by the standard error of the Pope et al, 2002 study was one and one-half times the mean benefit estimate at the 95<sup>th</sup> percentile and less than one-half of the mean at the 5<sup>th</sup> percentile. The expert elicitation provided mean estimates that ranged in value from less than one-third of the mean estimate from the Pope et al, 2002 study-based estimate to nearly one and one-half times the Pope et al., 2002-based estimate. The confidence intervals from the pilot elicitation applied to the CAND 2030 benefit analysis ranged in value from zero at the 5<sup>th</sup>

percentile to a value at the 95<sup>th</sup> percentile that is approximately three times higher than the Pope et al., 2002-based mean estimate.

These results are highly dependent on the air quality scenarios applied to the concentration-response functions of the Pope et al, 2002 study and the pilot expert elicitation. Thus, the characterization of uncertainty discussed in the CAND RIA could differ greatly from what would be observed for the proposed standards due to differences in population-weighted changes in concentrations of PM<sub>2.5</sub> (i.e., the location of populations exposure relative to the changes in air quality), and may be especially sensitive to the differences in baseline PM<sub>2.5</sub> air quality experienced by populations prior to the implementation of the proposed standards.

Table 12.6-1 shows the mean estimate and estimated 5<sup>th</sup> and 95<sup>th</sup> percentiles of premature deaths avoided for our 2030 scaled primary estimate based on the Pope et al. (2002) study and based on the scaled responses for each of the 5 experts. This table shows that for the proposed standards, our estimates are higher than those based on the functions provided by four of the experts and lower than that provided by one expert, but falls within the scaled uncertainty bounds of all but one expert. The table shows that for the proposed standards, the average estimated annual number of premature deaths avoided in 2030 ranges from approximately 260 (based on the judgments of Expert C) to 1,200 (based on the judgments of Expert E). The 5<sup>th</sup> to 95<sup>th</sup> percentile of all the estimates, including the Pope et al.-based distribution, overlap. Although the distributions for each expert include zero, and some distributions have significant percentiles at zero, all of the distributions have a positive mean estimate. EPA is continuing its research of methods to characterize uncertainty in total benefits estimates, and is conducting a full-scale expert elicitation. The full-scale expert elicitation is scheduled to be completed in 2006.

**Table 12.6-1. Results of Illustrative Application of Pilot Expert Elicitation: Annual Reductions in Premature Mortality in 2030 Associated with the Proposed Cold Temperature Vehicle Standards Scaled from the CAND Analysis**

Source of Mortality Estimate	2030 Primary Option		
	5 <sup>th</sup> Percentile	Mean	95 <sup>th</sup> Percentile
Pope et al. (2002)	410	910	1,400
Expert A	0	750	1,400
Expert B	0	410	1,800
Expert C	0	260	670
Expert D	0	630	1,600
Expert E	0	1,200	2,500

#### 12.6.1.1 PM-Mortality Cutpoint 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<sub>2.5</sub>. The consistent advice from EPA's SAB<sup>J</sup> has been to model premature 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<sub>2.5</sub> 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".<sup>62</sup> 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 proposed PM NAAQS RIA<sup>63</sup> constructed a sensitivity analysis by assigning different cutpoints below which changes in PM<sub>2.5</sub> are assumed to have no impact on premature mortality. In applying the cutpoints, the PM NAAQS analysis adjusted the mortality function slopes accordingly.<sup>K</sup> Four cutpoints were included in the sensitivity analysis: (a) 15 µg/m<sup>3</sup> (based on the current NAAQS); (b) 10 µg/m<sup>3</sup> (reflects comments from CASAC, 2005)<sup>64</sup>; (c) 7.5 µg/m<sup>3</sup> (reflects recommendations from SAB-HES (2004)<sup>65</sup> to consider estimating mortality benefits down to the lowest exposure levels considered in the Pope et al. (2002)<sup>66</sup> study used as the basis for modeling chronic mortality); and (d) background or 3 µg/m<sup>3</sup> (reflects NAS (2002)<sup>67</sup> recommendation to consider effects all the way to background). The results of the sensitivity analysis displayed the change in avoided mortality cases and associated monetary benefits associated with the alternative cutpoints (see the proposed PM NAAQS RIA, Chapter 3, Table 3-8).

A sensitivity analysis such as this can be difficult to interpret, because when a threshold above the lowest observed level of PM<sub>2.5</sub> in the underlying epidemiology 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.<sup>L</sup> 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,

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<sup>J</sup> The advice from the 2004 SAB-HES (EPA-SAB-COUNCIL-ADV-04-002)<sup>69</sup> 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<sub>2.5</sub> 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 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."

<sup>K</sup> Note that the PM NAAQS analysis only adjusted the mortality slopes for the 10 µg/m<sup>3</sup> and 15 µg/m<sup>3</sup> cutpoints since the 7.5 µg/m<sup>3</sup> 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.

<sup>L</sup> See NAS (2002)<sup>71</sup> and CASAC (2005)<sup>68</sup> for discussions of this issue.

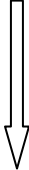
we present an example from the proposed PM NAAQS RIA. In its examination of the benefits of attaining alternative PM NAAQS in Chicago,<sup>M</sup> the analysis found that, because annual mean levels are generally higher in Chicago, there was a two-part pattern to the relationship between assumed threshold and mortality impacts. As the threshold increased from background to 7.5  $\mu\text{g}/\text{m}^3$ , the mortality impact fell (because there is no slope adjustment). However, at an assumed threshold of 10  $\mu\text{g}/\text{m}^3$ , estimated mortality impacts actually increased, because the populations exposed above 10  $\mu\text{g}/\text{m}^3$  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  $\mu\text{g}/\text{m}^3$  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 proposed 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 proposed 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 proposed cold temperature vehicle standards reflects a background threshold assumption of 3  $\mu\text{g}/\text{m}^3$ . For the final MSAT rule analysis, we plan on examining the impact cutpoints have on our primary estimate of PM mortality benefits related to the proposed cold temperature vehicle standards. For now, however, we present in Table 12.6-2 the results of our scaled PM-related mortality benefits in the context of its relationship to other cutpoints. Note that to the extent we are able, we will endeavor to quantify the omissions in this table in the analysis of the final MSAT rule.

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<sup>M</sup> See the proposed PM NAAQS RIA (2005),<sup>67</sup> Appendix A, pp. A63-A64.

**Table 12.6-2. PM-Related Mortality Benefits of the Proposed Cold Temperature Vehicle Standards: Cutpoint Sensitivity Analysis<sup>a</sup>**

<i>Certainty that Benefits are At Least Specified Value</i>	<i>Level of Assumed Threshold</i>	<i>Discount Rate</i>	<b>PM Mortality Benefits (Billion 2003\$)</b>	
			2020	2030
<div style="text-align: center;">  </div>	15 µg/m <sup>3</sup> <sup>c</sup>	3%	N/A <sup>b</sup>	
		7%		
	10 µg/m <sup>3</sup> <sup>d</sup>	3%	N/A	
		7%		
	7.5 µg/m <sup>3</sup> <sup>e</sup>	3%	N/A	
		7%		
Less Certain	3 µg/m <sup>3</sup> <sup>f</sup>	3%	\$3.1	\$6.0
		7%	\$2.8	\$5.9

<sup>a</sup> Note that this table only presents the effects of a cutpoint on PM-related mortality incidence and valuation estimates.

<sup>b</sup> We are unable to provide cutpoint analysis results for the proposed MSAT rule because of the analytical limitations of the PM benefits scaling procedure. To the extent we are able, we will endeavor to quantify the omissions in this table in the analysis of the final MSAT rule.

<sup>c</sup> EPA intends to analyze a cutpoint between 12 µg/m<sup>3</sup> and 15 µg/m<sup>3</sup> for the final RIA.

<sup>d</sup> CASAC (2005)<sup>68</sup>

<sup>e</sup> SAB-HES (2004)<sup>69</sup>

<sup>f</sup> NAS (2002)<sup>71</sup>

## 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) has 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 is expected to produce a report by the beginning of 2006. In the interim, however, agencies are expected to provide CEAs for rules covered by Circular A-4 requirements.

In Appendix G of the RIA for the CAIR,<sup>63</sup> EPA conducted an extensive cost-effectiveness analysis using morbidity inclusive life years (MILY). That analysis concluded that reductions in PM<sub>2.5</sub> 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 proposed 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.<sup>68</sup> 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 proposed 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 proposed cold temperature standards. We will, however, endeavor to conduct a formal health-based cost-effectiveness analysis for the final MSAT rule.

## **12.8 Comparison of Costs and Benefits**

This proposed rule provides three separate provisions that reduce air toxics emissions from mobile sources: cold temperature vehicle controls, an emissions control program for gas cans, 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<sub>2.5</sub>-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 proposed 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 proposed cold temperature vehicle standards and estimated social welfare costs for each of the proposed control programs.<sup>N</sup> The annual social welfare costs of all provisions of this proposed 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 would be approximately \$3,400 + B million or \$3,100 + B million annually in 2020 (using a 3 percent and 7 percent discount rate in the benefits analysis, respectively), compared to estimated social welfare costs of approximately \$11 million in the last year of the program (2019). These benefits are expected to increase to \$6,500 + B million or \$5,900 + B million annually in 2030 (using a 3 percent and 7 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 proposed rule provisions: an emissions control program for gas cans and a control program limiting benzene in 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 proposed cold temperature vehicle standards alone exceed the costs of all three proposed rule provisions combined.

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<sup>N</sup> 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.

**Table 12.8-1. Summary of Annual Benefits of the Proposed Cold Temperature Vehicle Standards and Costs of All Provisions of the Proposed Standards<sup>a</sup>**  
(Millions of 2003 dollars)

Description	2020 (Millions of 2003 dollars)	2030 (Millions of 2003 dollars)
<b>Estimated Social Welfare Costs<sup>b</sup></b>		
<b>Proposed Cold Temperature Vehicle Standards</b>	\$11 <sup>c</sup>	\$0
<b>Proposed Gasoline Container Standards</b>	\$32	\$39
<b>Proposed Fuel Standards<sup>d</sup></b>	\$210	\$250
<b>Total</b>	\$240	\$290
<b>Fuel Savings</b>	-\$73	-\$82
<b>Total Social Welfare Costs</b>	\$170	\$205
<b>Total PM<sub>2.5</sub>-Related Health Benefits of the Proposed Cold Temperature Vehicle Standards<sup>e</sup></b>		
<b>3 percent discount rate</b>	\$3,400 + B <sup>f</sup>	\$6,500 + B <sup>f</sup>
<b>7 percent discount rate</b>	\$3,100 + B <sup>f</sup>	\$5,900 + B <sup>f</sup>

<sup>a</sup> 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.

<sup>b</sup> Note that costs are the annual total costs of reducing all pollutants associated with each provision of the proposed MSAT control package. Also note that while the cost analysis only utilizes a 7 percent discount rate to calculate annual costs, the benefits analysis uses both a 3 percent and 7 percent discount rate to calculate annual benefits. Benefits reflect only direct PM reductions associated with the cold temperature vehicle standards.

<sup>c</sup> 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.

<sup>d</sup> Our modeling for the total costs of the proposed gasoline benzene program included California gasoline, since it was completed before we decided to propose that California gasoline not be covered by the program. California refineries comprise approximately 1 percent of these projected costs. For the final rule, we expect to exclude California refineries from the analysis.

<sup>e</sup> 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). 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).<sup>o</sup>

<sup>f</sup> 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.

<sup>o</sup>U.S. Environmental Protection Agency, 2000. Guidelines for Preparing Economic Analyses.  
[www.yosemite1.epa.gov/ee/epa/eed/hst/pages/Guideline.html](http://www.yosemite1.epa.gov/ee/epa/eed/hst/pages/Guideline.html).

Office of Management and Budget, The Executive Office of the President, 2003. Circular A-4.  
<http://www.whitehouse.gov/omb/circulars>.

## **Appendix 12A: Supplemental Analysis Addressing Uncertainties in the Benefits Analysis**

### **12A.1 Introduction**

The recent NAS report on estimating public health benefits of air pollution regulations recommended that EPA begin to move the assessment of uncertainties from its ancillary analyses into its primary analyses by conducting probabilistic, multiple-source uncertainty analyses. We present two approaches to generating probabilistic distributions designed to illustrate the potential influence of some aspects of the uncertainty in the C-R function in a PM benefits analysis. The first approach uses the results from a pilot expert elicitation designed to characterize certain aspects of uncertainty in the ambient PM<sub>2.5</sub>/mortality relationship. We present the results of that analysis in the discussion of primary benefits associated with the proposed standards (see Chapter 12). The second approach generates a probabilistic estimate of statistical uncertainty based on standard errors reported in the underlying studies used in the benefit modeling framework, with particular emphasis on the health impact functions. In this appendix, we describe this second approach toward characterizing uncertainties in our economic benefits estimates.

It should be recognized that in addition to uncertainty, the annual benefits estimates for the proposed standards also are inherently variable, due to the truly random processes that govern pollutant emissions and ambient air quality in a given year. Factors such as hourly rate of emissions and daily weather display constant variability regardless of our ability to accurately measure them. As such, the primary estimates of annual benefits presented in this chapter and the sensitivity analysis estimates presented in this and other appendices should be viewed as representative of the types of benefits that will be realized, rather than the actual benefits that would occur every year. The distributions of the estimate of annual benefits should therefore be viewed as representative of the types of benefits that will be realized, rather than the actual benefits that would occur every year.

#### **12A.1.1 General Approach**

For the proposed 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,<sup>P</sup> based on the same benefits transfer approach we used to estimate the benefits of the proposed standards presented in Chapter 12. 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.

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<sup>P</sup> 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.

We use the benefits transfer approach to scale those distributions to reflect the predicted direct PM emission reductions of the proposed 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 5<sup>th</sup> and 95<sup>th</sup> 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<sup>Q</sup> 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.<sup>R</sup> 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 5<sup>th</sup> percentile point of the likelihood distribution to the 95<sup>th</sup> 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.

## 12A.2 Monte-Carlo Based Uncertainty Analysis

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<sup>Q</sup> 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  $\beta^*$ .

<sup>R</sup> 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), pp. 168-172).

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.<sup>S</sup> 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  $X_1$ , then the mean of the distribution,  $E(X_1)$  and the variance of  $X_1$ , denoted  $Var(X_1)$ , and the 5th and 95th percentile points of the distribution (related to  $Var(X_1)$ ), 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  $X_2$ , the benefits from reductions in the incidence of both types of hospital admissions is  $X_1 + X_2$ . This variable has a distribution with mean  $E(X_1 + X_2) = E(X_1) + E(X_2)$ , and a variance of  $Var(X_1 + X_2) = Var(X_1) + Var(X_2) + 2Cov(X_1, X_2)$ ; if  $X_1$  and  $X_2$  are stochastically independent, then it has a variance of  $Var(X_1 + X_2) = Var(X_1) + Var(X_2)$ , and the covariance term is zero.

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<sup>S</sup> This method assumes that the incidence change and the unit dollar value for an endpoint are stochastically independent.

The benefits from reductions in all nonoverlapping PM-related health and welfare endpoints are ( $X_{m+1}, \dots, X_n$ ) is  $X = X_1 + \dots + X_n$ . The mean of the distribution of total benefits,  $X$ , is

$$E(X) = E(X_1) + E(X_2) + \dots + E(X_n)$$

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

$$\text{Var}(X) = \text{Var}(X_1) + \text{Var}(X_2) + \dots + \text{Var}(X_n)$$

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,

$$E(X_1) < E(X_1 + X_2) < E(X_1 + X_2 + X_3) < \dots < E(X_1 + \dots + X_n) = E(X)$$

$$\text{Var}(X_1) < \text{Var}(X_1 + X_2) < \text{Var}(X_1 + X_2 + X_3) < \dots < \text{Var}(X_1 + \dots + X_n) = \text{Var}(X)$$

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,  $X_1, X_2$ , through  $X_n$ ; 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.

### **12A.2.1 Monte Carlo Analysis Using Classical Statistical Sources of Uncertainty**

Based on the Monte Carlo techniques and benefits transfer methods described earlier, we scaled the CAND likelihood distributions for the dollar value of total PM health-related benefits for the proposed 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 12-7.

Results of the scaled Monte Carlo simulations are presented in Table 12A-1. 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 12A-1. Distribution of Value of Annual PM-Related Human Health Benefits in 2030 for the Proposed Mobile Source Air Toxics Rule: Cold Temperature Controls <sup>a</sup>**

Endpoint	Monetary Benefits <sup>b, c</sup> (Millions 2003\$, Adjusted for Income Growth)		
	5 <sup>th</sup> Percentile	Mean	95 <sup>th</sup> Percentile
Premature mortality <sup>c</sup> , Long-term exposure			
Adults, 30+ yrs and Infants, <1yr			
3% Discount Rate	\$1,400	\$6,000	\$12,000
7% Discount Rate	\$1,300	\$5,400	\$11,000
Chronic bronchitis (adults, 26 and over)	\$13	\$270	\$910
Nonfatal myocardial infarctions			
3% Discount Rate	\$33	\$150	\$340
7% Discount Rate	\$31	\$150	\$340
Hospital admissions from respiratory causes	\$3.2	\$10	\$17
Hospital admissions from cardiovascular causes	\$5.5	\$9.4	\$14
Emergency room visits for asthma	\$0.12	\$0.21	\$0.31
Acute bronchitis (children, aged 8–12)	(\$0.017)	\$0.58	\$1.4
Lower respiratory symptoms (children, aged 7–14)	\$0.12	\$0.30	\$0.56
Upper respiratory symptoms (asthmatic children, aged 9–11)	\$0.091	\$0.37	\$0.81
Asthma exacerbations	\$0.014	\$1.0	\$2.9
Work loss days (adults, aged 18–65)	\$12	\$14	\$16
Minor restricted-activity days (adults, aged 18–65)	\$21	\$36	\$52
Monetized Total <sup>d</sup>			
3% Discount Rate	\$1,500 + B	\$6,500 + B	\$13,000 + B
7% Discount Rate	\$1,400 + B	\$5,900 + B	\$12,000 + B

<sup>a</sup> Monetary benefits are rounded to two significant digits.

<sup>b</sup> Monetary benefits are adjusted to account for growth in real GDP per capita between 1990 and 2030.

<sup>c</sup> Results show 3 percent and 7 percent discount rates consistent with EPA and OMB guidelines for preparing economic analyses (EPA, 2000; OMB, 2003).

<sup>d</sup> 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 12-2.

## **Appendix 12B: Sensitivity Analyses of Key Parameters in the Benefits Analysis**

The primary analysis presented in Chapter 12 is based on our current interpretation of the scientific and economic literature. That interpretation requires judgments regarding the best available data, models, and modeling methodologies and the assumptions that are most appropriate to adopt in the face of important uncertainties and resource limitations. The majority of the analytical assumptions used to develop the primary estimates of benefits have been used to support similar rulemakings and approved by EPA's Science Advisory Board (SAB). Both EPA and the SAB recognize that data and modeling limitations as well as simplifying assumptions can introduce significant uncertainty into the benefit results and that alternative choices exist for some inputs to the analysis, such as the mortality C-R functions.

This appendix supplements our primary estimates of benefits with a series of sensitivity calculations that use other sources of health effect estimates and valuation data for key benefits categories. It should be noted, however, that these supplemental estimates have been scaled from results of the Clean Air Nonroad Diesel (CAND) supplemental sensitivity analysis using the same benefits transfer approach we used to estimate the benefits of the proposed standards presented in Chapter 12. Though the scaling approach adds another element of uncertainty that we cannot characterize in the sensitivity analyses, we believe the scaled results of the supplemental estimates presented here are a reasonable approximation of the primary estimates' sensitivity to the assumptions and judgments used in the benefits analysis.

The supplemental estimates examine sensitivity to both valuation issues (e.g., the form of the lag structure for PM-related premature mortality) and for physical effects issues (e.g., the effect of thresholds on PM-related premature mortality). These supplemental estimates are not meant to be comprehensive. Rather, they reflect some of the key issues identified by EPA or commentors as likely to have a significant impact on total benefits. The individual adjustments in the tables should not simply be added together because: 1) there may be overlap among the alternative assumptions; and 2) the joint probability among certain sets of alternative assumptions may be low.

### **12B.1 Premature Mortality - Long-Term Exposure**

Reduction in the risk of premature mortality is the most important PM-related health outcome in terms of contribution to dollar benefits in the analysis for this rule. There are at least three important analytical assumptions that may significantly impact the estimates of the number and valuation of avoided premature mortalities. These include selection of the C-R function, structure of the lag between reduced exposure and reduced mortality risk, and effect thresholds. Results of this set of sensitivity analyses are presented in Table 12B-1.

**Table 12B-1. Sensitivity of Benefits of Premature Mortality Reductions to Alternative Assumptions (Relative to Primary Benefits Estimates of the Proposed Standards)**

Description of Sensitivity Analysis		Avoided Incidences		Value (million 2003\$) <sup>b</sup>	
		2020	2030	2020	2030
<i>Alternative Concentration-Response Functions for PM-Related Premature Mortality</i>					
Pope/ACS Study (2002) <sup>c</sup>					
	Lung Cancer	70	140	\$470	\$910
	Cardiopulmonary	370	720	\$2,400	\$4,800
	Krewski/Harvard Six-Cities Study	1,050	2,000	\$6,700	\$13,000
<i>Alternative Lag Structures for PM-Related Premature Mortality</i>					
None	Incidences all occur in the first year	480	910	\$3,400	\$6,600
8-year	Incidences all occur in the 8 <sup>th</sup> year				
	3% Discount Rate	480	910	\$2,800	\$5,400
	7% Discount Rate	480	910	\$2,100	\$4,100
15-year	Incidences all occur in the 15 <sup>th</sup> year				
	3% Discount Rate	480	910	\$2,300	\$4,400
	7% Discount Rate	480	910	\$1,300	\$2,600
Alternative Segmented	20 percent of incidences occur in 1 <sup>st</sup> year, 50 percent in years 2 to 5, and 30 percent in years 6 to 20				
	3% Discount Rate	480	910	\$3,000	\$5,800
	7% Discount Rate	480	910	\$2,600	\$5,000
5-Year Distributed	50 percent of incidences occur in years 1 and 2 and 50 percent in years 2 to 5				
	3% Discount Rate	480	910	\$3,200	\$6,300
	7% Discount Rate	480	910	\$3,000	\$5,900

<sup>a</sup> Incidences rounded to two significant digits.

<sup>b</sup> Dollar values rounded to two significant digits. Note that dollar values reflect the use of a 3 percent discount rate in the lag adjustment for mortality valuation for the alternative C-R function and alternative threshold analyses. The alternative lag structure analysis presents benefits calculated using both a 3 percent and 7 percent discount rate.

<sup>c</sup> Note that the sum of lung cancer and cardiopulmonary deaths will not be equal to the total all-cause death estimate. Some residual mortality is associated with long-term exposures to PM<sub>2.5</sub> that is not captured by the cardiopulmonary and lung cancer categories.

### 12B.1.1 Alternative C-R Functions

Following the advice of the most recent EPA SAB-Health Effects Subcommittee (HES), we used the Pope et al. (2002)<sup>69</sup> all-cause mortality model to derive our primary estimate of avoided premature mortality (EPA-SAB-COUNCIL-ADV-04-002, 2004).<sup>70</sup> While the SAB-HES “recommends that the base case rely on the Pope et al. (2002) study and that EPA use total mortality concentration-response functions (C-R), rather than separate cause-specific C-R functions, to calculate total PM mortality cases,” (EPA-SAB-COUNCIL-ADV-04-002, 2004, p.2) they also suggested that “the cause-specific estimates can be used to communicate the relative contribution of the main air pollution related causes of death.” (EPA-SAB-COUNCIL-ADV-04-002, 2004, p.18) As such, in Table B-1 we provide the scaled estimates of cardiopulmonary and lung cancer deaths based on the Pope et al. (2002) study.

In addition, the SAB-HES noted that the ACS cohort used in Pope et al. (2002) “has some inherent deficiencies, in particular the imprecise exposure data, and the nonrepresentative (albeit very large) population” (EPA-SAB-COUNCIL-ADV-04-002, 2004, p.18). The SAB-HES suggests that while not necessarily a better study, the ACS is a prudent choice for the primary estimate. They go on to note that “the Harvard Six-Cities C-R functions are valid estimates on a more representative, although geographically selected, population, and its updated analysis has not yet been published. 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, 2004, p.18).

In previous advice, the SAB has noted that “the [Harvard Six-Cities] study had better monitoring with less measurement error than did most other studies,” (EPA-SAB-COUNCIL-ADV-99-012, 1999).<sup>71</sup> The demographics of the ACS study population (i.e., largely white and middle to upper middle-class) may also produce a downward bias in the estimated PM mortality coefficient, because a variety of analyses indicate that the effects of PM tend to be significantly greater among groups of lower socioeconomic status (Krewski et al., 2000),<sup>72</sup> although the cause of this difference has not been identified. The Harvard Six-Cities study also covered a broader age category (25 and older compared to 30 and older in the ACS study). We emphasize that, based on our understanding of the relative merits of the two datasets, the Pope et al. (2002) ACS model based on mean PM<sub>2.5</sub> levels in 63 cities is the most appropriate model for analyzing premature mortality impacts. Thus it is used for our primary estimate of this important health effect.

### **12B.1.2 Alternative Lag Structures**

Over the last ten years, there has been a continuing discussion and evolving advice regarding the timing of changes in health effects following changes in ambient air pollution. It has been hypothesized that some reductions in premature mortality from exposure to ambient PM<sub>2.5</sub> will occur over short periods of time in individuals with compromised health status, but other effects are likely to occur among individuals who, at baseline, have reasonably good health that will deteriorate because of continued exposure. No animal models have yet been developed to quantify these cumulative effects, nor are there epidemiologic studies bearing on this question.

The SAB-HES has recognized this lack of direct evidence. However, in early advice, they also note that “although there is substantial evidence that a portion of the mortality effect of PM is manifest within a short period of time, i.e., less than one year, it can be argued that, if no lag assumption is made, the entire mortality excess observed in the cohort studies will be analyzed as immediate effects, and this will result in an overestimate of the health benefits of improved air quality. Thus some time lag is appropriate for distributing the cumulative mortality effect of PM in the population,” (EPA-SAB-COUNCIL-ADV-00-001, 1999, p. 9).<sup>73</sup> In recent advice, the SAB-HES suggests that appropriate lag structures may be developed based on the distribution of cause-specific deaths within the overall all-cause estimate (EPA-SAB-COUNCIL-ADV-04-002, 2004). They suggest that diseases with longer progressions should be

characterized by longer-term lag structures, while air pollution impacts occurring in populations with existing disease may be characterized by shorter-term lags.

A key question is the distribution of causes of death within the relatively broad categories analyzed in the long-term cohort studies. Although it may be reasonable to assume the cessation lag for lung cancer deaths mirrors the long latency of the disease, it is not at all clear what the appropriate lag structure should be for cardiopulmonary deaths, which include both respiratory and cardiovascular causes. Some respiratory diseases may have a long period of progression, while others, such as pneumonia, have a very short duration. In the case of cardiovascular disease, there is an important question of whether air pollution is causing the disease, which would imply a relatively long cessation lag, or whether air pollution is causing premature death in individuals with preexisting heart disease, which would imply very short cessation lags.

The SAB-HES provides several recommendations for future research that could support the development of defensible lag structures, including using disease-specific lag models and constructing a segmented lag distribution to combine differential lags across causes of death (EPA-SAB-COUNCIL-ADV-04-002, 2004). The SAB-HES indicated support for using “a Weibull distribution or a simpler distributional form made up of several segments to cover the response mechanisms outlined above, given our lack of knowledge on the specific form of the distributions,” (EPA-SAB-COUNCIL-ADV-04-002, 2004, p. 24). However, they noted that “an important question to be resolved is what the relative magnitudes of these segments should be, and how many of the acute effects are assumed to be included in the cohort effect estimate,” (EPA-SAB-COUNCIL-ADV-04-002, 2004, p. 24-25). Since the publication of that report in March 2004, EPA has sought additional clarification from this committee. In its follow-up advice provided in December 2004, the SAB suggested 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  $PM_{2.5}$  (EPA-COUNCIL-LTR-05-001, 2004).<sup>74</sup> 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. Furthermore, in their advisory letter, the SAB-HES recommended that EPA include sensitivity analyses on other possible lag structures. In this appendix, we investigate the sensitivity of premature mortality-reduction related benefits to alternative cessation lag structures, noting that ongoing and future research may result in changes to the lag structure used for the primary analysis.

In previous advice from the SAB-HES, they recommended an analysis of 0-, 8-, and 15-year lags, as well as variations on the proportions of mortality allocated to each segment in the segmented lag structure (EPA-SAB-COUNCIL-ADV-00-001, 1999, (EPA-COUNCIL-LTR-05-001, 2004). The 0-year lag is representative of EPA’s assumption in previous RIAs. The 8- and 15-year lags are based on the study periods from the Pope et al.

(1995)<sup>75</sup> and Dockery et al. (1993)<sup>76</sup> studies, respectively.<sup>T</sup> However, neither the Pope et al. nor Dockery et al. studies assumed any lag structure when estimating the relative risks from PM exposure. In fact, the Pope et al. and Dockery et al. analyses do not support or refute the existence of a lag. Therefore, any lag structure applied to the avoided incidences estimated from either of these studies will be an assumed structure. The 8- and 15-year lags implicitly assume that all premature mortalities occur at the end of the study periods (i.e., at 8 and 15 years).

In addition to the simple 8- and 15-year lags, we have added two additional sensitivity analyses examining the impact of assuming different allocations of mortality to the segmented lag of the type suggested by the SAB-HES. The first sensitivity analysis assumes that more of the mortality impact is associated with chronic lung diseases or lung cancer and less with acute cardiopulmonary causes. This illustrative lag structure is characterized by 20 percent of mortality reductions occurring in the first year, 50 percent occurring evenly over years 2 to 5 after the reduction in PM<sub>2.5</sub>, and 30 percent occurring evenly over the years 6 to 20 after the reduction in PM<sub>2.5</sub>. The second sensitivity analysis assumes the 5-year distributed lag structure used in previous analyses, which is equivalent to a three-segment lag structure with 50 percent in the first 2-year segment, 50 percent in the second 3-year segment, and 0 percent in the 6- to 20-year segment.

The estimated impacts (scaled from the CAND analysis) of alternative lag structures on the monetary benefits associated with reductions in PM-related premature mortality (estimated with the Pope et al. ACS impact function) are presented in Table B-1. These estimates are based on the value of statistical lives saved approach (i.e., \$5.5 million per incidence) and are presented using both a 3 percent and 7 percent discount rate over the lag period.

## **12B.2 Summary of Results**

The results of these scaled sensitivity analyses demonstrate that choice of effect estimate can have a large impact on benefits, potentially doubling benefits if the effect estimate is derived from the HEI reanalysis of the Harvard Six-Cities data (Krewski et al., 2000). Because of discounting of delayed benefits, the lag structure may also have a large downward impact on monetized benefits if an extreme assumption that no effects occur until after 15 years is applied. However, for most reasonable distributed lag structures, differences in the specific shape of the lag function have relatively small impacts on overall benefits. For example, the overall impact of moving from the previous 5-year distributed lag to the segmented lag recommended by the SAB-HES in 2004 in the 2030 primary estimate is relatively modest, reducing benefits by approximately 5 percent when a 3 percent discount rate is used and approximately 10 percent when a 7 percent discount rate is used. If no lag is assumed, benefits increase by around 10 percent relative to the segmented lag with a 3 percent discount rate and 23 percent with a 7 percent discount rate.

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<sup>T</sup>Although these studies were conducted for 8 and 15 years, respectively, the choice of the duration of the study by the authors was not likely due to observations of a lag in effects but is more likely due to the expense of conducting long-term exposure studies or the amount of satisfactory data that could be collected during this time period.

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## CHAPTER 13: Economic Impact Analysis

We prepared a draft Economic Impact Analysis (EIA) to estimate the economic impacts of the proposed emission control program on the gas can, 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 economic sectors. We also present the result of our analysis.

We estimate the net social costs of the proposed program to be about \$171.5 million in 2020. This estimate reflects the estimated costs associated with the gasoline, gas can, and vehicle controls and the expected fuel savings from better evaporative controls on gas cans. The results of the economic impact modeling performed for the gasoline fuel and gas can control programs suggest that the social costs of those two programs are expected to be about \$244.3 million in 2020, with consumers of these products expected to bear about 60 percent of these costs. We estimate fuel savings of about \$72.8 million in 2020, which will accrue to consumers. There are no social costs associated with the vehicle program in 2020. 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 0.1 percent (0.2 cents per gallon), for PADD 5.<sup>A</sup> The price of gas cans is expected to increase by about 1.8 percent (\$0.20 per can) in areas that already have gas can 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* (EPA 2000, p 113), *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. 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 proposed emission control program 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.

#### 13.1.2 What is the Economic Impact Model?

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<sup>A</sup> PADD: Petroleum Administration for Defense District.

The Economic Impact Model (EIM) is a behavioral model developed for this proposal to estimate price and quantity changes and total social costs associated with the emission controls under consideration. 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 as a result of the proposed 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 proposed program 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. The control program under consideration would 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 proposal: gas cans, 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 gas can and gasoline fuel markets. This approach is appropriate for several reasons. As described in Chapter 8, above, the compliance costs for the proposed 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 gas can programs.

With regard to the gasoline fuel and gas can 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 (gas cans) and do not separately model how the costs of complying with the proposed programs may affect the production of goods and services that use gasoline fuel or gas cans 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 gas cans 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 (DoE 2004, Table A-2 and Supplemental Table 34). According to DoE, only about 6 percent of gasoline fuel is used for commercial or industrial transportation, and the remaining 2 percent is used in recreational marine vessels. Similarly, although there is little publicly available national data on the users of gas cans, a recent study by CARB (1999) found that 94 percent of portable fuel containers in California were used by residential households. In addition, for most commercial users the share of these products to total production costs is small (e.g., the cost of a gas can 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).

With regard to the gasoline fuel analysis, it should be noted that this Economic Impact Analysis does not include California fuels in the market analysis. California fuels are only included, as a separate line item, in the economic welfare analysis. California currently has state-level controls that address air toxics from gasoline fuels (Title 13, California Code of Regulations, Section 2262). The California program benzene levels are very similar to those being proposed in this federal program and any actions that refiners may take to comply with the federal program are expected to be small and not affect market prices or quantities in that state. However, because the estimated fuel program compliance costs include a small compliance cost for California, and this cost would be a cost to society, it is necessary to include those costs in the total economic welfare costs of the proposal. This is done by including the estimated engineering compliance costs as a separate line item.

Consistent with the cost analysis, the economic impact analysis for the gasoline fuel market does not distinguish between reformulated and conventional gasoline fuels.<sup>B</sup> 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.

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<sup>B</sup> 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 proposed standards and because the cost modeling technique does not allow for estimating how the blending of gasoline blendstocks will occur. See Chapter 9 for more information on how gasoline compliance costs were estimated.

The EIM relies on the estimated compliance costs for the gas can 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 proposed program on four gasoline fuel markets and two gas can 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 proposal (see Chapter 4 and RTI 2004a and 2004b).

**Table 13.1-1. Summary of Markets in Economic Impact Model**

<b>Model Dimension</b>	<b>Light-Duty Vehicles</b>	<b>Gasoline (4)</b>	<b>Gas Cans (2)</b>
Number of Markets	Not included in market analysis; engineering costs used to estimate total social costs	Four regions <ul style="list-style-type: none"> <li>• PADDs 1 &amp; 3</li> <li>• PADD 2</li> <li>• PADD 4</li> <li>• PADD 5 (includes Alaska and Hawaii; California gasoline fuel treated separately)</li> </ul> No distinction between conventional and reformulated gasoline	Two markets <ul style="list-style-type: none"> <li>• States with current controls (12 plus DC)</li> <li>• States without current controls (38)</li> </ul>
Geographic scope		50-state; California fuel volumes treated separately	50-State
Market structure		Perfectly competitive	Perfectly competitive
Baseline population		Energy Information Administration (DoE 2003)	Provided by manufacturers (RTI 2004a)
Growth projections		Energy Information Administration (DoE 2005)	2% (RTI 2004a)
Supply elasticity		Literature estimate: 0.2 (inelastic)	Econometric estimate: 1.5 (elastic)
Demand elasticity		Literature estimate: -0.2 (inelastic)	Derived demand estimate: -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 gas cans. 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 gas

cans, 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 proposed 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 proposed rule) offset by operating cost savings (the fuel savings associated with better evaporative controls for gas cans).

Economic impact results of our modeling are summarized in this section. More detailed results are included in the appendices to this chapter.

#### **13.1.4.1 Market Analysis Results**

The market analysis results for all years are presented in Appendices A and B and are summarized below. Market impacts are the estimated changes in the quantity of affected goods produced and their prices. As explained above, we estimated market impacts for only gasoline fuel and gas cans, and California fuel is not included in the market analysis for PADD 5. The estimated market impacts are presented in Table 13.1-2. In this table, the market results for gasoline are presented for 2015 only because the compliance costs for the gasoline fuel program are constant for all years and therefore the results of the market analysis are the same for all years.<sup>C</sup> The market results for gas cans are presented for 2009 and 2015, reflecting the changes in estimated compliance costs due to amortization of fixed costs over the first five years of the program. After 2013 the compliance costs remain constant for all future years.<sup>D</sup>

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 about 0.15 percent or less, depending on PADD. The expected reduction in quantity of fuel produced is expected to be less than 0.03 percent. The market impacts for the gas can program are expected to be more significant. In 2009, the first year of gas can program, the model predicts a price increase of about 7 percent for gas cans in states that currently have regulations for gas cans 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 gas can price increase is expected to be less than 2 percent for states that currently regulate gas cans and about 32.5 percent for states without such regulations. The quantity

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<sup>C</sup> The number of gallons of gasoline fuel produced is expected to decrease in future years but the percent decrease is expected to remain the same; this is due to the growth in fuel consumption generally.

<sup>D</sup> The number of gas cans produced is expected to decrease in future years but the percent decrease is expected to remain the same; this is due to the growth in gas can production generally.

produced is expected to decrease by less than 0.4 percent. These changes are expected to remain constant for future years, even though the absolute quantities produced are expected to increase somewhat.

**Table 13.1-2. Summary of Market Impacts**

Market	Engineering Cost Per Unit	Change in Price		Change in Quantity	
		Absolute	Percent	Absolute	Percent
2009					
Gasoline Fuel PADD 1 & 3 PADD 2 PADD 4 PADD 5 (w/out CA)	N/A (gasoline fuel control program begins in 2011)				
Gas Cans States with existing Programs States without existing programs	\$ /can			Thousand Cans	
	\$0.77	\$0.76	6.9%	-6.8	-0.07%
	\$2.70	\$2.68	57.4%	-88.5	-0.57%
2015					
Gasoline Fuel PADD 1 & 3 PADD 2 PADD 4 PADD 5 (w/out CA)	¢ /gallon			Million Gallons	
	0.049¢	0.03¢	0.02%	-3.1	-0.004%
	0.202¢	0.11¢	0.07%	-6.9	-0.015%
	0.358¢	0.19¢	0.12%	-1.4	-0.025%
	0.391¢	0.21¢	0.13%	-2.5	-0.026%
Gas Cans States with existing Programs States without existing programs	\$ /can			Thousand Cans	
	\$0.21	\$0.20	1.9%	-2.1	-0.02%
	\$1.53	\$1.52	32.5%	-56.4	-0.32%

#### 13.1.4.2 Economic Welfare Results

In the economic welfare analysis we look at the costs to society of the proposed program in terms of losses to consumer and producer surplus. These surplus losses are combined with estimated vehicle compliance costs, fuel savings, and government revenue losses to estimate the net economic welfare impacts of the program. Detailed economic welfare results for the proposed program are presented in Appendix C and are summarized below. This economic welfare analysis includes the compliance costs associated with affected California fuel.

Estimated annual net social costs are presented in Table 13.1-3. Initially, the estimated social costs of the program are relatively small and are attributable to the gas can program, which begins in 2009, and the vehicle program, which begins in 2010. For 2009 and 2010 the estimated social costs are less than \$40 million. In 2011 the estimated social costs increase to \$215 million, reflecting the beginning of the gasoline fuel program. In subsequent years estimated social costs increase due to growth. However, they decrease in 2014, to \$169 million, when the gas can fixed costs are fully recovered and in 2020, to \$171.5 million, when the vehicle

program compliance costs are terminated.

**Table 13.1-3. Net Social Costs Estimates for the Proposed Program  
(2009 to 2035) (2003\$, \$million)**

Year	Total Social Costs (includes fuel savings)
2009	\$38.4
2010	\$39.2
2011	\$215.0
2012	\$208.6
2013	\$202.2
2014	\$169.3
2015	\$171.6
2016	\$173.6
2017	\$175.5
2018	\$177.3
2019	\$179.7
2020	\$171.5
2021	\$174.2
2022	\$176.9
2023	\$179.9
2024	\$183.3
2025	\$186.8
2026	\$190.3
2027	\$193.9
2028	\$197.6
2029	\$201.3
2030	\$205.2
2031	\$209.1
2032	\$213.1
2033	\$217.2
2034	\$221.4
2035	\$225.7
NPV at 3%	\$2,937.3

Year	Total Social Costs (includes fuel savings)
NPV at 7%	\$1,633.0

Table 13.1-4 contains more detailed estimated social costs for 2009, when the gas can program begins, 2011, when the gasoline fuel program begins, and 2015 when gas can fixed costs are fully recovered. The vehicle program applies from 2010 through 2019. According to these results, consumers are expected to bear approximately 99 percent of the cost of the gas can 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 54.5 percent expected to be borne consumers and 45.5 percent expected to be borne by producers. In all years, the estimated loss to consumer welfare will be offset somewhat by the fuel savings associated with gas cans. Beginning at about \$11 million per year, these savings increase to about \$68 million by 2015 as compliant gas cans are phased in. These savings accrue for the life of the gas cans.

**Table 13.1-4. Summary of Net Social Costs Estimates Associated with Primary Program (2009, 2011, and 2015) (2003\$, \$million)**

Market	Change in Consumer Surplus	Change in Producer Surplus	Total
<b>2009</b>			
Gasoline US PADD 1 & 3 PADD 2 PADD 4 PADD 5 (w/out CA)	N/A (gasoline fuel control program begins in 2011)		
Gas Cans US	-\$48.7 (99.3%)	-\$0.3 (0.7%)	-\$49.0
States with existing programs	-\$7.5	-\$0.1	
States without existing programs	-\$41.2	-\$0.3	
<b>Subtotal</b>	<b>-48.7</b> (99.3%)	<b>-0.3</b> (1%)	<b>-\$49.0</b>
Fuel Savings			\$10.6
Vehicle Program			\$0
California fuel <sup>a</sup>			\$0
<b>Total</b>			<b>-\$38.4</b>
<b>2011</b>			
Gasoline US	-\$100.3 (54.5%)	-\$83.6 (45.5%)	-\$183.9
PADD 1 & 3	-\$21.6	-\$18.0	
PADD 2	-\$49.1	-\$40.9	
PADD 4	-\$10.2	-\$8.5	
PADD 5 (w/out CA)	-\$19.4	-\$16.2	
Gas Cans US	-\$50.7 (99.4%)	-\$0.3 (0.7%)	-\$51.0
States with existing programs	-\$7.8	-\$0.1	
States without existing programs	-\$42.9	-\$0.3	
<b>Subtotal</b>	<b>-\$150.9</b>	<b>-\$83.9</b>	<b>-\$234.8</b>

Market	Change in Consumer Surplus	Change in Producer Surplus	Total
	<b>(64.3%)</b>	<b>(35.7%)</b>	
Fuel Savings			\$33.3
Vehicle Program			-\$11.8
California fuel <sup>a</sup>			-\$1.7
<b>Total</b>			<b>-\$215.0</b>
<b>2015</b>			
Gasoline US	-\$107.1 (54.5%)	-\$89.4 (45.5%)	-\$196.5
PADD 1 & 3	-\$23.1	-\$19.3	
PADD 2	-\$52.4	-\$43.7	
PADD 4	-\$10.9	-\$9.1	
PADD 5 (w/out CA)	-\$20.7	-\$17.3	
Gas Cans US	-\$28.5 (99.3%)	-\$0.2 (0.7%)	-\$28.7
States with existing programs	-\$2.3	\$0.0	
States without existing programs	-\$26.3	-\$0.2	
<b>Subtotal</b>	<b>-\$135.7 (60.3%)</b>	<b>-\$89.5 (39.7%)</b>	<b>-\$225.2</b>
Fuel Savings			\$68.3
Vehicle Program			-\$12.9
California fuel <sup>a</sup>			-\$1.8
<b>Total</b>			<b>-\$171.6</b>

<sup>a</sup>California fuel costs are considered separately. See Section 13.1.3 of the RIA.

The present value of net social costs (discounted back to 2005) of the proposed standards through 2035, contained in Table 13.1-3, is estimated to be \$2.9 billion (2003\$). This present value is calculated using a social discount rate of 3 percent and the stream of economic welfare costs from 2009 through 2035. We also performed an analysis using a 7 percent social discount rate.<sup>E</sup> Using that discount rate, the present value of the net social costs through 2035 is estimated to be \$1.6 billion (2003\$).

<sup>E</sup> EPA has historically presented the present value of cost and benefits estimates using both a 3 percent and a 7 percent social discount rate. The 3 percent rate represents a demand-side approach and reflects the time preference of consumption (the rate at which society is willing to trade current consumption for future consumption). The 7 percent rate is a cost-side approach and reflects the shadow price of capital.

**Table 13.1-5. Summary of NPV Net Social Costs Estimates Associated with Primary Program**  
**(3%, 2009 to 2035) (2003\$, \$million)**

Market	Change in Consumer Surplus	Change in Producer Surplus	Total
Gasoline, U.S.			
PADD 1 & 3	-\$384.0	-\$320.0	-\$704.0
PADD 2	-\$871.1	-\$726.0	-\$1,597.1
PADD 4	-\$180.8	-\$150.7	-\$331.4
PADD 5 (w/out CA)	-\$344.2	-\$286.9	-\$631.0
Gas Cans US			
States with existing programs	-\$66.6	-\$0.5	-\$67.2
States without existing programs	-\$572.1	-\$3.8	-\$575.9
Subtotal	-\$2,418.8 61.9%	-\$1,487.8 38.1%	-\$3,906.5
Fuel Savings			\$1,090.5
Vehicle Program			-\$91.1
California fuel <sup>a</sup>			-\$30.2
Total			-\$2,937.3

<sup>a</sup>California fuel costs are considered separately. See Section 13.1.3 of the RIA.

## 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 gas cans 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* (EPA 1999). 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 (1999) note, this framework provides “a richer story” of the expected distribution of economic welfare changes across producers and consumers. 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” (Berck and Hoffmann, 2002).

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 approach, and considers gasoline fuel and gas can markets separately.<sup>F</sup> This means there are two separate models, built the same way, that are not linked in this analysis (there is no feedback mechanism between the gas can and gasoline fuel model segments). 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 gas cans is not expected to have an impact on the production and supply of gasoline, 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).

In addition, this approach is reasonable because, as described above, most of the users of these products are households. Also, with regard to the gasoline fuel market, the estimated compliance costs on a per gallon basis are very small and are well within the normal price variations of gasoline. Therefore, the impacts on the economy more generally are expected to be minimal. With regard to gas cans, these products are used only by a small segment of the general economy and are principally used for non-production purposes (i.e., residential uses). For all of these reasons, the additional costs of using a general equilibrium or multimarket approach far outweigh the additional precision in the results.

### **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

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<sup>F</sup> Market impacts were not modeled for the vehicle market; see Section 13.1.3, above.

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 proposed 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 (OMB, 1996).

Perfect competition is a widely accepted economic practice for this type of analysis and only in rare cases are other approaches used (EPA 2000, p. 126). For the markets under consideration in this EIA, 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 proposal (RTI 2004b). Therefore, it is reasonable to assume a competitive market structure in this analysis.

With regard to the gas can market, the small number of firms in the market is offset by several features of this market. Because gas cans 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 gas cans as good substitutes for one another. 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).<sup>G</sup> As a result of these conditions, producers and consumers in the gas can market take the market price as given when making their production and consumption choices. For all these reasons, the market can be modeled as a competitive market even though the number of producers is small.<sup>H</sup>

### 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* (U.S. EPA, 1999).

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.

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<sup>G</sup> A monopoly or firms in oligopoly may not behave as neoclassical economic theories of the firm predict because they 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 will 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. (Baumol, Panzer, and Wilig, 1982; Baumol, 1982).

<sup>H</sup> More information about the structure of the gas can industry organization can be found in Section 3 of the industry characterization prepared for this proposal. See RTI 2004a.

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 this time horizon for this analysis because it assumes economic entities have no flexibility to adjust factors of production.

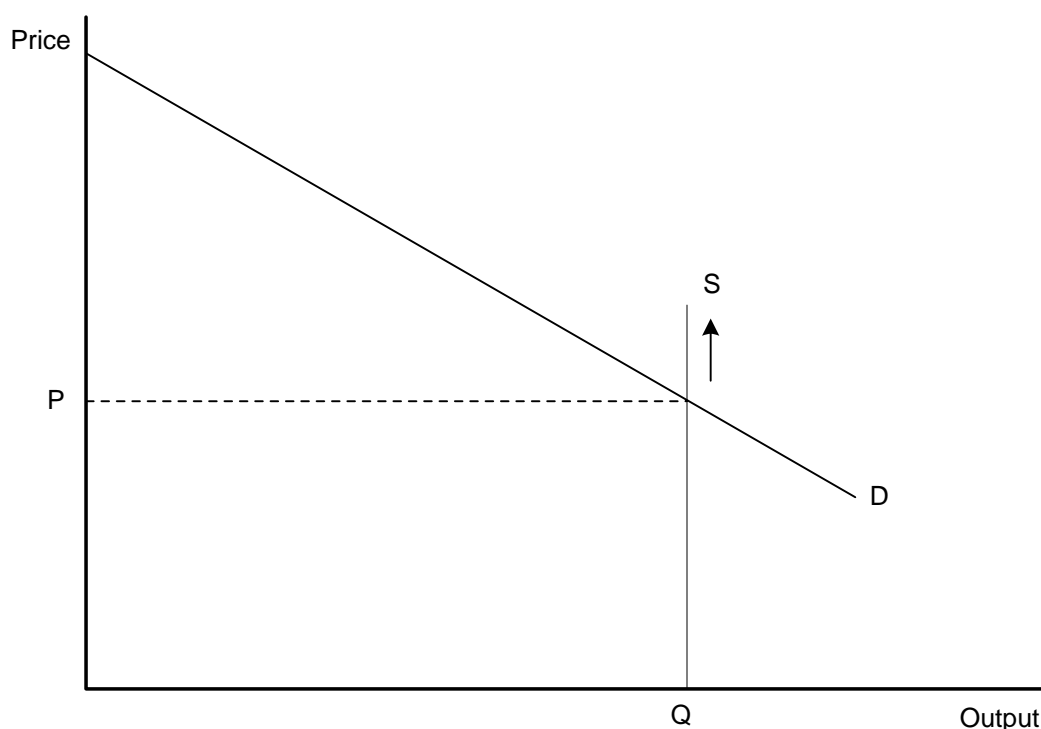


Figure 13.2-1. Short Run: All Costs Borne by Producers

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.<sup>1</sup> 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

<sup>1</sup> 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.

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  $PacP'$ ). 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.

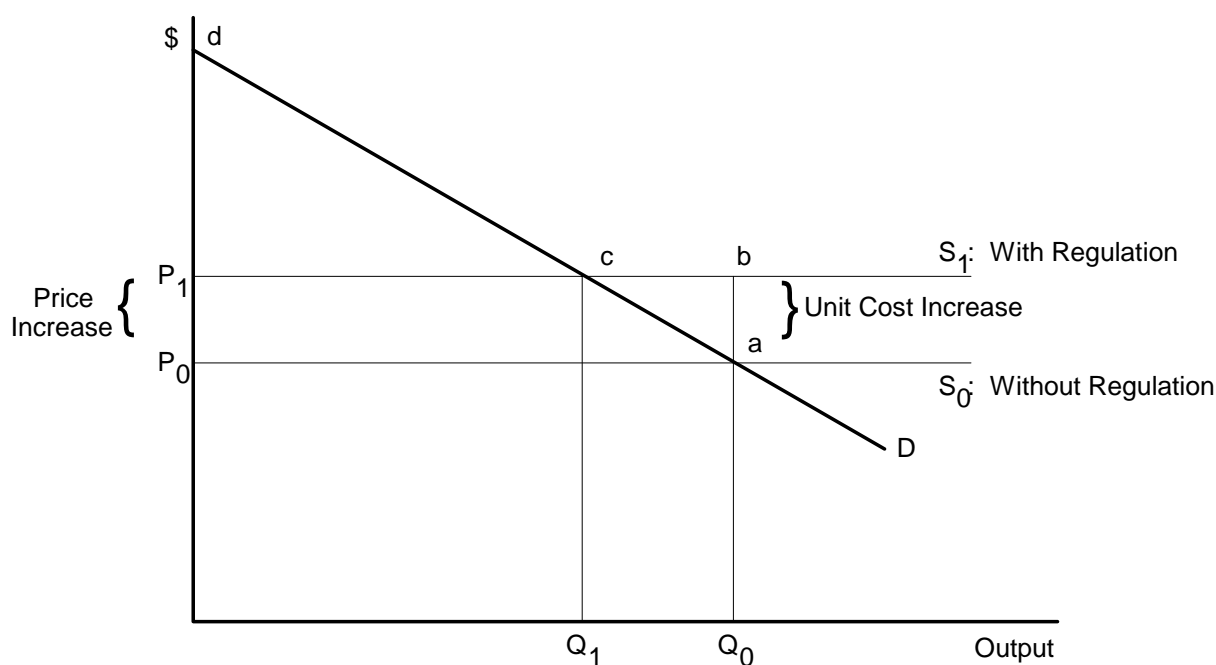


Figure 13.2-2. Long Run: Full Cost Pass Through

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 today's capital vintage, 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.<sup>J</sup> 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)

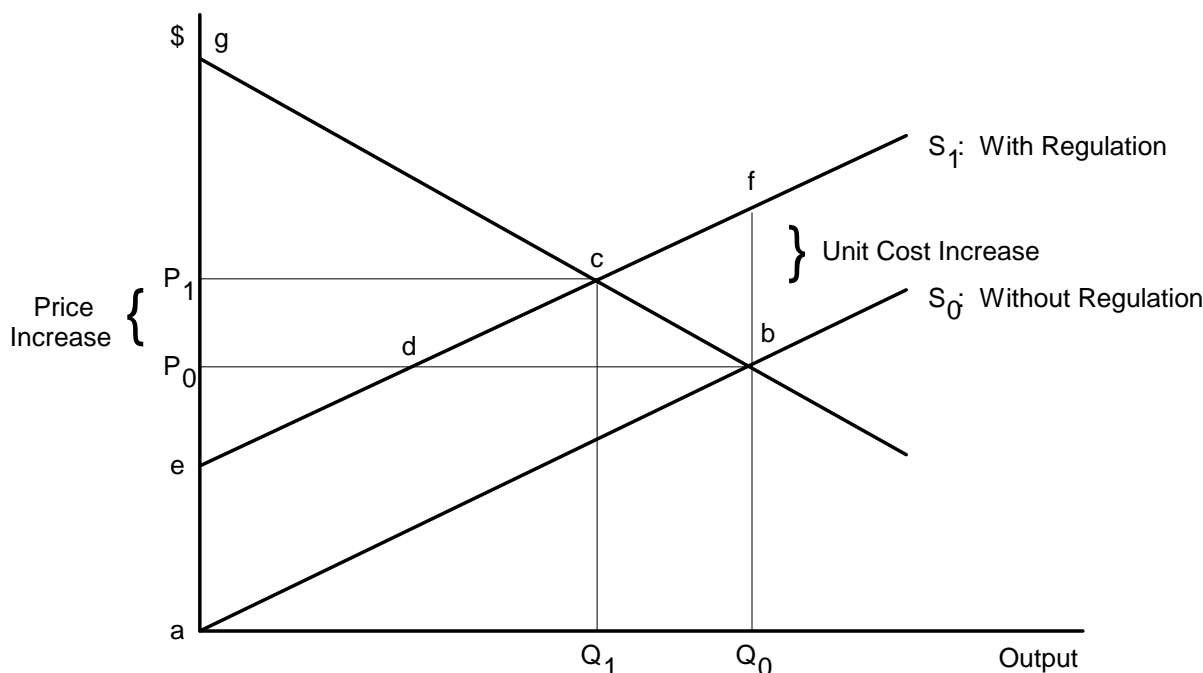


Figure 13.2-3. Intermediate Run: Partial Cost Pass Through  
function that rises with the output rate, as shown in Figure 13.2-3.

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

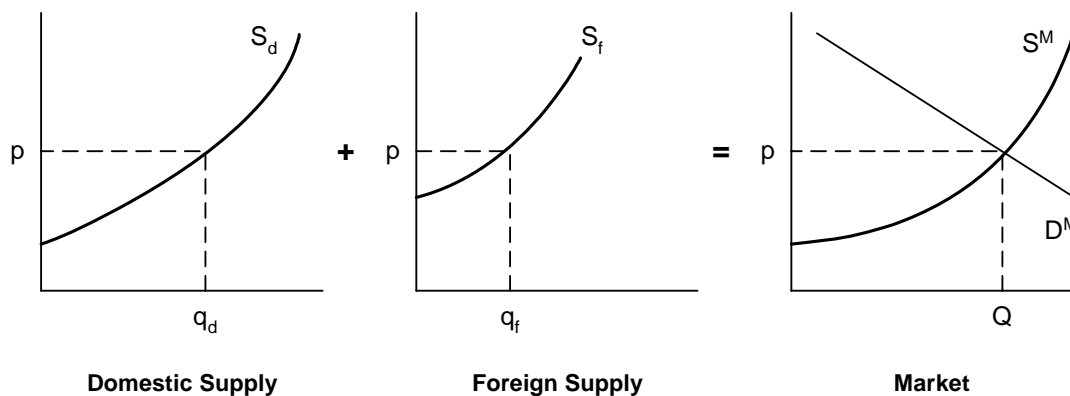
<sup>J</sup> As a semantical matter, the situation where some factors are variable and some are fixed is often referred to as the “short run” in economics, but the term “intermediate run” is used here to avoid any confusion with the term “very short run.”

relative supply and demand elasticity parameters used in the model. For example, if demand for gas cans 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 gas can consumers in the form of higher prices.

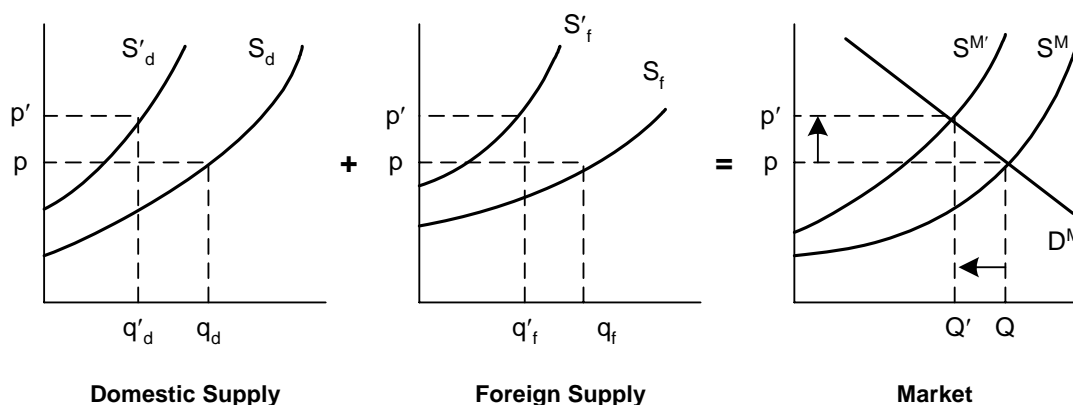
### **13.2.3 How is the EIM Used to Estimate Economic Impacts?**

#### **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 ( $p, Q$ ) are 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.

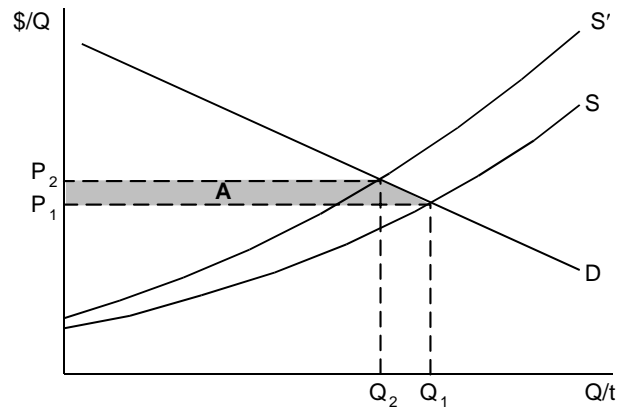
At baseline without the proposed rule, the industry produces total output,  $Q$ , at price,  $p$ , with domestic producers supplying the amount  $q_d$  and imports accounting for  $Q$  minus  $q_d$ , or  $q_f$ . With the regulation, the market price increases from  $p$  to  $p'$ , and market output (as 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 proposed standards are applied the supply curve will shift upward by the amount of the estimated compliance costs. The demand curve, however,

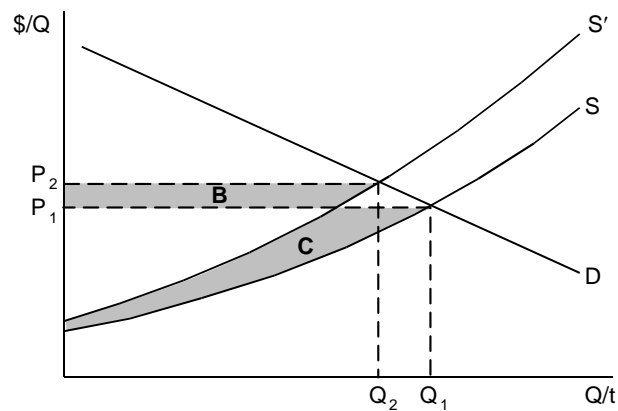
does not shift. This is because a shift in the demand curve is determined by changes in factors such as income, tastes, prices of substitute and complementary goods, expectations, and population. The standards under consideration do not affect these factors and so it is appropriate to assume all these factors remain constant.

#### **13.2.3.2 Estimation of Social Costs**

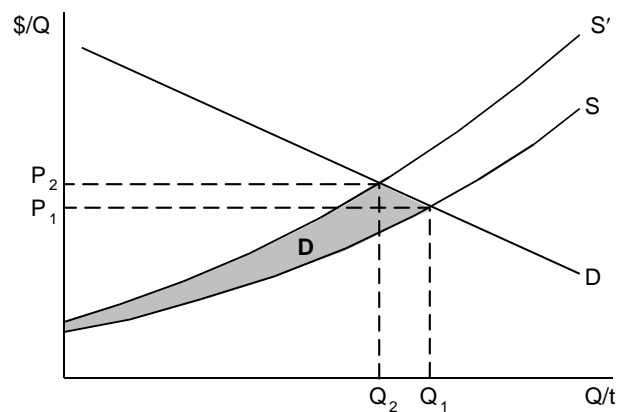
The economic welfare implications of the market price and output changes with the regulation can be examined by calculating consumer and producer net “surplus” changes associated with these adjustments. This is a measure of the negative impact of an environmental policy change and is commonly referred 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  $P_1$  with quantity  $Q_1$ . 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,  $Q_1 - Q_2$ .

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 proposed 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 gas can and gasoline fuel markets that need to be addressed in the EIM. These are the treatment of 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.

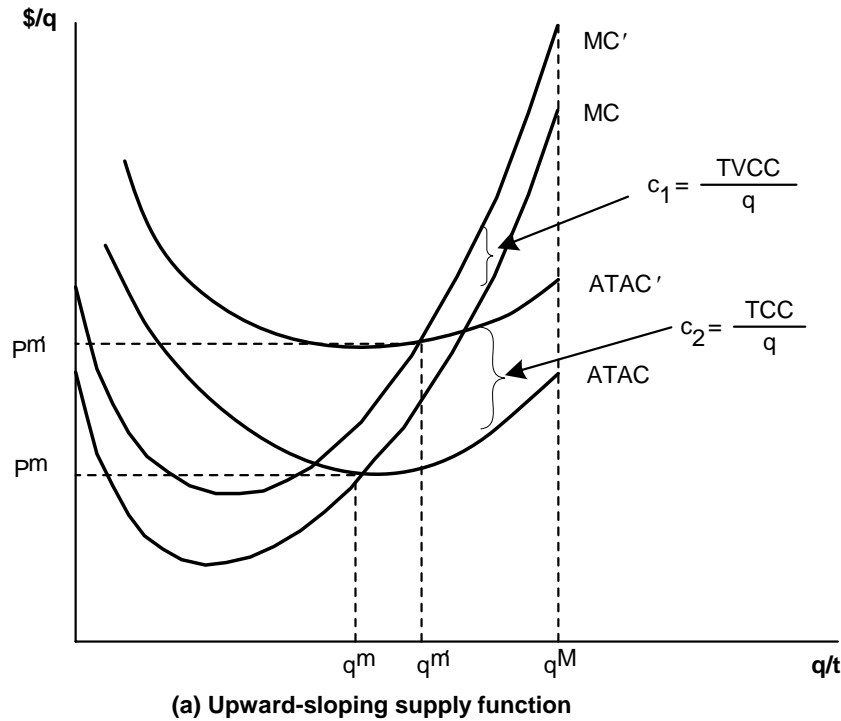


Figure 13.2-6. Modeling Fixed Costs

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 gas can 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, gas can manufacturers produce a product that changes very little over time. Gas cans 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 proposed standards will require gas can manufacturers to devote new funds and resources to product redesign and

facilities changes. Gas can 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 proposed program 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 using sensitivity analyses.

#### **13.2.4.2 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 proposed gas can controls are expected to reduce evaporative emissions from fuel storage, resulting in 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. 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 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 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 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 affected gas cans. Consumers have only limited alternatives for safely storing gasoline: approved metal or plastic gas cans. Plastic gas cans account for the vast majority of gas cans sold due to their safety characteristics and ease of use. They are light-weight, are very durable, and do not rust. Plastic gas cans are also cheaper to manufacturer than their metal counterparts. Consequently, about 95 percent of the gas cans 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, or diesel fuel containers), the extent to which they do this is not known. This rule will make approved plastic gasoline containers 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 gasoline. Consumers are generally aware that gasoline must be transported and stored safely and are not likely to view these alternatives as safe relative to an approved gasoline container. Finally, it is illegal in most if not all states to dispense gasoline into unapproved containers, with this prohibition clearly marked on gas pumps.

The elasticity of demand for gas cans 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 gas can find some other way to store gasoline (e.g., inappropriate containers) or opt not to purchase a gas can (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 gas can 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 gas can 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 gas can standards. Table 13.2-1 below provides a rough estimate of the losses in VOC emission reductions. 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 gas cans 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 Gas Cans (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 proposal 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 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 markets under consideration. 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 under consideration (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 gas can markets and four gasoline fuel markets. While the vehicle market will also be affected by the proposed 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 proposal (RTI 2004a and RTI 2004b).

##### **13.3.1.1 Gas Can Market**

Gas cans allow people to refuel equipment in circumstances where refueling at a retail gasoline establishment is not convenient. Therefore, they support the use of a wide variety of small gasoline-powered equipment such as lawnmowers, chainsaws, string trimmers, and tractors. They are also used in recreational vehicles such as all-terrain vehicles, off-road motorcycles, and gasoline-powered golf carts. The demand for gas cans is directly linked to the demand for other household goods and services. Industry representatives suggest that sales of gas cans 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 gas cans. Economic theory for derived demand suggests that under some reasonable assumptions we can predict that an increase in the price of gas cans will have little impact on sales of gas cans both because gas cans represent a very small fraction of total expenditures and they are an essential input into household and business production functions (Hicks, 1961; Hicks, 1966; and Allen, 1938). In addition, there are only limited alternatives for storing gasoline.

There is little additional publicly available national data on the users of gas cans. However, a recent study by CARB (1999) found that 94 percent of portable fuel containers in California were used by residential households. Commercial businesses account for a remaining gas can use.

The vast majority of gas cans sold in the United States are plastic (about 98 percent). Gas can 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 gas can manufacturers have very limited market share, are more geared for industrial use, and/or fill a niche specialty market. Manufacturing gas cans is not constrained geographically in that these containers are lightweight and fairly inexpensive to transport to distant markets.

Plastic gas cans 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 gas cans that began in 2001 (CARB 1999). 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 proposed standards is expected to be reduced for these states (fewer changes will be necessary for these gas cans). 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 (DoT 2002) reported that the United States consumed over 130 billion gallons of gasoline in 2002. 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 nonhighway use (i.e., lawn and garden equipment and marine uses).

Consumers can respond to price changes in gasoline in two general ways. First, they may simply consider reducing the number of vehicle miles traveled or their use of nonroad equipment. 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.

Refineries produce finished motor gasoline through a complex process that converts crude oil into several products. 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.

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.

Given the existing region-specific gasoline performance standards and other physical and economic barriers, the national gasoline market is broken down into five for the purpose of the Economic Impact Analysis. These are the five Petroleum Administration for Defense Districts (PADDs) defined by the Department of Energy. This economic impact analysis distinguishes between these regions. 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 treated separately).

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 similar although not identical fuel benzene controls and any additional refinery costs associated with the federal program for California fuel are expected to be small and not affect market prices or quantities in that state. However, because the estimated fuel program compliance costs include a small compliance cost for California, and this cost would be a cost to society, it is necessary to include those costs in the total economic welfare costs of the proposal.

This is done by including the estimated engineering compliance costs as a separate line item. 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 gas can and gasoline markets.

#### 13.3.2.1 Gas Can Market Quantities and Prices

The gas can 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 (RTI 2004a, Section 4). Industry sales data from 2002 were grown for future years using a 2 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 gas can prices from 2003 were obtained from industry. The prices in Table 3.3-2 are weighted averages of the observed prices of 3 sizes of gas cans (1 gallon, 2 gallon, and 5 gallon; 33 percent weight for each). Gas can 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. Gas Can Sales Data**

Year	States without Controls	States With Controls	Total
2009	15,415,362	9,855,723	25,271,085
2010	15,723,669	10,052,837	25,776,506
2011	16,038,142	10,253,894	26,292,037
2012	16,358,905	10,458,972	26,817,877
2013	16,686,083	10,668,152	27,354,235
2014	17,019,805	10,881,515	27,901,319
2015	17,360,201	11,099,145	28,459,346
2016	17,707,405	11,321,128	29,028,533
2017	18,061,553	11,547,550	29,609,103
2018	18,422,784	11,778,501	30,201,286
2019	18,791,240	12,014,071	30,805,311
2020	19,167,065	12,254,353	31,421,417
2021	19,550,406	12,499,440	32,049,846
2022	19,941,414	12,749,429	32,690,843
2023	20,340,242	13,004,417	33,344,660
2024	20,747,047	13,264,506	34,011,553
2025	21,161,988	13,529,796	34,691,784

Year	States without Controls	States With Controls	Total
2026	21,585,228	13,800,392	35,385,619
2027	22,016,932	14,076,399	36,093,332
2028	22,457,271	14,357,927	36,815,199
2029	22,906,417	14,645,086	37,551,502
2030	23,364,545	14,937,988	38,302,533
2031	23,831,836	15,236,747	39,068,583
2032	24,308,472	15,541,482	39,849,955
2033	24,794,642	15,852,312	40,646,954
2034	25,290,535	16,169,358	41,459,893
2035	25,796,345	16,492,745	42,289,091

**Table 13.3-2. Gas Can 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 proposal.<sup>K</sup> Also, California gasoline is considered separately from PADD 5 because, as explained above, California has a state-level program that controls fuel benzene.

The sales data is Energy Information Administration data, based on the Energy Information Administration's Petroleum Market Annual fuel consumption data for 2003 (DoE 2003, Table 48). This data was adjusted using the growth rates from the Energy Information Administration's Annual Energy Outlook 2005 (DoE 2005). 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 (see RTI 2005 for more information). 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 (DoE 2003, Table 31). Next, state and federal motor gasoline taxes data were obtained from the Department of Transportation's 2003 *Highway Statistics* to

<sup>K</sup> See Note B, above.

create an average state tax per model region (DoT 2003, Table MF-121T). 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.

**Table 13.3-3. Gasoline Fuel Sales Data, by Region (MM gallons)**

Year	PADD 1 & 3	PADD 2	PADD 4	PADD 5 w/out CA	California	Total
2009	77,221	42,908	5,025	8,759	16,411	150,324
2010	78,764	43,766	5,125	8,934	16,739	153,328
2011	80,147	44,534	5,215	9,091	17,033	156,020
2012	81,520	45,298	5,305	9,247	17,325	158,695
2013	82,886	46,056	5,393	9,402	17,615	161,352
2014	84,282	46,832	5,484	9,560	17,911	164,069
2015	85,654	47,595	5,574	9,716	18,203	166,742
2016	86,933	48,305	5,657	9,861	18,475	169,231
2017	88,216	49,018	5,740	10,006	18,747	171,727
2018	89,449	49,703	5,820	10,146	19,010	174,128
2019	90,662	50,377	5,899	10,284	19,267	176,489
2020	91,842	51,033	5,976	10,418	19,518	178,787
2021	93,095	51,729	6,058	10,560	19,784	181,226
2022	94,407	52,458	6,143	10,709	20,063	183,780
2023	95,807	53,236	6,234	10,867	20,361	186,505
2024	97,366	54,102	6,336	11,044	20,692	189,540
2025	98,957	54,987	6,439	11,225	21,030	192,638
2026	100,575	55,885	6,544	11,408	21,374	195,786
2027	102,219	56,799	6,651	11,595	21,723	198,987
2028	103,889	57,727	6,760	11,784	22,078	202,238
2029	105,588	58,671	6,871	11,977	22,439	205,546
2030	107,313	59,630	6,983	12,173	22,806	208,905
2031	109,067	60,604	7,097	12,372	23,179	212,319
2032	110,850	61,595	7,213	12,574	23,558	215,790
2033	112,662	62,602	7,331	12,779	23,943	219,317
2034	114,503	63,625	7,451	12,988	24,334	222,901
2035	116,375	64,665	7,573	13,200	24,732	226,545

**Table 13.3-4. Gasoline Fuel Prices (2003\$; includes fuel taxes)**

PADD 1 & 3	PADD 2	PADD 4	PADD 5 w/out CA	California
\$1.48	\$1.51	\$1.57	\$1.67	\$1.69

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 proposed 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 Gas Can Compliance Costs**

The economic impacts of the proposed gas can 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.

Even though this is a competitive market, the gas can 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, gas can 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 gas cans 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 gas cans into compliance with the standards.

**Table 13.3-5. Gas Can Compliance Costs, Per Unit**

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. These costs are summarized in Table 13.3-6. The gasoline compliance costs are different across regions, reflecting different refinery production practices. 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.

Unlike gas can compliance costs, gasoline fuel compliance costs are constant for all years. This is because 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 proposed 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 three compliance cost scenarios. In the primary analysis, fuel compliance costs are based on the average variable 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 proposed benzene control program, then economic theory suggests that the last or highest increment of control in that market would determine the gasoline price. Two max cost scenarios are explored in the sensitivity analysis 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 by Region**  
(¢/gallon, 2003\$)

Scenario	PADD 1 & 3	PADD 2	PADD 4	PADD 5 (w/out California)	California
Total Average (Fixed + Variable) Cost – Primary Analysis	0.049¢	0.202¢	0.358¢	0.391¢	0.010¢
Maximum Total (Fixed + Variable) Cost	0.606¢	1.154¢	1.459¢	1.142¢	0.148¢
Maximum Variable Cost	0.537¢	1.067¢	1.459¢	1.142¢	0.077¢

### 13.3.3.3 Vehicle Compliance Costs

The market impacts of the proposed 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 gas can 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 will 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 Fuel Savings**

As noted in section 13.2.4.1, there are fuel savings attributable to the gas can 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 gas cans 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 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 reductions attributable to gas can controls. California fuel is not included in this estimate because there are no emission reductions attributable to the proposed 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* (DoE 2003, Table 31). The results of this analysis are shown in Tables 13.3-8 and 13.3-9.

**Table 13.3-8. Estimated National Average 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 (DoE 2004).

From 2009 until 2016 the estimated consumer savings associated with reduced gasoline consumption from the gas can controls increases sharply, from \$14.3 million to \$93.1 million. After 2016 the savings continue to accrue, but at a reduced rate as the gas can population turns over and fuel savings are due to the continuing benefits of using compliant gas cans. Similarly, the tax revenue losses are expected to increase from \$3.7 million in 2009 to \$24 million in 2016, but only \$6 million more, to \$30 million, by 2035.

**Table 13.3-9. Estimated Fuel Savings and Tax Revenue Impacts (2003\$)**

Year	Gallons	Consumer Fuel Savings (\$Million)	Tax revenue Impacts (\$Million)	Net Fuel Savings (\$Million)
2009	9,461,282	\$14.3	-\$3.7	\$10.6
2010	19,602,073	\$29.6	-\$7.6	\$21.9
2011	29,742,864	\$44.8	-\$11.5	\$33.3
2012	39,883,656	\$60.1	-\$15.5	\$44.6
2013	50,024,447	\$75.4	-\$19.4	\$56.0
2014	60,165,238	\$90.7	-\$23.4	\$67.3
2015	60,977,696	\$91.9	-\$23.7	\$68.3
2016	61,790,154	\$93.1	-\$24.0	\$69.2
2017	62,602,611	\$94.4	-\$24.3	\$70.1
2018	63,415,069	\$96.5	-\$24.6	\$71.0
2019	64,227,527	\$96.8	-\$24.9	\$71.9
2020	65,039,985	\$98.0	-\$25.2	\$72.8
2021	65,852,443	\$99.3	-\$25.6	\$73.7
2022	66,664,901	\$100.5	-\$25.9	\$74.6
2023	67,477,359	\$101.7	-\$26.2	\$75.5
2024	68,289,817	\$102.9	-\$26.5	\$76.4
2025	69,102,275	\$104.2	-\$26.8	\$77.3
2026	69,914,732	\$105.4	-\$27.1	\$78.3
2027	70,727,190	\$106.6	-\$27.5	\$79.2
2028	71,539,648	\$107.8	-\$27.8	\$80.1
2029	72,352,106	\$109.1	-\$28.1	\$81.0
2030	73,164,564	\$110.3	-\$28.4	\$81.9
2031	73,977,022	\$111.5	-\$28.7	\$82.8
2032	74,789,480	\$112.7	-\$29.0	\$83.7
2033	75,601,938	\$114.0	-\$29.3	\$84.6
2034	76,414,396	\$115.2	-\$29.7	\$85.5
2035	77,226,853	\$116.4	-\$30.0	\$86.4

### 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 gas can 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 proposed 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 gas can 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 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, supply and demand are expected to be more elastic since more substitutes may become available.

The price elasticity parameters for gas cans 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 gas cans demanded. This makes intuitive sense since if households need to store gasoline for convenient use they do not have many alternatives. However, supply is fairly elastic, meaning producers are expected to respond to a change in price. This also makes intuitive sense since it is fairly easy for these producers to store finished gas cans and it is inexpensive for them to increase output. Therefore, consumers are expected to bear more of the burden of gas can 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)	Literature estimate	NA
Gas Can	1.50	EPA econometric estimate (see Appendix C)	Cobb-Douglas production function	Bartlesman et al. (2000); 1980–1996; SIC 3089
Demand Elasticities				
Gasoline Fuel	–0.20	FTC (2001)	Literature estimate	NA
Gas Can	–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 proposed standards. The impacts on the gasoline and gas can 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 (gas can manufacturers, gasoline fuel refiners) and one group of consumers (residential gas can 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 (Berck and Hoffmann, 2002; Fullerton and Metcalfe, 2002). 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).

$$\Delta \text{price} = \frac{\text{Supply Elasticity}}{(\text{Supply Elasticity} - \text{Demand Elasticity})} \times \text{per - unit cost}$$

Given the market price change due to increased cost required by the proposed rule and the demand elasticity for each market, we can also estimate the market quantity change.

$$\Delta \text{quantity} = \Delta \text{price} \times \text{Demand Elasticity}$$

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## **Appendix 13A: Impacts on Gas Can Markets**

This appendix provides the time series of impacts from 2009 through 2035 for the gas can 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 gas can prices are assumed to be constant during the period of analysis.

**Table 13A-1. Regional Impacts: Gas Can 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 \$)
2009	\$2.70	\$2.68	57.4%	-88.5	-0.57%	-\$41.18	-\$0.28	-\$41.46
2010	\$2.70	\$2.68	57.4%	-90.3	-0.57%	-\$42.01	-\$0.28	-\$42.29
2011	\$2.70	\$2.68	57.4%	-92.1	-0.57%	-\$42.85	-\$0.29	-\$43.13
2012	\$2.70	\$2.68	57.4%	-94.0	-0.57%	-\$43.70	-\$0.29	-\$44.00
2013	\$2.70	\$2.68	57.4%	-95.8	-0.57%	-\$44.58	-\$0.30	-\$44.88
2014	\$1.53	\$1.52	32.5%	-55.3	-0.32%	-\$25.75	-\$0.17	-\$25.92
2015	\$1.53	\$1.52	32.5%	-56.4	-0.32%	-\$26.27	-\$0.18	-\$26.44
2016	\$1.53	\$1.52	32.5%	-57.5	-0.32%	-\$26.79	-\$0.18	-\$26.97
2017	\$1.53	\$1.52	32.5%	-58.7	-0.32%	-\$27.33	-\$0.18	-\$27.51
2018	\$1.53	\$1.52	32.5%	-59.9	-0.32%	-\$27.87	-\$0.19	-\$28.06
2019	\$1.53	\$1.52	32.5%	-61.1	-0.32%	-\$28.43	-\$0.19	-\$28.62
2020	\$1.53	\$1.52	32.5%	-62.3	-0.32%	-\$29.00	-\$0.19	-\$29.19
2021	\$1.53	\$1.52	32.5%	-63.5	-0.32%	-\$29.58	-\$0.20	-\$29.78
2022	\$1.53	\$1.52	32.5%	-64.8	-0.32%	-\$30.17	-\$0.20	-\$30.37
2023	\$1.53	\$1.52	32.5%	-66.1	-0.32%	-\$30.78	-\$0.21	-\$30.98
2024	\$1.53	\$1.52	32.5%	-67.4	-0.32%	-\$31.39	-\$0.21	-\$31.60
2025	\$1.53	\$1.52	32.5%	-68.8	-0.32%	-\$32.02	-\$0.21	-\$32.23
2026	\$1.53	\$1.52	32.5%	-70.1	-0.32%	-\$32.66	-\$0.22	-\$32.88
2027	\$1.53	\$1.52	32.5%	-71.5	-0.32%	-\$33.31	-\$0.22	-\$33.54
2028	\$1.53	\$1.52	32.5%	-73.0	-0.32%	-\$33.98	-\$0.23	-\$34.21
2029	\$1.53	\$1.52	32.5%	-74.4	-0.32%	-\$34.66	-\$0.23	-\$34.89
2030	\$1.53	\$1.52	32.5%	-75.9	-0.32%	-\$35.35	-\$0.24	-\$35.59
2031	\$1.53	\$1.52	32.5%	-77.4	-0.32%	-\$36.06	-\$0.24	-\$36.30
2032	\$1.53	\$1.52	32.5%	-79.0	-0.32%	-\$36.78	-\$0.25	-\$37.03
2033	\$1.53	\$1.52	32.5%	-80.6	-0.32%	-\$37.52	-\$0.25	-\$37.77
2034	\$1.53	\$1.52	32.5%	-82.2	-0.32%	-\$38.27	-\$0.26	-\$38.52
2035	\$1.53	\$1.52	32.5%	-83.8	-0.32%	-\$39.03	-\$0.26	-\$39.29
NPV 3%						-\$572.11	-\$3.84	-\$575.94
NPV 7%						-\$338.24	-\$2.27	-\$340.50

(continued)

**Table 13A-1. Regional Impacts: Gas Can 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 \$)
2009	\$0.77	\$0.76	6.89%	-6.8	-0.07%	-\$7.49	-\$0.05	-\$7.54
2010	\$0.77	\$0.76	6.89%	-6.9	-0.07%	-\$7.64	-\$0.05	-\$7.69
2011	\$0.77	\$0.76	6.89%	-7.1	-0.07%	-\$7.80	-\$0.05	-\$7.85
2012	\$0.77	\$0.76	6.89%	-7.2	-0.07%	-\$7.95	-\$0.05	-\$8.01
2013	\$0.77	\$0.76	6.89%	-7.3	-0.07%	-\$8.11	-\$0.05	-\$8.17
2014	\$0.21	\$0.20	1.85%	-2.0	-0.02%	-\$2.23	-\$0.01	-\$2.24
2015	\$0.21	\$0.20	1.85%	-2.1	-0.02%	-\$2.27	-\$0.02	-\$2.29
2016	\$0.21	\$0.20	1.85%	-2.1	-0.02%	-\$2.32	-\$0.02	-\$2.33
2017	\$0.21	\$0.20	1.85%	-2.1	-0.02%	-\$2.36	-\$0.02	-\$2.38
2018	\$0.21	\$0.20	1.85%	-2.2	-0.02%	-\$2.41	-\$0.02	-\$2.43
2019	\$0.21	\$0.20	1.85%	-2.2	-0.02%	-\$2.46	-\$0.02	-\$2.48
2020	\$0.21	\$0.20	1.85%	-2.3	-0.02%	-\$2.51	-\$0.02	-\$2.52
2021	\$0.21	\$0.20	1.85%	-2.3	-0.02%	-\$2.56	-\$0.02	-\$2.58
2022	\$0.21	\$0.20	1.85%	-2.4	-0.02%	-\$2.61	-\$0.02	-\$2.63
2023	\$0.21	\$0.20	1.85%	-2.4	-0.02%	-\$2.66	-\$0.02	-\$2.68
2024	\$0.21	\$0.20	1.85%	-2.5	-0.02%	-\$2.72	-\$0.02	-\$2.73
2025	\$0.21	\$0.20	1.85%	-2.5	-0.02%	-\$2.77	-\$0.02	-\$2.79
2026	\$0.21	\$0.20	1.85%	-2.6	-0.02%	-\$2.82	-\$0.02	-\$2.84
2027	\$0.21	\$0.20	1.85%	-2.6	-0.02%	-\$2.88	-\$0.02	-\$2.90
2028	\$0.21	\$0.20	1.85%	-2.7	-0.02%	-\$2.94	-\$0.02	-\$2.96
2029	\$0.21	\$0.20	1.85%	-2.7	-0.02%	-\$3.00	-\$0.02	-\$3.02
2030	\$0.21	\$0.20	1.85%	-2.8	-0.02%	-\$3.06	-\$0.02	-\$3.08
2031	\$0.21	\$0.20	1.85%	-2.8	-0.02%	-\$3.12	-\$0.02	-\$3.14
2032	\$0.21	\$0.20	1.85%	-2.9	-0.02%	-\$3.18	-\$0.02	-\$3.20
2033	\$0.21	\$0.20	1.85%	-2.9	-0.02%	-\$3.24	-\$0.02	-\$3.27
2034	\$0.21	\$0.20	1.85%	-3.0	-0.02%	-\$3.31	-\$0.02	-\$3.33
2035	\$0.21	\$0.20	1.85%	-3.1	-0.02%	-\$3.38	-\$0.02	-\$3.40
NPV 3%						-\$66.61	-\$0.45	-\$67.07
NPV 7%						-\$42.91	-\$0.29	-\$43.20

## **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 that are not affected by the program 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**

PADD I & III (Average price \$1.45)								
Year	Average Total Cost (cents/ gallon)	Change in Price (cents/ gallon)	Change in Price (%)	Change in Quantity (Absolute)	Change in Quantity (%)	CS Loss (million \$)	PS Loss (million \$)	Total Social Cost (million \$)
2009	0.0000	0.0000	0.000%	0	0.0000%	\$0.000	\$0.000	\$0.000
2010	0.0000	0.0000	0.000%	0	0.0000%	\$0.000	\$0.000	\$0.000
2011	0.0495	0.0270	0.019%	-3	-0.0037%	-\$21.630	-\$18.020	-\$39.650
2012	0.0495	0.0270	0.019%	-3	-0.0037%	-\$22.000	-\$18.330	-\$40.330
2013	0.0495	0.0270	0.019%	-3	-0.0037%	-\$22.370	-\$18.640	-\$41.010
2014	0.0495	0.0270	0.019%	-3	-0.0037%	-\$22.740	-\$18.950	-\$41.700
2015	0.0495	0.0270	0.019%	-3	-0.0037%	-\$23.120	-\$19.260	-\$42.380
2016	0.0495	0.0270	0.019%	-3	-0.0037%	-\$23.460	-\$19.550	-\$43.010
2017	0.0495	0.0270	0.019%	-3	-0.0037%	-\$23.810	-\$19.840	-\$43.650
2018	0.0495	0.0270	0.019%	-3	-0.0037%	-\$24.140	-\$20.120	-\$44.260
2019	0.0495	0.0270	0.019%	-3	-0.0037%	-\$24.470	-\$20.390	-\$44.860
2020	0.0495	0.0270	0.019%	-3	-0.0037%	-\$24.790	-\$20.660	-\$45.440
2021	0.0495	0.0270	0.019%	-3	-0.0037%	-\$25.120	-\$20.940	-\$46.060
2022	0.0495	0.0270	0.019%	-3	-0.0037%	-\$25.480	-\$21.230	-\$46.710
2023	0.0495	0.0270	0.019%	-4	-0.0037%	-\$25.860	-\$21.550	-\$47.400
2024	0.0495	0.0270	0.019%	-4	-0.0037%	-\$26.280	-\$21.900	-\$48.170
2025	0.0495	0.0270	0.019%	-4	-0.0037%	-\$26.710	-\$22.260	-\$48.960
2026	0.0495	0.0270	0.019%	-4	-0.0037%	-\$27.140	-\$22.620	-\$49.760
2027	0.0495	0.0270	0.019%	-4	-0.0037%	-\$27.590	-\$22.990	-\$50.570
2028	0.0495	0.0270	0.019%	-4	-0.0037%	-\$28.040	-\$23.360	-\$51.400
2029	0.0495	0.0270	0.019%	-4	-0.0037%	-\$28.490	-\$23.750	-\$52.240
2030	0.0495	0.0270	0.019%	-4	-0.0037%	-\$28.960	-\$24.130	-\$53.090
2031	0.0495	0.0270	0.019%	-4	-0.0037%	-\$29.430	-\$24.530	-\$53.960
2032	0.0495	0.0270	0.019%	-4	-0.0037%	-\$29.910	-\$24.930	-\$54.840
2033	0.0495	0.0270	0.019%	-4	-0.0037%	-\$30.400	-\$25.340	-\$55.740
2034	0.0495	0.0270	0.019%	-4	-0.0037%	-\$30.900	-\$25.750	-\$56.650
2035	0.0495	0.0270	0.019%	-4	-0.0037%	-\$31.410	-\$26.170	-\$57.580
NPV 3%						-\$384.00	-\$320.00	-\$703.97
NPV 7%						-\$206.43	-\$172.02	-\$378.45

(continued)

**Table 13B-1. Regional Impacts: Gasoline Markets (continued)**

PADD II (Average price \$1.50)								
Year	Average Total Cost (cents/ gallon)	Change in Price (cents/ gallon)	Change in Price (%)	Change in Quantity (Absolute)	Change in Quantity (%)	CS Loss (million \$)	PS Loss (million \$)	Total Social Cost (million \$)
2009	0.0000	0.0000	0.000%	0	0.0000%	\$0.000	\$0.000	\$0.000
2010	0.0000	0.0000	0.000%	0	0.0000%	\$0.000	\$0.000	\$0.000
2011	0.2020	0.1102	0.073%	-7	-0.0146%	-\$49.070	-\$40.890	-\$89.960
2012	0.2020	0.1102	0.073%	-7	-0.0146%	-\$49.910	-\$41.590	-\$91.500
2013	0.2020	0.1102	0.073%	-7	-0.0146%	-\$50.740	-\$42.290	-\$93.030
2014	0.2020	0.1102	0.073%	-7	-0.0146%	-\$51.600	-\$43.000	-\$94.600
2015	0.2020	0.1102	0.073%	-7	-0.0146%	-\$52.440	-\$43.700	-\$96.140
2016	0.2020	0.1102	0.073%	-7	-0.0146%	-\$53.220	-\$44.360	-\$97.580
2017	0.2020	0.1102	0.073%	-7	-0.0146%	-\$54.000	-\$45.010	-\$99.020
2018	0.2020	0.1102	0.073%	-7	-0.0146%	-\$54.760	-\$45.640	-\$100.400
2019	0.2020	0.1102	0.073%	-7	-0.0146%	-\$55.500	-\$46.260	-\$101.760
2020	0.2020	0.1102	0.073%	-7	-0.0146%	-\$56.220	-\$46.860	-\$103.090
2021	0.2020	0.1102	0.073%	-8	-0.0146%	-\$56.990	-\$47.500	-\$104.490
2022	0.2020	0.1102	0.073%	-8	-0.0146%	-\$57.800	-\$48.170	-\$105.960
2023	0.2020	0.1102	0.073%	-8	-0.0146%	-\$58.650	-\$48.880	-\$107.540
2024	0.2020	0.1102	0.073%	-8	-0.0146%	-\$59.610	-\$49.680	-\$109.290
2025	0.2020	0.1102	0.073%	-8	-0.0146%	-\$60.580	-\$50.490	-\$111.070
2026	0.2020	0.1102	0.073%	-8	-0.0146%	-\$61.570	-\$51.320	-\$112.890
2027	0.2020	0.1102	0.073%	-8	-0.0146%	-\$62.580	-\$52.160	-\$114.730
2028	0.2020	0.1102	0.073%	-8	-0.0146%	-\$63.600	-\$53.010	-\$116.610
2029	0.2020	0.1102	0.073%	-9	-0.0146%	-\$64.640	-\$53.870	-\$118.510
2030	0.2020	0.1102	0.073%	-9	-0.0146%	-\$65.700	-\$54.750	-\$120.450
2031	0.2020	0.1102	0.073%	-9	-0.0146%	-\$66.770	-\$55.650	-\$122.420
2032	0.2020	0.1102	0.073%	-9	-0.0146%	-\$67.860	-\$56.560	-\$124.420
2033	0.2020	0.1102	0.073%	-9	-0.0146%	-\$68.970	-\$57.480	-\$126.450
2034	0.2020	0.1102	0.073%	-9	-0.0146%	-\$70.100	-\$58.420	-\$128.520
2035	0.2020	0.1102	0.073%	-9	-0.0146%	-\$71.240	-\$59.380	-\$130.620
NPV 3%						-\$871.07	-\$725.98	-\$1,597.06
NPV 7%						-\$468.28	-\$390.27	-\$858.56

(continued)

**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 (Absolute)	Change in Quantity (%)	CS Loss (million \$)	PS Loss (million \$)	Total Social Cost (million \$)
2009	0.0000	0.0000	0.000%	0	0.0000%	\$0.000	\$0.000	\$0.000
2010	0.0000	0.0000	0.000%	0	0.0000%	\$0.000	\$0.000	\$0.000
2011	0.3580	0.1953	0.124%	-1	-0.0248%	-\$10.180	-\$8.490	-\$18.670
2012	0.3580	0.1953	0.124%	-1	-0.0248%	-\$10.360	-\$8.630	-\$18.990
2013	0.3580	0.1953	0.124%	-1	-0.0248%	-\$10.530	-\$8.780	-\$19.310
2014	0.3580	0.1953	0.124%	-1	-0.0248%	-\$10.710	-\$8.930	-\$19.630
2015	0.3580	0.1953	0.124%	-1	-0.0248%	-\$10.880	-\$9.070	-\$19.950
2016	0.3580	0.1953	0.124%	-1	-0.0248%	-\$11.040	-\$9.210	-\$20.250
2017	0.3580	0.1953	0.124%	-1	-0.0248%	-\$11.210	-\$9.340	-\$20.550
2018	0.3580	0.1953	0.124%	-1	-0.0248%	-\$11.360	-\$9.470	-\$20.840
2019	0.3580	0.1953	0.124%	-1	-0.0248%	-\$11.520	-\$9.600	-\$21.120
2020	0.3580	0.1953	0.124%	-1	-0.0248%	-\$11.670	-\$9.730	-\$21.390
2021	0.3580	0.1953	0.124%	-2	-0.0248%	-\$11.830	-\$9.860	-\$21.690
2022	0.3580	0.1953	0.124%	-2	-0.0248%	-\$11.990	-\$10.000	-\$21.990
2023	0.3580	0.1953	0.124%	-2	-0.0248%	-\$12.170	-\$10.150	-\$22.320
2024	0.3580	0.1953	0.124%	-2	-0.0248%	-\$12.370	-\$10.310	-\$22.680
2025	0.3580	0.1953	0.124%	-2	-0.0248%	-\$12.570	-\$10.480	-\$23.050
2026	0.3580	0.1953	0.124%	-2	-0.0248%	-\$12.780	-\$10.650	-\$23.430
2027	0.3580	0.1953	0.124%	-2	-0.0248%	-\$12.990	-\$10.830	-\$23.810
2028	0.3580	0.1953	0.124%	-2	-0.0248%	-\$13.200	-\$11.000	-\$24.200
2029	0.3580	0.1953	0.124%	-2	-0.0248%	-\$13.410	-\$11.180	-\$24.600
2030	0.3580	0.1953	0.124%	-2	-0.0248%	-\$13.630	-\$11.360	-\$25.000
2031	0.3580	0.1953	0.124%	-2	-0.0248%	-\$13.860	-\$11.550	-\$25.410
2032	0.3580	0.1953	0.124%	-2	-0.0248%	-\$14.080	-\$11.740	-\$25.820
2033	0.3580	0.1953	0.124%	-2	-0.0248%	-\$14.310	-\$11.930	-\$26.240
2034	0.3580	0.1953	0.124%	-2	-0.0248%	-\$14.550	-\$12.130	-\$26.670
2035	0.3580	0.1953	0.124%	-2	-0.0248%	-\$14.790	-\$12.320	-\$27.110
NPV 3%						-\$180.77	-\$150.69	-\$331.45
NPV 7%						-\$97.18	-\$81.01	-\$178.18

(continued)

**Table 13B-1. Regional Impacts: Gasoline Markets (continued)**

PADD V (excluding California) (Average price \$1.69)								
Year	Average Total Cost (cents/ gallon)	Change in Price (cents/ gallon)	Change in Price (%)	Change in Quantity (Absolute)	Change in Quantity (%)	CS Loss (million \$)	PS Loss (million \$)	Total Social Cost (million \$)
2009	0.0000	0.0000	0.000%	0	0.0000%	\$0.000	\$0.000	\$0.000
2010	0.0000	0.0000	0.000%	0	0.0000%	\$0.000	\$0.000	\$0.000
2011	0.3910	0.2133	0.126%	-2	-0.0252%	-\$19.390	-\$16.160	-\$35.550
2012	0.3910	0.2133	0.126%	-2	-0.0252%	-\$19.720	-\$16.440	-\$36.150
2013	0.3910	0.2133	0.126%	-2	-0.0252%	-\$20.050	-\$16.710	-\$36.760
2014	0.3910	0.2133	0.126%	-2	-0.0252%	-\$20.390	-\$16.990	-\$37.380
2015	0.3910	0.2133	0.126%	-2	-0.0252%	-\$20.720	-\$17.270	-\$37.990
2016	0.3910	0.2133	0.126%	-2	-0.0252%	-\$21.030	-\$17.530	-\$38.560
2017	0.3910	0.2133	0.126%	-3	-0.0252%	-\$21.340	-\$17.790	-\$39.120
2018	0.3910	0.2133	0.126%	-3	-0.0252%	-\$21.640	-\$18.030	-\$39.670
2019	0.3910	0.2133	0.126%	-3	-0.0252%	-\$21.930	-\$18.280	-\$40.210
2020	0.3910	0.2133	0.126%	-3	-0.0252%	-\$22.220	-\$18.520	-\$40.730
2021	0.3910	0.2133	0.126%	-3	-0.0252%	-\$22.520	-\$18.770	-\$41.290
2022	0.3910	0.2133	0.126%	-3	-0.0252%	-\$22.840	-\$19.030	-\$41.870
2023	0.3910	0.2133	0.126%	-3	-0.0252%	-\$23.170	-\$19.320	-\$42.490
2024	0.3910	0.2133	0.126%	-3	-0.0252%	-\$23.550	-\$19.630	-\$43.180
2025	0.3910	0.2133	0.126%	-3	-0.0252%	-\$23.940	-\$19.950	-\$43.890
2026	0.3910	0.2133	0.126%	-3	-0.0252%	-\$24.330	-\$20.280	-\$44.610
2027	0.3910	0.2133	0.126%	-3	-0.0252%	-\$24.730	-\$20.610	-\$45.330
2028	0.3910	0.2133	0.126%	-3	-0.0252%	-\$25.130	-\$20.950	-\$46.080
2029	0.3910	0.2133	0.126%	-3	-0.0252%	-\$25.540	-\$21.290	-\$46.830
2030	0.3910	0.2133	0.126%	-3	-0.0252%	-\$25.960	-\$21.640	-\$47.590
2031	0.3910	0.2133	0.126%	-3	-0.0252%	-\$26.380	-\$21.990	-\$48.370
2032	0.3910	0.2133	0.126%	-3	-0.0252%	-\$26.810	-\$22.350	-\$49.160
2033	0.3910	0.2133	0.126%	-3	-0.0252%	-\$27.250	-\$22.720	-\$49.970
2034	0.3910	0.2133	0.126%	-3	-0.0252%	-\$27.700	-\$23.090	-\$50.780
2035	0.3910	0.2133	0.126%	-3	-0.0252%	-\$28.150	-\$23.460	-\$51.610
NPV 3%						-\$344.19	-\$286.89	-\$631.05
NPV 7%						-\$185.04	-\$154.23	-\$339.24

## **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

	2009	2010	2011	2012	2013	2014	2015	2016	2017
<b>Consumer Surplus Change, Total</b>	<b>-\$48.7</b>	<b>-\$49.7</b>	<b>-\$150.9</b>	<b>-\$153.6</b>	<b>-\$156.4</b>	<b>-\$133.4</b>	<b>-\$135.7</b>	<b>-\$137.9</b>	<b>-\$140.1</b>
<i>Gasoline, U.S.</i>	\$0.0	\$0.0	-\$100.3	-\$102.0	-\$103.7	-\$105.4	-\$107.2	-\$108.8	-\$110.4
PADD I & III	\$0.0	\$0.0	-\$21.6	-\$22.0	-\$22.4	-\$22.7	-\$23.1	-\$23.5	-\$23.8
PADD II	\$0.0	\$0.0	-\$49.1	-\$49.9	-\$50.7	-\$51.6	-\$52.4	-\$53.2	-\$54.0
PADD IV	\$0.0	\$0.0	-\$10.2	-\$10.4	-\$10.5	-\$10.7	-\$10.9	-\$11.0	-\$11.2
PADD V (excludes California)	\$0.0	\$0.0	-\$19.4	-\$19.7	-\$20.1	-\$20.4	-\$20.7	-\$21.0	-\$21.3
<i>Gas Cans, U.S.</i>	-\$48.7	-\$49.7	-\$50.7	-\$51.7	-\$52.7	-\$28.0	-\$28.5	-\$29.1	-\$29.7
States With State Regulatory Programs	-\$7.5	-\$7.6	-\$7.8	-\$8.0	-\$8.1	-\$2.2	-\$2.3	-\$2.3	-\$2.4
States Without State Regulatory Programs	-\$41.2	-\$42.0	-\$42.9	-\$43.7	-\$44.6	-\$25.8	-\$26.3	-\$26.8	-\$27.3
<b>Producer Surplus Change, Total</b>	<b>-\$0.3</b>	<b>-\$0.3</b>	<b>-\$85.6</b>	<b>-\$87.1</b>	<b>-\$88.5</b>	<b>-\$89.8</b>	<b>-\$91.3</b>	<b>-\$92.7</b>	<b>-\$94.1</b>
<i>Gasoline, U.S.</i>	\$0.0	\$0.0	-\$85.3	-\$86.7	-\$88.2	-\$89.7	-\$91.1	-\$92.5	-\$93.9
PADD I & III	\$0.0	\$0.0	-\$18.0	-\$18.3	-\$18.6	-\$19.0	-\$19.3	-\$19.6	-\$19.8
PADD II	\$0.0	\$0.0	-\$40.9	-\$41.6	-\$42.3	-\$43.0	-\$43.7	-\$44.4	-\$45.0
PADD IV	\$0.0	\$0.0	-\$8.5	-\$8.6	-\$8.8	-\$8.9	-\$9.1	-\$9.2	-\$9.3
PADD V (excludes California)	\$0.0	\$0.0	-\$16.2	-\$16.4	-\$16.7	-\$17.0	-\$17.3	-\$17.5	-\$17.8
PADD V (California)	\$0.0	\$0.0	-\$1.7	-\$1.7	-\$1.8	-\$1.8	-\$1.8	-\$1.8	-\$1.9
<i>Gas Cans, U.S.</i>	-\$0.3	-\$0.3	-\$0.3	-\$0.3	-\$0.4	-\$0.2	-\$0.2	-\$0.2	-\$0.2
States With State Regulatory Programs	-\$0.1	-\$0.1	-\$0.1	-\$0.1	-\$0.1	\$0.0	\$0.0	\$0.0	\$0.0
States Without State Regulatory Programs	-\$0.3	-\$0.3	-\$0.3	-\$0.3	-\$0.3	-\$0.2	-\$0.2	-\$0.2	-\$0.2
<b>Fuel Savings</b>	<b>\$10.6</b>	<b>\$21.9</b>	<b>\$33.3</b>	<b>\$44.6</b>	<b>\$56.0</b>	<b>\$67.3</b>	<b>\$68.3</b>	<b>\$69.2</b>	<b>\$70.1</b>
Consumer Savings	\$14.3	\$29.6	\$44.8	\$60.1	\$75.4	\$90.7	\$91.9	\$93.1	\$94.4
Fuel	\$10.6	\$21.9	\$33.3	\$44.6	\$56.0	\$67.3	\$68.3	\$69.2	\$70.1
Tax	\$3.7	\$7.6	\$11.5	\$15.5	\$19.4	\$23.4	\$23.7	\$24.0	\$24.3
Government Revenue	-\$3.7	-\$7.6	-\$11.5	-\$15.5	-\$19.4	-\$23.4	-\$23.7	-\$24.0	-\$24.3
<b>Vehicle Program</b>	<b>\$0.0</b>	<b>-\$11.1</b>	<b>-\$11.8</b>	<b>-\$12.5</b>	<b>-\$13.3</b>	<b>-\$13.4</b>	<b>-\$12.9</b>	<b>-\$12.2</b>	<b>-\$11.4</b>
<b>Total Surplus Change</b>	<b>-\$38.4</b>	<b>-\$39.2</b>	<b>-\$215.0</b>	<b>-\$208.6</b>	<b>-\$202.2</b>	<b>-\$169.3</b>	<b>-\$171.6</b>	<b>-\$173.6</b>	<b>-\$175.5</b>

(continued)

**Table 13C-1. Time Series of Social Costs (continued)**

	2018	2019	2020	2021	2022	2023	2024	2025	2026
<b>Consumer Surplus Change, Total</b>	<b>-\$142.2</b>	<b>-\$144.3</b>	<b>-\$146.4</b>	<b>-\$148.6</b>	<b>-\$150.9</b>	<b>-\$153.3</b>	<b>-\$155.9</b>	<b>-\$158.6</b>	<b>-\$161.3</b>
<i>Gasoline, U.S.</i>	-\$111.9	-\$113.4	-\$114.9	-\$116.5	-\$118.1	-\$119.9	-\$121.8	-\$123.8	-\$125.8
PADD I & III	-\$24.1	-\$24.5	-\$24.8	-\$25.1	-\$25.5	-\$25.9	-\$26.3	-\$26.7	-\$27.1
PADD II	-\$54.8	-\$55.5	-\$56.2	-\$57.0	-\$57.8	-\$58.7	-\$59.6	-\$60.6	-\$61.6
PADD IV	-\$11.4	-\$11.5	-\$11.7	-\$11.8	-\$12.0	-\$12.2	-\$12.4	-\$12.6	-\$12.8
PADD V (excludes California)	-\$21.6	-\$21.9	-\$22.2	-\$22.5	-\$22.8	-\$23.2	-\$23.6	-\$23.9	-\$24.3
<i>Gas Cans, U.S.</i>	-\$30.3	-\$30.9	-\$31.5	-\$32.1	-\$32.8	-\$33.4	-\$34.1	-\$34.8	-\$35.5
States With State Regulatory Programs	-\$2.4	-\$2.5	-\$2.5	-\$2.6	-\$2.6	-\$2.7	-\$2.7	-\$2.8	-\$2.8
States Without State Regulatory Programs	-\$27.9	-\$28.4	-\$29.0	-\$29.6	-\$30.2	-\$30.8	-\$31.4	-\$32.0	-\$32.7
<b>Producer Surplus Change, Total</b>	<b>-\$95.4</b>	<b>-\$96.7</b>	<b>-\$97.9</b>	<b>-\$99.3</b>	<b>-\$100.7</b>	<b>-\$102.2</b>	<b>-\$103.8</b>	<b>-\$105.5</b>	<b>-\$107.2</b>
<i>Gasoline, U.S.</i>	-\$95.2	-\$96.5	-\$97.7	-\$99.0	-\$100.4	-\$101.9	-\$103.6	-\$105.3	-\$107.0
PADD I & III	-\$20.1	-\$20.4	-\$20.7	-\$20.9	-\$21.2	-\$21.6	-\$21.9	-\$22.3	-\$22.6
PADD II	-\$45.6	-\$46.3	-\$46.9	-\$47.5	-\$48.2	-\$48.9	-\$49.7	-\$50.5	-\$51.3
PADD IV	-\$9.5	-\$9.6	-\$9.7	-\$9.9	-\$10.0	-\$10.2	-\$10.3	-\$10.5	-\$10.7
PADD V (excludes California)	-\$18.0	-\$18.3	-\$18.5	-\$18.8	-\$19.0	-\$19.3	-\$19.6	-\$20.0	-\$20.3
PADD V (California)	-\$1.9	-\$1.9	-\$2.0	-\$2.0	-\$2.0	-\$2.0	-\$2.1	-\$2.1	-\$2.1
<i>Gas Cans, U.S.</i>	-\$0.2	-\$0.2	-\$0.2	-\$0.2	-\$0.2	-\$0.2	-\$0.2	-\$0.2	-\$0.2
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	-\$0.2	-\$0.2	-\$0.2	-\$0.2	-\$0.2	-\$0.2	-\$0.2	-\$0.2	-\$0.2
<b>Fuel Savings</b>	<b>\$71.0</b>	<b>\$71.9</b>	<b>\$72.8</b>	<b>\$73.7</b>	<b>\$74.6</b>	<b>\$75.5</b>	<b>\$76.4</b>	<b>\$77.3</b>	<b>\$78.3</b>
Consumer Savings	\$95.6	\$96.8	\$98.0	\$99.3	\$100.5	\$101.7	\$102.9	\$104.2	\$105.4
Fuel	\$71.0	\$71.9	\$72.8	\$73.7	\$74.6	\$75.5	\$76.4	\$77.3	\$78.3
Tax	\$24.6	\$24.9	\$25.2	\$25.6	\$25.9	\$26.2	\$26.5	\$26.8	\$27.1
Government Revenue	-\$24.6	-\$24.9	-\$25.2	-\$25.6	-\$25.9	-\$26.2	-\$26.5	-\$26.8	-\$27.1
<b>Vehicle Program</b>	<b>-\$10.7</b>	<b>-\$10.6</b>	<b>\$0.0</b>	<b>\$0.0</b>	<b>\$0.0</b>	<b>\$0.0</b>	<b>\$0.0</b>	<b>\$0.0</b>	<b>\$0.0</b>
<b>Total Surplus Change</b>	<b>-\$177.3</b>	<b>-\$179.7</b>	<b>-\$171.5</b>	<b>-\$174.2</b>	<b>-\$176.9</b>	<b>-\$179.9</b>	<b>-\$183.3</b>	<b>-\$186.8</b>	<b>-\$190.3</b>

(continued)

**Table 13C-1. Time Series of Social Costs (continued)**

	<b>2027</b>	<b>2028</b>	<b>2029</b>	<b>2030</b>	<b>2031</b>	<b>2032</b>	<b>2033</b>	<b>2034</b>	<b>2035</b>
<b>Consumer Surplus Change, Total</b>	<b>-\$164.1</b>	<b>-\$166.9</b>	<b>-\$169.7</b>	<b>-\$172.7</b>	<b>-\$175.6</b>	<b>-\$178.6</b>	<b>-\$181.7</b>	<b>-\$184.8</b>	<b>-\$188.0</b>
<i>Gasoline, U.S.</i>	-\$127.9	-\$130.0	-\$132.1	-\$134.3	-\$136.4	-\$138.7	-\$140.9	-\$143.3	-\$145.6
PADD I & III	-\$27.6	-\$28.0	-\$28.5	-\$29.0	-\$29.4	-\$29.9	-\$30.4	-\$30.9	-\$31.4
PADD II	-\$62.6	-\$63.6	-\$64.6	-\$65.7	-\$66.8	-\$67.9	-\$69.0	-\$70.1	-\$71.2
PADD IV	-\$13.0	-\$13.2	-\$13.4	-\$13.6	-\$13.9	-\$14.1	-\$14.3	-\$14.6	-\$14.8
PADD V (excludes California)	-\$24.7	-\$25.1	-\$25.5	-\$26.0	-\$26.4	-\$26.8	-\$27.3	-\$27.7	-\$28.2
<i>Gas Cans, U.S.</i>	-\$36.2	-\$36.9	-\$37.7	-\$38.4	-\$39.2	-\$40.0	-\$40.8	-\$41.6	-\$42.4
States With State Regulatory Programs	-\$2.9	-\$2.9	-\$3.0	-\$3.1	-\$3.1	-\$3.2	-\$3.2	-\$3.3	-\$3.4
States Without State Regulatory Programs	-\$33.3	-\$34.0	-\$34.7	-\$35.4	-\$36.1	-\$36.8	-\$37.5	-\$38.3	-\$39.0
<b>Producer Surplus Change, Total</b>	<b>-\$109.0</b>	<b>-\$110.8</b>	<b>-\$112.6</b>	<b>-\$114.4</b>	<b>-\$116.3</b>	<b>-\$118.2</b>	<b>-\$120.1</b>	<b>-\$122.1</b>	<b>-\$124.1</b>
<i>Gasoline, U.S.</i>	-\$108.8	-\$110.5	-\$112.3	-\$114.2	-\$116.0	-\$117.9	-\$119.9	-\$121.8	-\$123.8
PADD I & III	-\$23.0	-\$23.4	-\$23.8	-\$24.1	-\$24.5	-\$24.9	-\$25.3	-\$25.8	-\$26.2
PADD II	-\$52.2	-\$53.0	-\$53.9	-\$54.8	-\$55.7	-\$56.6	-\$57.5	-\$58.4	-\$59.4
PADD IV	-\$10.8	-\$11.0	-\$11.2	-\$11.4	-\$11.6	-\$11.7	-\$11.9	-\$12.1	-\$12.3
PADD V (excludes California)	-\$20.6	-\$21.0	-\$21.3	-\$21.6	-\$22.0	-\$22.4	-\$22.7	-\$23.1	-\$23.5
PADD V (California)	-\$2.2	-\$2.2	-\$2.2	-\$2.3	-\$2.3	-\$2.4	-\$2.4	-\$2.4	-\$2.5
<i>Gas Cans, U.S.</i>	-\$0.2	-\$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	-\$0.2	-\$0.2	-\$0.2	-\$0.2	-\$0.2	-\$0.3	-\$0.3	-\$0.3	-\$0.3
<b>Fuel Savings</b>	<b>\$79.2</b>	<b>\$80.1</b>	<b>\$81.0</b>	<b>\$81.9</b>	<b>\$82.8</b>	<b>\$83.7</b>	<b>\$84.6</b>	<b>\$85.5</b>	<b>\$86.4</b>
Consumer Savings	\$106.6	\$107.8	\$109.1	\$110.3	\$111.5	\$112.7	\$114.0	\$115.2	\$116.4
Fuel	\$79.2	\$80.1	\$81.0	\$81.9	\$82.8	\$83.7	\$84.6	\$85.5	\$86.4
Tax	\$27.5	\$27.8	\$28.1	\$28.4	\$28.7	\$29.0	\$29.3	\$29.7	\$30.0
Government Revenue	-\$27.5	-\$27.8	-\$28.1	-\$28.4	-\$28.7	-\$29.0	-\$29.3	-\$29.7	-\$30.0
<b>Vehicle Program</b>	<b>\$0.0</b>	<b>\$0.0</b>	<b>\$0.0</b>	<b>\$0.0</b>	<b>\$0.0</b>	<b>\$0.0</b>	<b>\$0.0</b>	<b>\$0.0</b>	<b>\$0.0</b>
<b>Total Surplus Change</b>	<b>-\$193.9</b>	<b>-\$197.6</b>	<b>-\$201.3</b>	<b>-\$205.2</b>	<b>-\$209.1</b>	<b>-\$213.1</b>	<b>-\$217.2</b>	<b>-\$221.4</b>	<b>-\$225.6</b>

## 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 (see, for example, Fullerton and Metcalfe [2002]).

### 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:

$$\epsilon_s \equiv \frac{dQ_s / Q_s}{dp / p} \quad (\text{D.1})$$

Next, we can use “hat” notation to transform Eq. (D.1) to proportional changes and rearrange terms:

$$\hat{Q}_s = \epsilon_s \hat{p} \quad (\text{D.1a})$$

$\hat{Q}_s$  = percentage change in the quantity of market supply,

$\epsilon_s$  = market elasticity of supply, and

$\hat{p}$  = percentage change in market price.

As Fullerton and Metcalfe (2002) 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:

$$\hat{Q}_d = \eta_d \hat{p} \quad (\text{D.2})$$

$\hat{Q}_d$  = percentage change in the quantity of market demand,

$\eta_d$  = 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:

$$\hat{MC} = \frac{c}{MC_o} = \frac{c}{p_o} \quad (\text{D.3})$$

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:

$$\hat{Q}_s = \hat{Q}_d \quad (D.4)$$

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 ( $\epsilon_s$  and  $\eta_d$ ) and the proportional change in marginal cost:

$$\hat{p} = \frac{\epsilon_s}{\epsilon_s - \eta_d} \bullet \hat{MC} \quad (D.5)$$

Given this solution, we can solve for the proportional change in market quantity using Eq. (D.2).

### 13D.2 Consumer and Producer Welfare Calculations

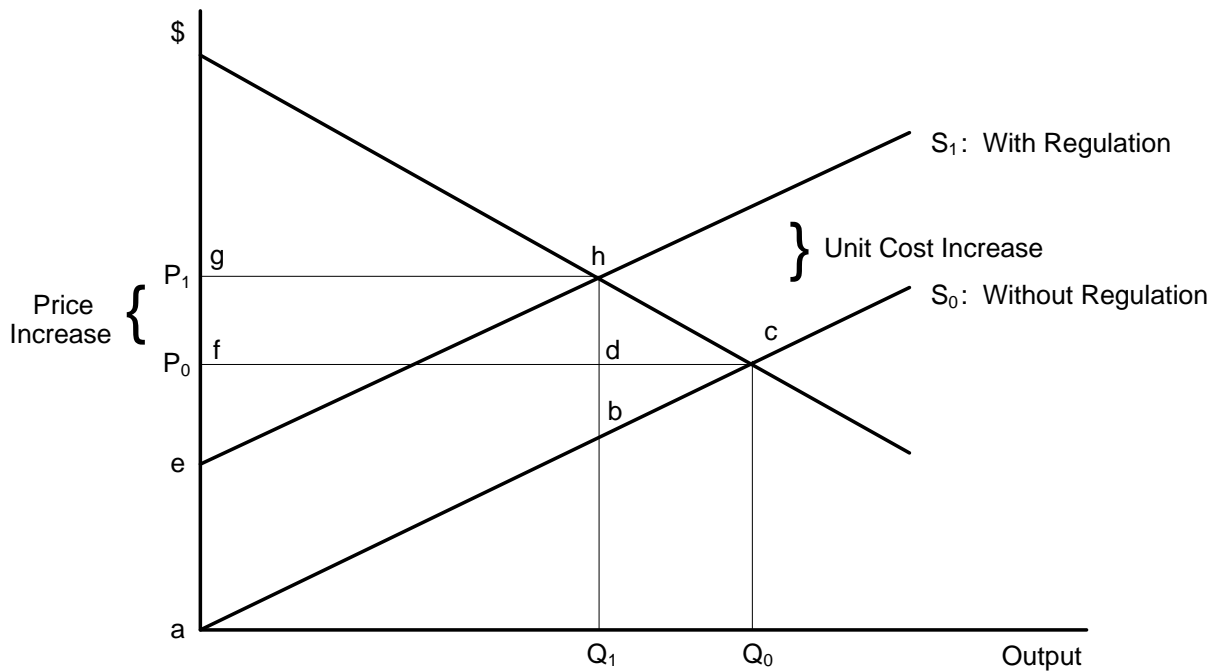
The change in consumer surplus in the affected markets can be estimated using the following linear approximation method:

$$\Delta CS = -Q_1 \bullet \Delta p + 0.5 \bullet \Delta Q \bullet \Delta p. \quad (D.6)$$

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:

$$\Delta PS = Q_1 \bullet (\Delta p - c) - 0.5 \bullet \Delta Q \bullet (\Delta p - c). \quad (D.7)$$



$$\Delta \text{ consumer surplus} = -[fghd + dhc]$$

$$\Delta \text{ producer surplus} = [fghd - aehb] - bdc$$

$$\Delta \text{ total surplus} = -[aehb + dhc + bdc]$$

**Figure D-1. Welfare Calculations**

Increased regulatory costs and output declines have a negative effect on producer surplus, because the net price change ( $\Delta p - c$ ) 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.<sup>L</sup> 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
<b>All Gasoline Markets</b>	0.24	Considine (2002)	Literature estimate	NA
<b>Gas Can Markets</b>	1.50	EPA econometric estimate (see Section 13E.4)	Cobb-Douglas production function	Bartlesman et al. (2000); 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 (2001)	Literature estimate	NA
Gas Can 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” (Finizza, 2002). 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 (FTC, 2001).

Greene and Tishchishyna (2000) reviewed supply elasticity estimates available in the literature. 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 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.

<sup>L</sup>The models equations are described in Appendix A.

A recent paper by Considine (2002) provides one of the few supply elasticity estimates for refining production (excluding extraction and distribution) based on historical price and quantity data. 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 (EPA, 1997, page 3-19<sup>M</sup>). 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 used by other Federal government analysis (FTC, 2001). This value is consistent with recent surveys of the gasoline demand literature (Graham and Glaister, 2002; Espey, 1998). In addition, recent applied work on the incidence of gas taxes (Chouinard and Perloff, 2004) suggests that the national demand elasticity should approximately equal the negative of the national supply elasticity (see page 57). 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 Gas Can Market Parameters

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<sup>M</sup> Industry Profile for the Petroleum Refinery NESHAP, Draft for EPA, by Methtech and Pechan & Associates, Feb 1997, EPA Contract No. 68-D4-0107, WA No. II-17.

Source:

[http://www.epa.gov/ttnecas1/regdata/IPs/Petroleum%20Refinery%20\(Sulfur%20Recovery%20Units,%20Catalytic%20Crackin.pdf](http://www.epa.gov/ttnecas1/regdata/IPs/Petroleum%20Refinery%20(Sulfur%20Recovery%20Units,%20Catalytic%20Crackin.pdf)

There are no estimated gas can 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 gas cans. Using this value, a 1 percent change in the price of gas cans would lead to approximately a 0.014 percent reduction in the quantity of gas cans demanded by consumers.

There are also no estimated gas can 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 gas cans would lead to a 1.5 percent increase in the quantity of gas cans manufacturers would be willing to sell in the market.

### **13E.3 Gas Can Demand Elasticity Estimation Procedure**

Gas cans 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 gas can consumption is expected to be quite small in response to an increased price because gas cans represent a small fraction of overall lawn and garden or recreation expenditures. In addition, because gas cans are in many cases a necessity for small engine use, households have limited ability to substitute away from gas cans as their price increases.

However, it is probably not appropriate to assume that the demand elasticity for gas cans is zero. There will likely be some behavior response to the increased price of gas cans—even though it is anticipated to be small. Unfortunately, an elasticity of demand for gas cans 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 gas cans as an input in the household production function for household lawn and garden activities and develop a derived demand for gas cans through changes in the household for lawn and garden products and services market. Because over 90 percent of gas cans are used to support lawn and garden activities, we use the lawn and garden market to derive a demand elasticity for gas cans.

The demand for gas cans is directly linked to the demand for lawn and garden products and services. When the price of gas cans 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 gas can

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 gas can purchases, which in turn determines the derived demand point  $d_1$  in Figure E-1.<sup>N</sup>

### 13E.3.1 Numerical Example: Base Case

Because gas cans represent such a 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 gas cans 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 (Hicks, 1961, 1966; Allen, 1938):

- 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,

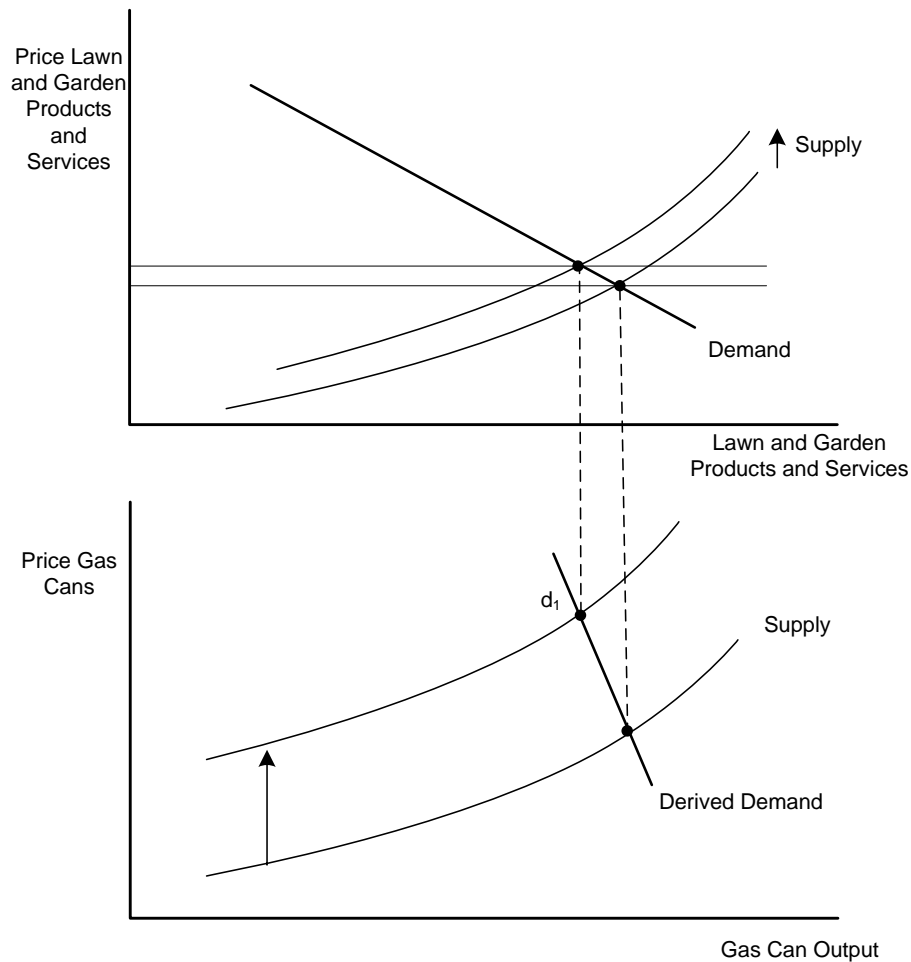
$$E_{dc} = [ \alpha * (E_{df} + E_{si}) + C * E_{si} * (E_{df} - \alpha) ] / [(E_{df} + E_{si}) - C * (E_{df} - \alpha)] \quad (E.1)$$

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
- $\alpha$  = elasticity of substitution between cans and all other inputs.

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<sup>N</sup>This assumes that gas cans are a fixed proportion input into the lawn and garden services market.



**Figure 13E-1. Derived Demand for Gas Cans**

Using the parameter values in Table E-3, we conducted a Monte Carlo simulation and generated the following derived demand elasticity estimate for gas cans:

Mean Value =  $-0.01$

Standard Deviation =  $0.004$

Using the mean value, a 100 percent change in the price of gas cans would lead to approximately a 1.0 percent reduction in the quantity of gas cans 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 gas cans and all other inputs. This implies that consumers do not substitute away from gas cans as the price increases. However, we acknowledge that there is a potential for households

with more than one gas can 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

**Table 13E-3. Assumed Parameter Values Used to Generate Derived Demand Elasticity for Gas Cans**

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 gas can, with household lawn and garden expenditures of \$500 to \$2,500
$\alpha$		$0$	Assume fixed proportions technology

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 gas can.

To investigate the potential impact of substitution in the gas can market, we conducted a sensitivity analysis. Unfortunately, neither a literature estimate of substitution elasticity for gas cans nor the data to estimate such an elasticity 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 gas cans would lead to approximately a 25 percent reduction in the quantity of gas cans demanded by consumers. Specific impact estimates were estimated with engineering cost data.

### 13E.4 Gas Can 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

$$Q_t = A (K_t)^{\alpha_K} (L_t)^{\alpha_L} (M_t)^{\alpha_M} t^{\lambda} \quad (\text{E.2})$$

**Table 13E-4. Assumed Parameter Values Used to Generate Derived Demand Elasticity for Gas Cans**

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 gas can, with household expenditures of \$500 to \$2,500 on lawn and garden services
$\alpha$		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,  $\alpha_K$ ,  $\alpha_L$ ,  $\alpha_M$ , can then be estimated using linear regression techniques:

$$\ln Q_t = \ln A + \alpha_K \ln K_t + \alpha_L \ln L_t + \alpha_M \ln M_t + \lambda \ln t. \quad (E.3)$$

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:

$$\text{Supply Elasticity} = (\alpha_L + \alpha_M) / (1 - \alpha_L - \alpha_M). \quad (E.4)$$

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 (Bartlesman, Becker, and Gray, 2000) publishes industry-level data used for the analysis (years 1958 to 1996). 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 (BEA, 2004)<sup>O</sup>. The following variables were used:

- value of shipments (NBER-CES),
- price index of value shipments (NBER-CES),
- production worker wages (NBER-CES),
- GDP deflator (BEA),
- cost of materials (NBER-CES),
- price index for materials (NBER-CES), and
- value added (NBER-CES).

To provide a measure of capital consumed, a capital variable is calculated as follows:

$$\text{Capital} = (\text{Value added} - \text{Production worker wages})/\text{GDP deflator}.$$

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 (CPSC, 2003) identified plastic cans were introduced. The data covers 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 (EPA, 2004), with some of the independent variables updated with the most recent data. In addition, we also tested the assumption of constant error variance using a Goldfeld-Quandt test and could not reject the hypothesis of

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<sup>O</sup> “Table 1.1.9, Implicit Price deflator for Gross Domestic Product”, BEA, Quarterly, from 2002 to 2004, Source: <http://www.bea.gov/bea/dn/nipaweb/SelectTable.asp>. All values are expressed in \$1987. Note the GDP deflators have been updated since the previous estimation of engine and lawn and garden supply elasticities for the nonroad rule (See Chapter 10 of the Final Regulatory Analysis for the Clean Air Nonroad Diesel Rule, EPA 420-R-04-007, May 2004; <http://www.epa.gov/nonroad-diesel/2004fr/420r04007.pdf>) As a result, the supply elasticity estimates are the same; however, the coefficient estimates may vary slightly.

homoskedasticity. Using this model, we estimate a supply elasticity of 1.5 for this industry (see Table E-5).

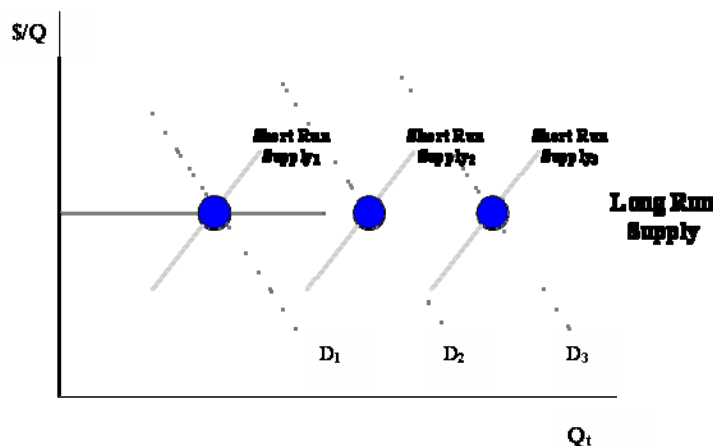
**Table 13E-5. Supply Elasticity Estimate for SIC 3089, Plastic Products, Not Elsewhere Classified: 1980–1996**

Supply elasticity =	1.5		
Number of observations =	17		
R-squared =	99.79		
Goldfeld-Quandt F(4,4) =	2.62 (p-value = 0.187)		
d <sub>DW</sub> =	1.40		
d <sub>l</sub> =	0.90		
d <sub>u</sub> =	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 (see EPA 1999, p. 5-25). 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 gas cans 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 2009 through 2035.

In general, varying the model parameters does not significantly change the estimated net impacts on economic welfare, with net surplus losses (consumer plus producer) remaining the same across the sensitivity analysis scenarios at about \$171.6 million. The sole exception is the Maximum Total Cost alternative for Scenario 3. In this case, net welfare losses are about \$133 million, as much of the consumer surplus loss is captured by refiners in the form of excess profits and resulting in a net gain for producers.

However, even if net surplus losses are the same across most scenarios, varying the model parameters has an impact on how costs are distributed between producers and consumers. In some scenarios consumers bear more of the burden than in others. Varying the supply elasticity in Scenario 1, for example, results in the consumer share of the gasoline fuel program varying from \$32.7 million to \$178.6 million, compared to \$107.2 for the primary analysis. Similarly, as noted above, the Maximum Total Cost fuel example in Scenario 2 shows a much higher loss of consumer surplus, \$1,259 million, compared to the primary analysis estimate of \$107 million. 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 gas can 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 gas can 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
<b>Gasoline Market</b>				
Supply	Literature estimate (EPA 2004 – NRT4)	0.04	0.24	2.0
Demand	Literature estimate (FTC 2001)	-0.10	-0.20	-0.40
<b>Gas Can Market</b>				
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 elasticities for the gas can 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 gas can expenditures are only such a small portion of total household production inputs, households are not expected to switch their preferences for gas cans due to the proposed standards. The sensitivity analysis reflects a hypothetical assumption that 10 percent of demand is substituted away from gas cans, a fairly large assumption since it is not clear what consumers would use instead of gas cans 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 gas cans to -0.25 from -0.01. In other words, a 1.0 percent increase in the price of gas cans 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. According to these results, market prices are relatively stable across the upper- and lower-bound sensitivity scenarios.

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 0.01 cent per gallon and the largest about 0.36 cent per gallon, as compared to 0.3 to 0.21 cent per gallon in the primary case.

In the gas can case, changes in the elasticity parameters have no impacts on the price of gas cans. 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 62 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 gas can 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 \$171 million.

**Table 13G.1-2. Application Market Sensitivity Analysis for Supply Elasticities<sup>a, b</sup>**

Scenario	Supply Lower Bound		Base Case		Supply Upper Bound	
	Absolute	Relative <sup>c</sup>	Absolute	Relative <sup>c</sup>	Absolute	Relative <sup>c</sup>
<b>Gasoline Fuel</b>						
Price (¢/q)						
PADD I+III	0.01¢	0.01%	0.03¢	0.02%	0.04¢	0.03%
PADD II	0.03¢	0.02%	0.11¢	0.07%	0.18¢	0.12%
PADD IV	0.06¢	0.04%	0.20¢	0.12%	0.33¢	0.21%
PADD V (w/out CA)	0.07¢	0.04%	0.21¢	0.13%	0.36¢	0.21%
Change in Consumer Surplus (\$10 <sup>6</sup> /yr)	−\$32.7	16.7%	−\$107.2	54.5%	−\$178.6	90.9%
Change in Producer Surplus (\$10 <sup>6</sup> /yr)	−\$163.7	83.3%	−\$89.3	45.5%	−\$17.9	9.1%
<b>Gas Cans</b>						
Price (\$/q)						
States w/Programs	\$0.20	1.8%	\$0.20	2.0%	\$0.20	2.0%
States w/out Programs	\$1.50	32.2%	\$1.52	32.0%	\$1.48	32.0%
Change in Consumer Surplus (\$10 <sup>6</sup> /yr)	−\$28.3	98.6%	−\$28.5	99.4%	−\$28.0	99.7%
Change in Producer Surplus (\$10 <sup>6</sup> /yr)	−\$0.4	1.4%	−\$0.2	0.6%	−\$0.1	0.3%
<b>Subtotal Social Costs</b>	−\$225.2		−\$225.2		−\$225.2	
<b>Fuel Savings</b>	\$68.3		\$68.3		\$68.3	
<b>Vehicle Program</b>	−\$12.9		−\$12.9		−\$12.9	
<b>California Fuel</b>	−\$1.8		−\$1.8		−\$1.8	
<b>Total Social Costs (\$10<sup>6</sup>/yr)</b>	<b>−\$171.6</b>		<b>−\$171.6</b>		<b>−\$171.6</b>	

<sup>a</sup> Sensitivity analysis is presented for 2015.

<sup>b</sup> Figures are in 2003 dollars.

<sup>c</sup> 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<sup>a, b</sup>**

Scenario	Demand Lower Bound		Base Case		Demand Upper Bound	
	Absolute	Relative <sup>c</sup>	Absolute	Relative <sup>c</sup>	Absolute	Relative <sup>c</sup>
<b>Gasoline Fuel</b>						
Price (¢/q)						
PADD I+III	0.03¢	0.02%	0.03¢	0.02%	0.02¢	0.01%
PADD II	0.14¢	0.09%	0.11¢	0.07%	0.08¢	0.05%
PADD IV	0.25¢	0.16%	0.20¢	0.12%	0.13¢	0.09%
PADD V (w/out CA)	0.28¢	0.17%	0.21¢	0.13%	0.15¢	0.09%
Change in Consumer Surplus (\$10 <sup>6</sup> /yr)	−\$138.7	70.6%	−\$107.2	54.5%	−\$73.7	37.5%
Change in Producer Surplus (\$10 <sup>6</sup> /yr)	−\$57.8	29.4%	−\$89.3	45.5%	−\$122.8	62.5%
<b>Gas Cans</b>						
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 <sup>6</sup> /yr)	−\$28.8	100.0%	−\$28.5	99.3%	−\$23.9	84.9%
Change in Producer Surplus (\$10 <sup>6</sup> /yr)	\$0.0	0.0%	−\$0.2	0.7%	−\$4.3	15.1%
<b>Subtotal Social Costs</b>	−\$225.2		−\$225.2		−\$224.6	
<b>Fuel Savings</b>	\$68.3		\$68.3		\$68.3	
<b>Vehicle Program</b>	−\$12.9		−\$12.9		−\$12.9	
<b>California Fuel</b>	−\$1.8		−\$1.8		−\$1.8	
<b>Total Social Costs (\$10<sup>6</sup>/yr)</b>	<b>−\$171.7</b>		<b>−\$171.6</b>		<b>−\$170.0</b>	

<sup>a</sup> Sensitivity analysis is presented for 2015.<sup>b</sup> Figures are in 2003 dollars.<sup>c</sup> 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

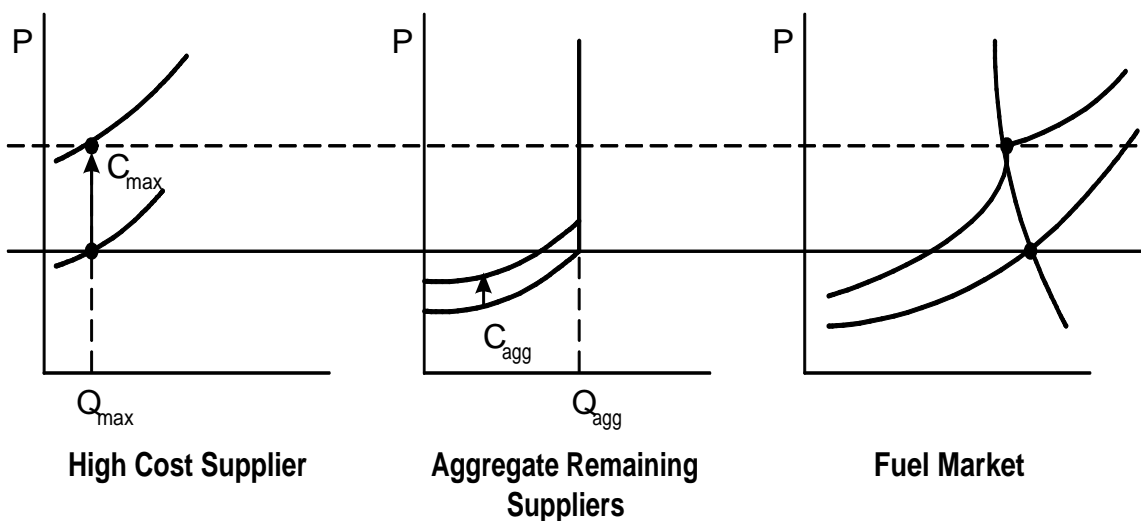
Section 13.2 discusses alternative approaches to shifting the supply curve in the market model. Three alternatives for the fuel market supply shift are investigated in this sensitivity analysis:

- 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

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  $C_{\max}$  (either total or variable), and the aggregate supply curve is shifted by  $C_{\text{agg}}$ . 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.



### Figure 13G2-1. High Cost Producer Drives Price Increases

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 ( $C_{agg}$ ) is calculated from the following:

$$C_{ave} * Q_{tot} = C_{max} * Q_{max} + C_{agg} * Q_{agg} \quad (13G.1)$$

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 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 0.03 to 0.21 cents per gallon, depending on the PADD. In the Maximum Total Cost scenario, prices are expected to increase from 0.61 to 1.46 cents per gallon. In the Maximum Variable Cost scenario, the estimated prices increases range from 0.54 to 1.46 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, with an increase in producer surplus of about \$1,101 million. Consumers, on the other hand, will bear a much larger share of the burden: \$1,259 million in surplus loss compared to \$107 million in the primary case.

**Table 13G.2-1. Sensitivity Analysis to Cost Shifts in the Gasoline Fuel Market (2015)<sup>a,b</sup>**

Scenario	Total Average Scenario		Maximum Total Scenario		Maximum Variable Scenario	
	Absolute	Relative <sup>c</sup>	Absolute	Relative <sup>c</sup>	Absolute	Relative <sup>c</sup>
<b>Gasoline Fuel</b>						
Price (¢/q)						
PADD I+III	0.03¢	0.02%	0.61¢	0.41%	0.54¢	0.36%
PADD II	0.11¢	0.07%	1.15¢	0.76%	1.07¢	0.71%
PADD IV	0.20¢	0.12%	1.46¢	0.93%	1.46¢	0.93%
PADD V (w/out CA)	0.21¢	0.13%	1.14¢	0.69%	1.14¢	0.69%

Scenario	Total Average Scenario		Maximum Total Scenario		Maximum Variable Scenario	
	Absolute	Relative <sup>c</sup>	Absolute	Relative <sup>c</sup>	Absolute	Relative <sup>c</sup>
Change in Consumer Surplus (\$10 <sup>6</sup> /yr)	–\$107.2		–\$1,259.3		–\$1,159.7	
Change in Producer Surplus (\$10 <sup>6</sup> /yr)	–\$89.3		\$1,101.1		\$963.9	
<b>Gas Cans</b>						
Price (\$/q)						
States w/Programs	\$0.20	1.9%	\$0.20	1.9%	\$0.20	2.0%
States w/out Programs	\$1.52	32.5%	\$1.52	32.5%	\$1.52	32.0%
Change in Consumer Surplus (\$10 <sup>6</sup> /yr)	–\$28.5	99.3%	–\$28.5	99.3%	–\$28.5	99.4%
Change in Producer Surplus (\$10 <sup>6</sup> /yr)	–\$0.2	0.7%	–\$0.2	0.7%	–\$0.2	0.7%
<b>Subtotal Social Costs</b>	–\$225.2		–\$187.0		–\$224.5	
<b>Fuel Savings</b>	\$68.3		\$68.3		\$68.3	
<b>Vehicle Program</b>	–\$12.9		–\$12.9		–\$12.9	
<b>California Fuel</b>	–\$1.8		–\$1.8		–\$1.8	
<b>Total Social Costs (\$10<sup>6</sup>/yr)</b>	<b>–\$171.6</b>		<b>–\$133.4</b>		<b>–\$171.0</b>	

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 \$89.3 million, or 45 percent of total social costs. Under this scenario, prices are expected to increase about 0.01 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 \$1,101 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: \$1,259 million compared to \$107 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 \$964 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 (\$964 million compared to \$1,101 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 \$1,159 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 0.93 percent in PADD 4) 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.

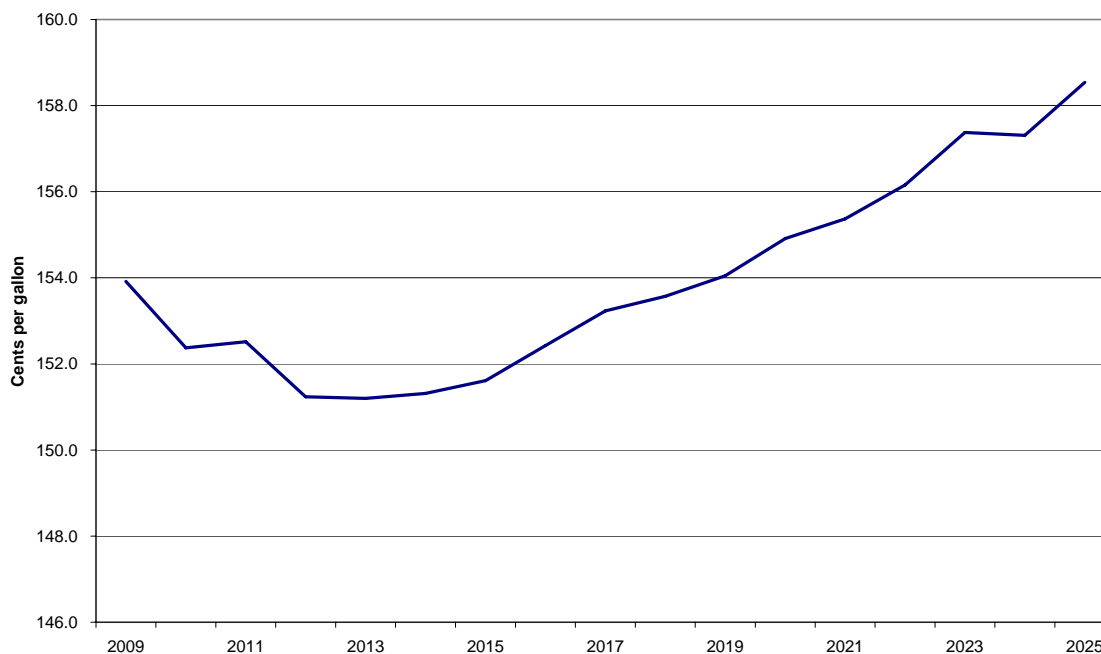
### **13G.3      Scenario 3: Alternative Gasoline Price**

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 gas can market because there are no publicly available price forecasts for that market. Gasoline price forecasts are available through the Annual Energy Outlook (DoE 2005, Appendix A). Gasoline fuel forecast prices are presented in Figure 13G-2. This graph shows that prices are initially expected to decrease from 2009 to about 2013, and then gradually increase after 2013.

**Figure 13G-2. AEO 2005 Motor Fuel Forecast Prices  
(Includes Federal, State, and Local Taxes)**



The AEO price forecasts are national averages. To estimate forecast prices by PADD, an adjustment factor was calculated for each year based on the percent difference between the AEO national price forecast for that year and the 2003 national price. Because the final year of the AEO projections is 2025, 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 2025. The resulting adjustment factors were applied to the individual PADD prices presented in Table 13.3-4 (2003 price multiplied by one plus the adjustment factor). The resulting price forecasts by PADD are presented in Table 13G.3-1.

**Table 13G.3-1. Forecast Gasoline Prices**

Year	Change from 2003	PADD 1 & 3	PADD 2	PADD 4	PADD 5
Constant Price (Primary Case)		\$1.48	\$1.51	\$1.67	\$1.69
		Forecast Prices			
2009	-0.0374	\$1.43	\$1.45	\$1.52	\$1.60
2010	-0.0469	\$1.41	\$1.44	\$1.50	\$1.58
2011	-0.0460	\$1.42	\$1.44	\$1.50	\$1.59
2012	-0.0541	\$1.40	\$1.43	\$1.49	\$1.57
2013	-0.0545	\$1.40	\$1.43	\$1.49	\$1.57
2014	-0.0538	\$1.40	\$1.43	\$1.49	\$1.57
2015	-0.0518	\$1.41	\$1.43	\$1.49	\$1.58
2016	-0.0470	\$1.41	\$1.44	\$1.50	\$1.58
2017	-0.0419	\$1.42	\$1.45	\$1.51	\$1.59
2018	-0.0399	\$1.43	\$1.45	\$1.51	\$1.60
2019	-0.0369	\$1.43	\$1.45	\$1.52	\$1.60
2020	-0.0315	\$1.44	\$1.46	\$1.52	\$1.61
2021	-0.0286	\$1.44	\$1.47	\$1.53	\$1.62
2022	-0.0237	\$1.45	\$1.47	\$1.54	\$1.62
2023	-0.0161	\$1.46	\$1.48	\$1.55	\$1.64
2024	-0.0165	\$1.46	\$1.48	\$1.55	\$1.64
2025	-0.0089	\$1.47	\$1.50	\$1.56	\$1.65
2026	-0.0048	\$1.48	\$1.50	\$1.57	\$1.65
2027	-0.0008	\$1.48	\$1.51	\$1.57	\$1.66
2028	0.0033	\$1.49	\$1.51	\$1.58	\$1.67
2029	0.0074	\$1.50	\$1.52	\$1.59	\$1.67
2030	0.0115	\$1.50	\$1.53	\$1.59	\$1.68
2031	0.0156	\$1.51	\$1.53	\$1.60	\$1.69
2032	0.0197	\$1.51	\$1.54	\$1.61	\$1.70
2033	0.0239	\$1.52	\$1.55	\$1.61	\$1.70
2034	0.0281	\$1.53	\$1.55	\$1.62	\$1.71

2035	0.0323	\$1.53	\$1.56	\$1.62	\$1.72
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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 proposed standard on gasoline prices or in the distribution of social welfare costs among producers and consumers of gasoline fuel. 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**

Scenario	2015				2020				2030			
	Constant Price		Variable Price		Constant Price		Variable Price		Constant Price		Variable Price	
	Absolute	Relative	Absolute	Relative	Absolute	Relative	Relative	Relative	Absolute	Relative	Absolute	Relative
<b>Gasoline Fuel</b>												
Price (¢/q)												
PADD I+III	\$0.03	0.02%	\$0.03	0.02%	\$0.03	0.02%	\$0.03	0.02%	\$0.03	0.02%	\$0.03	0.02%
PADD II	\$0.11	0.07%	\$0.11	0.08%	\$0.11	0.07%	\$0.11	0.08%	\$0.11	0.07%	\$0.11	0.07%
PADD IV	\$0.20	0.12%	\$0.20	0.13%	\$0.20	0.12%	\$0.20	0.13%	\$0.20	0.12%	\$0.20	0.13%
PADD V (w/out CA)	\$0.21	0.13%	\$0.21	0.14%	\$0.21	0.13%	\$0.21	0.13%	\$0.2	0.13%	\$0.21	0.13%
Change in Consumer Surplus (\$10 <sup>6</sup> /yr)												
PADD I+III	–\$23.1	11.8%	–\$23.1	11.8%	–\$24.8	11.8%	–\$24.8	11.8%	–\$29.0	11.8%	–\$29.0	11.8%
PADD II	–\$52.4	26.7%	–\$52.4	26.7%	–\$56.2	26.7%	–\$56.2	26.7%	–\$65.7	26.7%	–\$65.7	26.7%
PADD IV	–\$10.9	5.5%	–\$10.9	5.5%	–\$11.7	5.5%	–\$11.7	5.5%	–\$13.6	5.5%	–\$13.6	5.5%
PADD V (w/out CA)	–\$20.7	10.5%	–\$20.7	10.5%	–\$22.2	10.5%	–\$22.2	10.5%	–\$26.0	10.5%	–\$26.0	10.5%
Change in Producer Surplus (\$10 <sup>6</sup> /yr)												
PADD I+III	–\$19.3	9.8%	–\$19.3	9.8%	–\$20.7	9.8%	–\$20.7	9.8%	–\$24.1	9.8%	–\$24.1	9.8%
PADD II	–\$43.7	22.2%	–\$43.7	22.2%	–\$46.9	22.2%	–\$46.9	22.2%	–\$54.8	22.2%	–\$54.8	22.2%
PADD IV	–\$9.1	4.6%	–\$9.1	4.6%	–\$9.7	4.6%	–\$9.7	4.6%	–\$11.4	4.6%	–\$11.4	4.6%
PADD V (w/out CA)	–\$17.3	8.8%	–\$17.3	8.8%	–\$18.5	8.8%	–\$18.5	8.8%	–\$21.6	8.8%	–\$21.6	8.8%
<b>Total Gasoline Fuel Social Costs</b>	–\$196.5	100.0%	–\$196.5	100.0%	–\$210.7	100.0%	–\$210.7	100.0%	–\$246.1	100.0%	–\$246.1	100.0%

## 13G.4 Scenario 4: Alternative Social Discount Rates

Future benefits and costs are commonly discounted to account for the time value of money. The market and economic impact estimates presented in Section 13.1 calculate the present value of economic impacts using a social discount rate of 3 percent, yielding a total social cost of \$2,937.3 billion from 2009 to 2035. The 3 percent discount rate reflects the commonly used substitution rate of consumption over time. An alternative is the OMB-recommended discount rate of 7 percent that reflects the commonly used real private rate of investment. Table 13G.4-1 shows the present value calculated over 2009 to 2035 using both the 3 and 7 percent social discount rates. With the 7 percent social discount rate, the present value of total social costs decreases to \$1,633 billion.<sup>P</sup>

**Table 13G.4-1. Summary of NPV Net Social Costs Estimates Associated with Primary Program**  
(3%, 2009 to 2035) (2003\$, \$million)

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	-\$384.0	-\$320.0	-\$704.0	-\$206.4	-\$172.0	-\$378.4
PADD 2	-\$871.1	-\$726.0	-\$1,597.1	-\$468.3	-\$290.3	-\$858.6
PADD 4	-\$180.8	-\$150.7	-\$331.4	-\$97.2	-\$81.0	-\$178.2
PADD 5 (w/out CA)	-\$344.2	-\$286.9	-\$631.0	-\$185.0	-\$154.2	-\$339.2
Gas Cans US						
States with existing programs	-\$66.3	-\$0.5	-\$67.1	-\$42.9	-\$0.3	-\$43.2
States without existing programs	-\$572.1	-\$3.8	-\$575.9	-\$338.2	-\$2.3	-\$340.5
Subtotal	-\$2,418.8 61.9%	-\$1,487.8 38.1%	-\$3,906.5	-\$1,338.1 62.6%	-\$800.1 37.4%	-\$2,126.9
Fuel Savings	\$1,090.5			\$585.9		
Vehicle Program	-\$91.1			-\$64.6		
California fuel <sup>a</sup>	-\$30.2			-\$16.3		
Total	-\$2,937.3			-\$1,633.0		

<sup>a</sup>California fuel costs are considered separately. See Section 13.1.3 of the RIA.

<sup>P</sup> EPA has historically presented the present value of cost and benefits estimates using both a 3 percent and a 7 percent social discount rate. The 3 percent rate represents a demand-side approach and reflects the time preference of consumption (the rate at which society is willing to trade current consumption for future consumption). The 7 percent rate is a cost-side approach and reflects the shadow price of capital.

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## **CHAPTER 14: Small-Business Flexibility Analysis**

This chapter discusses our Initial Regulatory Flexibility Analysis (IRFA) which evaluates the potential impacts of the proposed 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. Pursuant to this requirement, we have prepared an IRFA for the proposed rule. Throughout the process of developing the IRFA, we conducted outreach and held meetings with representatives from the various small entities that could be affected by the rulemaking to gain feedback, including recommendations, on how to reduce the impact of the rule on these entities. The small business recommendations stated here reflect the comments of the small entity representatives (SERs) and members of the Small Business Advocacy Review Panel (SBAR Panel, or ‘the Panel’).

### **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 IRFA. A summary of the Panel’s recommendations is presented in the preamble of this proposed rulemaking. Further, a detailed discussion of the Panel’s advice and recommendations is found in the Final Panel Report contained in the docket for this proposed rulemaking.

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 IRFA under section 603 of the Regulatory Flexibility Act. Key elements of an IRFA are:

- a description of and, where feasible, an estimate of the number of small entities to which the proposed rule will apply;
- projected reporting, record keeping, and other compliance requirements of the proposed rule, including an estimate of the classes of small entities which will be subject to the requirements and the type of professional skills necessary for preparation of the report or record;
- an identification to the extent practicable, of all other relevant Federal rules which may duplicate, overlap, or conflict with the proposed rule;
- any significant alternatives to the proposed rule which accomplish the stated objectives of applicable statutes and which 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 will 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 proposed rule are located in the preamble to the proposed rule. As previously stated, controlling emissions from light-duty highway vehicles, gasoline, and portable gasoline containers has important public health and welfare benefits.

Section 202(l)(2) of the Clean Air Act (CAA) directs EPA to establish requirements 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.

In other words, 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. To implement this provision, today's action proposes controls on VOCs and toxics for light-duty vehicles and on benzene emissions from gasoline.

Today's action also proposes controls for gas cans under CAA section 183(e) provisions applying to consumer and commercial products. 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 Small 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 14-1); (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.

**Table 14.3-1. Small Business Definitions**

<b>Industry</b>	<b>Defined as small entity by SBA if less than or equal to:</b>	<b>NAICS<sup>a</sup> Codes</b>
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	1500 employees <sup>b</sup>	324110
Portable Fuel Container Manufacturers: - plastic container manufacturers - metal gas can manufacturers	500 employees 1,000 employees	326199 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 in the small refiner definition for a nonroad diesel sulfur program as well.*

### **14.3.1 Description of Highway Light-Duty Vehicle Manufacturers**

To assess how many companies potentially affected by the proposed rule would meet these small-entity criteria, 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*.

### **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.

### **14.3.3 Description of Portable Gasoline 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 gas cans. 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.

## **14.4 Summary of Small Entities to Which the Rulemaking Will Apply**

The following sections discuss the small entities (namely highway light-duty vehicle manufacturers, gasoline refiners, and portable gasoline container manufacturers) directly regulated by the proposed rule.

### **14.4.1 Highway Light-Duty Vehicle Manufacturers**

Based on a preliminary assessment, EPA has 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.<sup>A</sup>

As described earlier, 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.

#### **14.4.1.1 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

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<sup>A</sup> Sales information used for this analysis was 2004 data.

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.

#### **14.4.1.2 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).<sup>B</sup> ICIs would likely have minimal increased cost from the new standards.

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 a 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.

#### **14.4.1.3 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.

#### **14.4.2 Gasoline Refiners**

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<sup>B</sup> 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.

Based on a preliminary industry characterization and 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 15 refiners, owning 17 refineries, meet SBA's 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 today's program) could be much different than these initial estimates.

#### **14.4.3 Portable Gasoline Container Manufacturers**

As discussed earlier, annual sales nationwide of gas cans are about 21 million units. 98 percent are plastic containers, and 2 percent are metal gas cans. 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, leading to significant industry consolidation over the past decade (25 manufacturers in 1985 to 5 in 2004). EPA has identified 4 domestic manufacturers and 1 foreign manufacturer. Of these 4 U.S. manufacturers, 3 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.

### **14.5 Related Federal Rules**

The primary federal rules that are related today's proposal are the first MSAT rule (*Federal Register Vol. 66, p. 17230, March 29, 2001*), the Tier 2 Vehicle/Gasoline Sulfur rulemaking (*Federal Register Vol. 65, p. 6698, February 10, 2000*), the fuel sulfur rules for highway diesel (*Federal Register Vol. 66, p. 5002, January 18, 2001*) and nonroad diesel (*Federal Register Vol. 69, p. 38958, June 29, 2004*), and the Cold Temperature Carbon Monoxide Rulemaking (*Federal Register Vol. 57, p. 31888, July 17, 1992*).<sup>C</sup>

In addition, the Evaporative Emissions Streamlining Direct Final Rulemaking was issued on December 8, 2005 (*Federal Register Vol. 70, page 72917*). For gas cans, OSHA has safety regulations for gasoline containers used in workplace settings. Cans 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.

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<sup>C</sup> The Cold Temperature Carbon Monoxide rulemaking is the basis for the 20° F test procedure which EPA would use.

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 will be addressed in the Regulatory Impact Analysis (RIA) to this rule and in future rulemakings, such as the RFS rule.

## **14.6 Projected Reporting, Recordkeeping, and Other Compliance Requirements**

As with any emission control program, the Agency must have the assurance that the regulated entities will meet the emissions standards and all related provisions. For highway light-duty vehicles, EPA is proposing to continue the reporting, recordkeeping, and compliance requirements prescribed for this category in 40 CFR 86. Key among these requirements are certification requirements and provisions related to reporting of production, emissions information, flexibility use, etc.

For a fuel control program, EPA must have assurance that fuel produced by refiners meets the applicable standard. EPA expects that recordkeeping, reporting and compliance provisions of the proposed rule will be fairly consistent with those in place today for other fuel programs. For example, reporting likely would involve the submission of pre-compliance reports, which are already required under the highway and nonroad diesel rules, to give EPA general information on refiners' plans and the projected credit availability.

For gas cans, there currently are not federal emission control requirements, and thus, EPA is proposing new reporting and record keeping requirements for gas can manufacturers that would be subject to the proposed standards. EPA is proposing requirements that would be similar to those in the California program, such as submitting emissions testing information, reporting of certification families, and use of transition provisions.

## **14.7 Regulatory Alternatives**

The Panel's findings and discussions are based on the information that was available during the term of the Panel and issues that were raised by the SERs during the outreach meetings and in their written comments. It was agreed that EPA should consider the issues raised by the SERs (and issues raised in the course of the Panel) and that EPA should consider the comments on flexibility alternatives that would help to mitigate any negative impacts on small businesses. Alternatives discussed throughout the Panel process include those offered in the development of the upcoming rule. Though some of the recommended flexibilities may be appropriate to apply to all entities affected by the rulemaking, the Panel's discussions and recommendations are focused mainly on the impacts, and ways to mitigate adverse impacts, on small businesses. A summary of the Panel's recommendations, along with those provisions that we are actually proposing in this action, are detailed below. A full discussion of the regulatory alternatives and hardship provisions discussed and recommended by the Panel, all written

comments received from SERs, and summaries of the two outreach meetings that were held with the SERs can be found in the SBREFA Final Panel Report.<sup>1</sup> In addition, all of the flexibilities (or ‘transition provisions’) that were proposed in the rulemaking for small businesses, as well as those for all entities that may be affected by the rulemaking, are described in the preamble to the proposed rule.

#### **14.7.1 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.

##### **14.7.1.1 Regulatory Flexibility Options for Highway Light-Duty Vehicle Manufacturers**

###### **14.7.1.1.1 SBAR Panel Recommendations**

For certification purposes (and for the sake of simplicity for Panel discussions regarding flexibility options), 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.

###### **14.7.1.1.2 EPA’s Proposed Regulatory Flexibility Options**

For cold VOC standards, we are proposing 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 are proposing that the SVM provision would be 100 percent in model year 2015.

We believe that the Panel's recommendation regarding evaporative emission standards is reasonable. Therefore, for a 2009 model year start date for light-duty vehicles and light light-duty trucks, we are proposing 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 propose that SVMs comply in model year 2012.

Although the SBAR panel did not specifically recommend it, we are also proposing 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 NO<sub>x</sub> fleet average standards, and today we are proposing 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 are proposing that ICIs not be allowed to utilize the deficit carryforward provisions of the proposed ABT program.

#### **14.7.1.2 Hardship Provisions for Highway Light-Duty Vehicle Manufacturers**

##### **14.7.1.2.1 SBAR Panel Recommendations**

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.

#### 14.7.1.2.2 EPA's Proposed Hardship Provisions

We are proposing 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 are proposing 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 are proposing 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.

### 14.7.2 Gasoline Refiners

#### 14.7.2.1 Flexibility Alternatives for Gasoline Refiners

##### 14.7.2.1.1 SBAR 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 is in support of allowing for refinery expansion and recommends 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, 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.

#### 14.7.2.1.2 EPA's Proposed Regulatory Alternatives

In general, we have chosen to propose the Panel's recommended regulatory flexibility provisions. The following is a discussion of the proposed provisions, as well as an additional provision that we have decided to propose based on additional analysis following the SBREFA Panel process.

##### Delay in Standards

We are proposing 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 is governed by the same rules as the general program, described in the preamble to the proposed rule in Section VII.E, the only difference being that small refiners 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 are now proposing that there be a limit on credit life. However, in order to encourage the trading of credits to small refiners, we are proposing 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 are proposing 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 are also proposing 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 will 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 will 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 are further requesting 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.

With respect to the first element, the SBAR Panel recommended that we consider establishing an additional hardship provision to assist those small refiners that are unable to comply with the benzene standard even with a viable credit market. Such a hardship provision would address the case of a small refinery for which compliance may be feasible only through the purchase of credits, but it is not economically feasible for the refiner to do so. This hardship would 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 up to two years. Following the two-year relief, a small refiner would be allowed to request multiple extensions of the hardship until the refinery's material situation changes. We are

proposing the inclusion of such a hardship provision which could be applied for following, and based on the results of, the ABT program review.

With respect to the second element, the Panel recommended that we develop options to help the credit market if it is found (following the review) that there is not an ample supply of credits or that small refiners are having difficulty obtaining credits. These options could include the ‘creation’ of credits by EPA that would be introduced into the credit market to ensure that there are additional credits available for small refiners. Another option the Panel discussed to assist the credit market was to impose additional requirements to encourage trading with small refiners. These could include a requirement that a percentage of all credits sold be set aside and only made available for small refiners. Similarly, we could require that credits sold, or a certain percentage of credits sold, be made available to small refiners before they are allowed to be sold to any other refiners. Options such as these would help to ensure that small refiners were able to purchase credits.

#### **14.7.2.2 Hardship Provisions for Gasoline Refiners**

##### **14.7.2.2.1 SBAR Panel Recommendations**

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.

##### **14.7.2.2.2 EPA’s Proposed Hardship Provisions**

We are in fact proposing the two hardship provisions that we stated above (and that the Panel recommended). These provisions would, at our discretion, permit a refiner to seek a temporary waiver from the MSAT benzene standard under certain rare circumstances. These waiver provisions are similar to provisions in prior fuel regulations, and would again be available all refiners regardless of size. We continue to believe that providing short-term relief to those refiners that need additional time due to hardship circumstances helps to facilitate the adoption of the overall MSAT program for the majority of the industry. However, we do not intend for hardship waiver provisions to encourage refiners to delay planning and investments they would otherwise make. Elements required for hardship waivers are discussed in more detail in Section VII.E.2 of the preamble.

#### **14.7.3 Portable Gasoline Container Manufacturers**

### **14.7.3.1 Flexibility Alternatives for Portable Gasoline Container Manufacturers**

#### **14.7.3.1.1 SBAR Panel Recommendations**

Since nearly all gas can manufacturers are small entities and they account for about 60 percent of sales, the Panel suggested that the flexibility options be offered to all gas can manufacturers. The flexibilities that the Panel recommended are detailed below.

##### **Design Certification**

The Panel recommended that we propose to permit gas can manufacturers to use design certification in lieu of running any or all of the durability aging cycles. Manufacturers could demonstrate the durability of their gas cans 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 gas can 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 gas cans as long as manufacturers do not create stockpiles of noncomplying gas cans prior to the start of the program.

#### 14.7.3.1.2 EPA's Proposed Regulatory Alternatives

Based upon the comments received from gas can small entity representatives during the SBREFA Panel process, we are proposing to include the Panel-recommended flexibility and hardship provisions for gas can manufacturers. As stated previously, nearly all gas can manufacturers (3 of 5 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 gas can manufacturers, and we are proposing that these flexibilities be offered to all gas can manufacturers. Moreover, implementation of the program would be much simpler by doing so.

#### **14.7.3.3 Hardship Provisions for Portable Gasoline Container Manufacturers**

##### 14.7.3.3.1 SBAR Panel Recommendations

The Panel recommended that we propose two types of hardship programs for small gas can manufacturers. The recommended provisions are:

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.

##### 14.7.3.3.2 EPA's Proposed Hardship Provisions

We are proposing that the two types of hardship provisions recommended by the Panel be extended to gas can manufacturers. These entities could, on a case-by-case basis, face hardship, and we are proposing these provisions to provide what could prove to be a needed safety valve for these entities.

## 14.8 Projected Economic Effects of the Proposed Rulemaking

Based on our outreach, fact-finding, and analysis of the potential impacts of our regulations on small businesses, the Panel concluded that small refiners in general would likely experience a significant and disproportionate financial hardship in reaching the objectives of the proposed benzene control program. Refinery modeling (of all refineries), indicates significantly higher refining costs for small refiners. Chapter 9 of this Draft RIA discusses our analysis and estimated costs for U.S. refiners complying with the proposed benzene control program. In this section we are reporting our estimated costs, based on the analysis discussed in Chapter 9, for small refiners to comply with the proposed benzene control program. To provide a perspective on these cost estimates, we compare the small refiner costs for complying with the proposed benzene standard to those for the U.S. refining industry.

We make this cost comparison between the small refiners and the U.S. refining industry in two different ways. First, we compare the small refiner costs to the costs of the U.S. refineries with the costs averaged only over the refineries, or their gasoline volume, projected to reduce their benzene levels. This will describe the average per-refinery costs in each group. Making this distinction is important because while virtually all the small refiners are expected to take action to reduce their benzene levels for the proposed benzene control program, there are 27 U.S. refineries, many of which are large, that are not expected to take action because their benzene levels are already very low. None of the small refiners have low benzene levels.

We are also comparing the small refiner per-gallon cost against the U.S. refining industry's per-gallon cost with the costs averaged over the entire U.S. refinery gasoline volume. This is a useful comparison to make because small refiners often sell their gasoline into a fungible distribution market which essentially requires them to compete with all refiners, regardless of how they comply with a future benzene standard. This cost comparison helps to demonstrate the cost issues faced by small refiners. Table 14.8-1 contains the small refiner costs as well as the costs for the entire U.S. refining industry, expressed in those two ways, for complying with the proposed benzene control standard.

**Table 14.8-1.**  
**Small Refiner and U.S. Refining Industry Costs for Proposed Benzene Control Standard**  
**(\$2002, 7% ROI before taxes)**

	Per-Refinery Capital Costs (\$ million)	Per-Refinery Total Annual Costs (\$ million/yr)	Per-Gallon Costs (c/gal)
Small Refiners	1.2	0.80	0.36
U.S. Refineries Reducing their Gasoline Benzene	5.6	1.9	0.20
All U.S. Refiners	-	-	0.13

As shown in Table 14.8-1, small refiner per-gallon costs are 75 percent higher than the subgroup of U.S. refineries which are projected to reduce their gasoline benzene levels. The small refiner per-gallon costs are over 150 percent higher than the U.S. refining industry's per-gallon costs when the U.S. refining industry's costs are amortized over all gasoline produced by all U.S. refiners. There are two reasons which we identified why small refiners experience higher costs. First, small refineries are faced with poorer economies of scale and higher labor costs for installed capital investments. It is widely understood that the smaller the refining unit installed, the higher the per-gallon cost incurred for that investment. Also most refineries owned by small refiners are located in areas of the country where labor costs are higher for construction, contributing to their higher costs. The second reason why small refiners experience higher costs is that except for a single small refinery, small refiners are not expected to have sufficient access to benzene markets to be able to take advantage of benzene extraction which is the lowest cost means for achieving benzene reduction in our cost model. It is important to point out though that the ABT program reduces the per-gallon cost difference between the small refiners and the rest of the U.S. refining industry. This is because small refiners can achieve a small amount of benzene reduction using benzene precursor rerouting coupled with isomerization and then purchase credits for showing compliance with the average benzene standard. Larger refiners can install the capital for deeper benzene reduction, generate credits and sell the credits to the small refiners. Our cost analysis captures the cost for all physical changes necessary to meet the proposed benzene standard. It does not consider the "cost" to credit purchasers, nor does it consider the "revenue" to credit sellers.

The cost analysis applies certain industry averages for several inputs because refinery-specific information was not available. However, during the SBREFA process, several small refiners shared specific refinery operations information with us to allow us to calibrate our refinery cost model using this information. Because this information was provided after the cost analysis was completed, we were unable to use this information to adjust our cost analysis for the proposal. We will integrate this information in the refinery model and re-estimate the small refiner costs for the final rule. It should not materially impact the overall costs estimates which are built on average assumptions, but may impact assessments for individual refineries.

Of the entities with publicly available sales data, we were able to estimate annual costs, and thus use this information to complete a preliminary screening analysis. Using a cost-to-sales ratio test (a ratio of the estimated annualized compliance costs to the value of sales per company) for the 15 small refiners, we found that: 53 percent (8 refiners) of small refiners were 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), 33 percent (5 refiners) were affected at greater than 1 percent but less than 3 percent, and 13 percent (2 refiners) were affected at greater than 3 percent of their sales. Therefore, we believe that our proposed flexibility provisions are necessary to help mitigate these impacts to small refiners.

In regard to the highway light-duty vehicle requirements of this proposed rule, small vehicle entities (which includes manufacturers, ICIs and converters) in general would likely be impacted similarly as large entities. As we discussed earlier in Chapters 5 and 8 of this Draft RIA, we are proposing to align 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 proposed flexibilities and hardship relief for small entities, as described earlier in Section 14.7, would reduce the burden on these entities.

In addition, as described earlier in Chapters 5 and 8, the proposed cold temperature exhaust (VOC) emission standards for light-duty vehicles can be achieved through calibration alone. It would 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 would be expected to add less than \$1 on average to the cost of vehicles. In general, small vehicle entities would likely experience similar impacts as large entities. Also, as described earlier in Section 14.7, the flexibility and hardship provisions would reduce the burden of the new cold VOC standard on small vehicle entities.

For gas cans, as discussed earlier in Section 14.7, nearly all manufacturers are small entities, thus, we are proposing that the flexibility and hardship provisions be offered to all gas can manufacturers. Moreover, small gas can manufacturers would 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 proposed evaporative emissions standard for gas cans. As discussed in Chapters 10 and 13, all gas cans range in price from \$3 to \$7 (typical sizes are 1, 2, 5, and 6 gallons), and the added variable and fixed costs for the new gas cans with auto-close spouts and permeation control is estimated to be about \$2.70 per unit on average. We anticipate that manufacturers will be able to pass on these costs without a significant impact on gas can sales. In addition, the flexibilities and hardship relief proposed for all gas can manufacturers would reduce the burden of the proposed new standards on small and large manufacturers.

For a complete discussion of the economic impacts of the proposed rulemaking, see Chapter 13, the economic impact analysis chapter, of this Draft Regulatory Impact Analysis.

## References for Chapter 14

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1. Final Report of the Small Business Advocacy Review Panel on EPA's Planned Proposed Rule-- Mobile Source Air Toxics: Control of Hazardous Air Pollutants from Mobile Sources, November 8, 2005.