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EPA

Draft Regulatory Impact Analysis

Control of Air Pollution from New Motor Vehicles: Tier 2 Motor Vehicle Emissions Standards and Gasoline Sulfur Control Requirements

U.S. Environmental Protection Agency
Office of Air and Radiation
Office of Mobile Sources

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Executive Summary

Proposed Vehicle Standards

Today's notice proposes new federal emission standards ("Tier 2 standards") for passenger cars and light trucks. The program is designed to reduce vehicle emissions of nitrogen oxides (NOx) and non-methane organic gases (NMOG) (which consist primarily of hydrocarbons (HC) and volatile organic compounds (VOCs)); NOx and NMOG contribute to the formation of ozone and particulate matter (PM) which are harmful air pollutants. The program would also, for the first time, apply the same federal standards to passenger cars and all light trucks ("light LDTs" and "heavy LDTs").

The proposed Tier 2 standards would reduce new vehicle NOx levels to an average of 0.07 grams per mile (g/mi). For new passenger cars and light LDTs, these standards would phase in beginning in 2004, with the standards to be fully phased in by 2007. For heavy LDTs, the proposed Tier 2 standards would be phased in beginning in 2008, with full compliance in 2009. During the phase-in period from 2004-2007, all passenger cars and light LDTs not certified to Tier 2 standards would have to meet an interim average standard of 0.30 g/mi NOx, equivalent to the current NLEV standards for LDVs. During the period 2004-2008, heavy LDTs not certified to Tier 2 standards would phase in an average standard of 0.20 g/mi NOx, with an emissions cap of 0.60 g/mi NOx

Manufacturers would be allowed to comply with the very stringent proposed new standards in a flexible way, assuring that the average emissions of a company's production met the target emission levels while allowing the manufacturer to choose from several more- and less-stringent emission categories for certification. The proposed requirements also include more stringent PM standards, which primarily affect diesel vehicles, and more stringent hydrocarbon controls (exhaust NMOG and evaporative emissions standards).

Proposed Gasoline Sulfur Requirements

The other major part of today's proposal would significantly reduce average gasoline sulfur levels nationwide beginning in 2004, and likely earlier due to the proposed incentive program to encourage early sulfur reductions. Refiners would generally install advanced refining equipment to remove sulfur in their refining processes. Importers of gasoline would be required to import and market only gasoline meeting the proposed sulfur limits. Temporary, less stringent standards would apply to certain small refiners.

EPA is proposing that gasoline produced by refiners and sold by gasoline importers generally meet an average sulfur standard of 30 ppm and a cap of 80 ppm. The proposed program builds upon the existing regulations covering gasoline content as it relates to emissions performance. It includes provisions for trading of sulfur credits, increasing the flexibility

available to refiners for complying with the new requirements. The proposed credit program is intended to ease compliance uncertainties by providing refiners the flexibility to phase in early controls in 2000-03 and use credits generated in these years to delay some control to 2006. As proposed, the program would achieve expected environmental benefits while providing substantial flexibility to refiners. The effect of the credit program is that those refiners that participate would have the opportunity for more overall lead-time to attain the final sulfur levels.

Cost-Effectiveness of the Proposed Tier2/Sulfur Program

A comparison of the costs of our proposed program with the emission reductions it is estimated to achieve leads us to conclude that it is a cost-effective means of reducing pollution. The cost-effectiveness of the Tier 2/gasoline sulfur proposal, considering only the NOx and hydrocarbon reductions which it will yield, ranges from $1,800 to $2,180 per ton. This range compares favorably with other mobile and stationary source controls. For example, both the Tier 1 and NLEV vehicle standards had similar cost-effectiveness to the standards we are proposing today. For stationary sources, similar levels of reductions in NOx and hydrocarbon emissions could cost up to $10,000 per ton. We believe that the program we are proposing today will be an efficient and significant step towards reaching attainment and maintenance of the NAAQS.

Highlights of the Benefit-Cost Analysis

We also made an assessment of the monetary value of the health and general welfare benefits that would result from our proposed standards. This assessment made use of many of the same data sets, models, and assumptions already used in previous EPA rulemakings. As a result, our benefits assessment included methods which have already received review by the public, other Federal agencies, and/or the independent Science Advisory Board.

In our benefits assessment, we estimated that our proposed standards would, in the long term, result in the yearly avoidance approximately 800 to 2400 premature deaths, approximately 4700 to 8000 cases of bronchitis, and significant numbers of hospital visits, lost work days, and an assortment of respiratory ailments. Our proposed standards will also produce welfare benefits relating to agricultural crop damage, visibility, and nitrogen deposition in rivers and lakes. The results indicate that, based on the particular assumptions, models, and data used in this preliminary benefit-cost analysis, the range of monetary benefits realized after full turnover of the fleet to Tier 2 vehicles would be approximately 3.3 billion to 19.5 billion dollars per year. Comparing this estimate of the economic benefits with the adjusted cost estimate indicates that the net economic benefit of the proposed standards to society could be from a net cost of 0.2 billion to a net benefit of 16.0 billion dollars per year. Our benefit-cost analysis should be considered preliminary due to limitations in the data and models available for analysis in advance of today's proposal. Additional, more refined analysis will be conducted prior to issuance of final standards.

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List of Acronyms

A/F	air/fuel ratio
AML	acute myeloid leukemia
ANPRM	Advanced Notice of Proposed Rulemaking
API	American Petroleum Institute
ASTM	American Society for Testing and Materialss
bbl	barrel
BCA	benefit-cost analysis
BTU	British Thermal Unit
C-R	concentration response
CAA or the Act	Clean Air Act
CAP	Compliance Assurance Program (2000)
CARB	California Air Resources Board
CASAC	Clean Air Science Advisory Committee
CG	conventional gasoline
CML	chronic myeloid leukemia
CO	carbon monoxide
COI	cost of illness
COPD	chronic obstructive pulmonary disease
cpsi	cells per square inch
CRC	Coordinating Research Council
CRDM	Climatological Regional Dispersion Model
DOE	U.S. Department of Energy
EGR	exhaust gas recirculation
EHC	electrically heated catalyst
EIA	Energy Information Administration
EPA or the Agency	U.S. Environmental Protection Agency
ERIC	Emissions Reduction and Intercept Control (system)
FCC	fluidized catalytic cracker
FTP	Federal Test Procedure
GDI	gasoline direct injection
GVWR	gross vehicle weight rating
HAPEM	Hazardous Air Pollutant Exposure Model

HC	hydrocarbon
HDV	heavy-duty vehicle
HEGO	heated exhaust gas oxygen (sensor)
I/M	inspection/maintenance
ICI	independent commercial importer
IRFA	initial regulatory flexibility analysis
LDT	light-duty truck
LDV	light-duty vehicle
LEV	low emission vehicle
LPG	liquid petroleum gas
MDV	medium-duty vehicle
MECA	Manufacturers of Emission Controls Association
MLE	maximum likelihood estimate
MRAD	minor restricted activity days
MSCF	thousand standard cubic feet
MTBE	methyl tertiary-butyl ether
NAAQS	National Ambient Air Quality Standards
NAPAP	National Acid Precipitation Assessment Program
NFRAQS	Northern Front Range Air Quality Study
NLEV	national low emission vehicle
NMHC	non-methane hydrocarbons
NMOG	non-methane organic gases
NO_2	nitrogen dioxide
NOx	oxides of nitrogen
NPC	National Petroleum Council
NPRA	National Petrochemical & Refiners Association
NPRM	Notice of Proposed Rulemaking
OAQPS	Office of Air Quality Planning and Standards
OBD	on-board diagnostics
OMB	Office of Management and Budget
OMS	Office of Mobile Sources
OMS	Office of Mobile Sources
ORNL	Oak Ridge National Laboratory
OSTP	(White House) Office of Science and Technology Policy
OTAG	Ozone Transport Assessment Group

PADD	Petroleum Administrative Districts for Defense
PCM	powertrain control module
Pd	palladium
PM	particulate matter
PNGV	Partnership for a New Generation of Vehicles
ppm	part per million
Pt	platinum
R&D	research and development
RFA	Regulatory Flexibility Act
RfC	reference concentration
RFG	reformulated gasoline
Rh	rhodium
ROI	return on investment
ROTR	Regional Ozone Transport Rule
RPE	retail price equivalent
RVP	Reid Vapor Pressure
S-R Matrix	Source-Receptor Matrix
S&P DRI	Standard & Poor's Data Research International
SAB	Science Advisory Board
SBA	U.S. Small Business Administration
SBARP or the Panel	Small Business Advocacy Review Panel
SBREFA	Small Business Regulatory Enforcement Fairness Act
SCR	selective catalytic reduction
SER	Small Entity Representative
SFTP	Supplemental Federal Test Procedure
SIC	Standard Industrial Classification
SIGMA	Society of Independent Gasoline Marketers of America
SIP	State Implementation Plan
SO_2	sulfur dioxide
SOx	oxides of sulfur
SULEV	super ultra low emission vehicle
SVM	small volume manufacturer
SVM	small volume manufacturer (of vehicles)
SwRI	Southwest Research Institute
TOG	total organic gases

TW	test weight
UAM	Urban Airshed Model
UCL	upper confidence limit
UEGO	universal exhaust gas oxygen (sensor)
ULEV	ultra low emission vehicle
UV	ultra violet
VMT	vehicle miles traveled
VNA	Voronoi Neighbor Averaging
VOC	volatile organic compound
WLD	work loss days
WTP	willingness to pay

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Chapter I: Introduction

The U.S. Environmental Protection Agency (EPA, the Agency) prepared this Regulatory Impact Analysis (RIA) for its proposed rule on Tier 2 Motor Vehicle Emissions Standards and Gasoline Sulfur Control Requirements. The purpose of this RIA is to present EPA's estimates of the likely costs, benefits, and industry impacts associated with the implementation of both the Tier 2 vehicle standards and the gasoline sulfur requirements.

The remainder of this chapter summarizes the background information and provisions of the proposed rulemaking. Subsequent chapters in this RIA present the following information:

- **Chapter II** presents the health and welfare concerns of motor vehicle emissions including, ozone (and ozone precursors), particulate matter, and carbon monoxide.

- **Chapter III** summarizes our analysis of the impact of the Tier 2/Sulfur proposal on emission inventories, ozone and visibility levels, and air toxics emissions and exposures.

- **Chapter IV** examines the technological feasibility of the proposed Tier 2 exhaust emissions standards for light-duty vehicles (LDVs) and light-duty trucks (LDTs), as well as the feasibility of removing sulfur from gasoline.

- **Chapter V** talks about the economic impact of the proposed rule, including the impact of the proposed Tier 2 standards on vehicle costs, the impact of the gasoline sulfur requirements on gasoline desulfurization costs, and the combined vehicle and fuel costs per vehicle and nationwide.

- **Chapter VI** discusses the cost-effectiveness of the proposed vehicle and fuel standards. The analysis in this chapter focuses on the costs and emission reductions associated with a single vehicle meeting the Tier 2 emissions standards while operating on low sulfur fuel.

- **Chapter VII** analyzes and estimates the economic impact of the proposed standards by defining and quantifying the various expected consequences and representing those consequences in terms of dollars. This analysis provides a means for comparing the expected benefits of the proposed standards to the expected costs.

- **Chapter VIII** concludes this RIA with a presentation of the Initial Regulatory Flexibility Analysis for the proposed rule. This analysis evaluates the impacts of the proposed Tier 2 motor vehicle and gasoline sulfur standards on small businesses.

A. Background

On July 31, 1998, EPA submitted its *Tier 2 Report to Congress*, a formal report which

contained the results of its draft Tier 2 Study.[a] The purpose of the Tier 2 Study was to examine the appropriateness of requiring more stringent emission standards for new passenger cars and light-duty trucks. More specifically, EPA was directed by Congress to assess the air quality need, technical feasibility, and cost-effectiveness of more stringent motor vehicle emission standards–emission standards more stringent than federal "Tier 1" standards.

The results of the study indicated that, beginning in 2004, emission reductions will be necessary to meet and maintain the National Ambient Air Quality Standards (NAAQS) for both ozone and particulate matter (PM). Air quality modeling showed that during 2007-10, when Tier 2 standards would be fully implemented, several areas in the U.S. would still be in nonattainment for ozone and PM, even after the implementation of existing emission controls. EPA also found ample evidence that technologies would be available to meet more stringent Tier 2 standards. In addition, the Tier 2 Study provided evidence that such standards could be implemented at a cost (per ton of reduced pollutants) comparable to the costs of other programs designed for similar air quality problems. Finally, the study identified several additional issues in need of further examination, including the relative stringency of car and light truck emission standards, the appropriateness of identical versus different standards for gasoline and diesel vehicles, and the effects of sulfur in gasoline on vehicle catalyst efficiency.

On May 1, 1998, EPA released its *Staff Paper on Gasoline Sulfur Issues* which presented its understanding of the impact of gasoline sulfur on emissions from motor vehicles and explored what gasoline producers and automobile manufacturers could do to reduce sulfur's impact on emissions. The staff paper noted that gasoline sulfur is a catalyst poison and that high sulfur levels in commercial gasoline could affect the ability of future automobiles to meet more stringent standards in use. It also pointed out that sulfur control would provide additional benefits by lowering emissions from the current fleet of vehicles.

Based on the statutory requirements described above and the evidence provided in the Tier 2 Study, as updated in the Preamble, EPA is proposing its determination that new, more stringent emission standards are indeed needed, technologically feasible, and cost effective.

B. Overview of the Proposal

Although the nation's air quality is improving, tens of millions of Americans will continue to be exposed to unhealthy air pollution levels in the future if new emission controls are not imposed on motor vehicles. EPA is therefore proposing a major, comprehensive program designed to significantly reduce emissions from passenger cars and light trucks (including sport-utility vehicles, minivans, and pickup trucks). Under the proposed program, automakers would produce vehicles designed to have very low emissions when operated on low-sulfur gasoline,

[a] On April 28, 1998, EPA published a notice of availability announcing the release of a draft of the Tier 2 study and requesting comments on the draft. The final report to Congress included a summary and analysis of the comments EPA received.

and oil refiners would provide that cleaner gasoline nationwide. In the proposed rule, EPA refers to this comprehensive program as the "Tier 2/Gasoline Sulfur Control Program" or simply as the "Tier 2/Sulfur Program."

1. Vehicle Emission Standards

Today's notice proposes new federal emission standards ("Tier 2 standards") for passenger cars and light trucks. The program is designed to reduce vehicle emissions of nitrogen oxides (NOx) and non-methane organic gases (NMOG) (which consist primarily of hydrocarbons (HC) and volatile organic compounds (VOCs)); NOx and NMOG contribute to the formation of ozone and particulate matter (PM) which are harmful air pollutants. The program would also, for the first time, apply the same federal standards to passenger cars and all light trucks ("light LDTs" and "heavy LDTs").

The proposed Tier 2 standards would reduce new vehicle NOx levels to an average of 0.07 grams per mile (g/mi). For new passenger cars and light LDTs, these standards would phase in beginning in 2004, with the standards to be fully phased in by 2007.[b] For heavy LDTs, the proposed Tier 2 standards would be phased in beginning in 2008, with full compliance in 2009. During the phase-in period from 2004-2007, all passenger cars and light LDTs not certified to Tier 2 standards would have to meet an interim average standard of 0.30 g/mi NOx, equivalent to the current NLEV standards for LDVs.[c] During the period 2004-2008, heavy LDTs not certified to Tier 2 standards would phase in an average standard of 0.20 g/mi NOx, with an emissions cap of 0.60 g/mi NOx.

Manufacturers would be allowed to comply with the very stringent proposed new standards in a flexible way, assuring that the average emissions of a company's production met the target emission levels while allowing the manufacturer to choose from several more- and less-stringent emission categories for certification. The proposed requirements also include more stringent PM standards, which primarily affect diesel vehicles, and more stringent hydrocarbon controls (exhaust NMOG and evaporative emissions standards).

2. Gasoline Sulfur Standards

The other major part of today's proposal would significantly reduce average gasoline sulfur levels nationwide beginning in 2004, and likely earlier due to the proposed incentive program to

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[b]By comparison, the NOx standards for the National Low Emission Vehicle (NLEV) program, which will be in place nationally in 2001, range from 0.30 g/mi for passenger cars to 0.50 g/mi for medium-sized light trucks. For further comparison, the standards met by today's Tier 1 vehicles range from 0.60 g/mi to 1.53 g/mi.

[c]There are also NMOG standards associated with both the interim and Tier 2 standards. The NMOG standards vary depending on which of various individual sets of emission standards manufacturers choose to use in complying with the average NOx standard. This "bin" approach is described more fully in section IV.B.

encourage early sulfur reductions. Refiners would generally install advanced refining equipment to remove sulfur in their refining processes. Importers of gasoline would be required to import and market only gasoline meeting the proposed sulfur limits. Temporary, less stringent standards would apply to certain small refiners.

EPA is proposing that gasoline produced by refiners and sold by gasoline importers generally meet an average sulfur standard of 30 ppm and a cap of 80 ppm. The proposed program builds upon the existing regulations covering gasoline content as it relates to emissions performance. It includes provisions for trading of sulfur credits, increasing the flexibility available to refiners for complying with the new requirements. The proposed credit program is intended to ease compliance uncertainties by providing refiners the flexibility to phase in early controls in 2000-03 and use credits generated in these years to delay some control to 2006. As proposed, the program would achieve expected environmental benefits while providing substantial flexibility to refiners. The effect of the credit program is that those refiners that participate would have the opportunity for more overall lead-time to attain the final sulfur levels.

Chapter II: Health and Welfare Concerns

This chapter describes the public health and welfare concerns associated with the pollutants impacted by this rulemaking, including ozone, particulate matter, carbon monoxide, air toxics, and regional haze.

A. Ozone

Ground-level ozone, the main ingredient in smog, is formed by complex chemical reactions of volatile organic compounds (VOC) and nitrogen oxides (NOx) in the presence of heat and sunlight. Ozone forms readily in the lower atmosphere, usually during hot summer weather. VOCs are emitted from a variety of sources, including motor vehicles, chemical plants, refineries, factories, consumer and commercial products, and other industrial sources. VOCs also are emitted by natural sources such as vegetation. NOx is emitted largely from motor vehicles, nonroad equipment, power plants, and other sources of combustion.

The science of ozone formation, transport, and accumulation is complex. Ground-level ozone is produced and destroyed in a cyclical set of chemical reactions involving NOx, VOC, heat, and sunlight.[d] As a result, differences in NOx and VOC emissions and weather patterns contribute to daily, seasonal, and yearly differences in ozone concentrations and differences from city to city. Many of the chemical reactions that are part of the ozone-forming cycle 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 produce 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 NOx emissions.

Emissions of NOx and VOC are necessary for the formation of ozone in the lower atmosphere. For example, small amounts of NOx enable ozone to form rapidly when VOC levels are high, but ozone production is quickly limited by removal of the NOx. Under these conditions, NOx reductions are highly effective in reducing ozone while VOC reductions have little effect. Such conditions are called “NOx 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 low can be NOx limited.

When NOx levels are high and VOC levels relatively low, NOx forms inorganic nitrates but little ozone. Such conditions are called “VOC limited.” Under these conditions, VOC

[d] Carbon monoxide also participates in the production of ozone, albeit at a much slower rate than most VOC and NOx compounds.

reductions are effective in reducing ozone, but NOx reductions can actually increase local ozone. The highest levels of ozone are produced when both VOC and NOx emissions are present in significant quantities.

Rural areas are almost always NOx limited, due to the relatively large amounts of biogenic VOC emissions in such areas. Urban areas can be either VOC or NOx limited, or a mixture of both, in which ozone levels exhibit moderate sensitivity to changes in either pollutant.

Ozone concentrations in an area also can be lowered by the reaction of nitric oxide with ozone, forming nitrogen dioxide (NO_2); as the air moves downwind and the cycle continues, the NO_2 forms additional ozone. The importance of this reaction depends, in part, on the relative concentrations of NOx, VOC, and ozone, all of which change with time and location.

1. Health and Welfare Effects of Ozone

Based on a large number of recent studies, EPA has identified several key health effects caused when people are exposed to levels of ozone found today in many areas of the country.[1, 2] Short-term exposures (1-3 hours) to high ambient ozone concentrations have been linked to increased hospital admissions and emergency room visits for respiratory problems. For example, studies conducted in the northeastern U.S. and Canada show that ozone air pollution is associated with 10-20 percent of all of the summertime respiratory-related hospital admissions. Repeated exposure to ozone can make people more susceptible to respiratory infection and lung inflammation and can aggravate preexisting respiratory diseases, such as asthma. Prolonged exposure to ozone can cause repeated inflammation of the lung, impairment of lung defense mechanisms, and irreversible changes in lung structure, which could lead to premature aging of the lungs and/or chronic respiratory illnesses such as emphysema and chronic bronchitis.

Children are most at risk from ozone exposure because they typically are active outside, playing and exercising, during the summer when ozone levels are highest. For example, summer camp studies in the eastern U.S. and southeastern Canada have reported significant reductions in lung function in children who are active outdoors. Further, children are more at risk than adults to ozone exposure because their respiratory systems are still developing. Adults who are outdoors and moderately active during the summer months, such as construction workers and other outdoor workers, also are among those most at risk. These individuals, as well as people with respiratory illnesses such as asthma, especially asthmatic children, can experience reduced lung function and increased respiratory symptoms, such as chest pain and cough, when exposed to relatively low ozone levels during periods of moderate exertion.

Several recent studies have shown a possible relationship between exposure to ambient ozone and premature mortality. This literature has been evolving rapidly. Of the 28 time-series epidemiology studies identified in the literature that report results on a possible association between daily ozone concentrations and daily mortality[3], 21 were published or presented since 1995. In particular, a series of studies published in 1995 through 1997 (after closure on the current ozone NAAQS Criteria Document) from multiple cities in western Europe has increased

significantly the body of studies finding a positive association. Fifteen of the 28 studies report a statistically significant relationship between ozone and mortality; the more recent studies tended to find statistical significance more often than the earlier studies. The ozone-mortality datasets also have tended to become larger in more recent studies, as longer series of air quality monitoring data have become available over time. This suggests that it may take many years of data before the ozone effect can be separated from the daily weather and seasonal patterns with which it tends to be correlated.

In 1997, as a part of the Regulatory Impact Analysis (RIA) for the ozone NAAQS promulgation, EPA staff reviewed this recent literature. They identified nine studies that met a defined set of selection criteria, and conducted a meta-analysis of the results of the nine studies. (U.S. EPA, 1997). See Chapter VII.C.3.a. for a further discussion of this meta-analysis.

In addition to human health effects, ozone adversely affects crop yield, vegetation and forest growth, and the durability of materials. Because ground-level ozone interferes with the ability of a plant to produce and store food, plants become more susceptible to disease, insect attack, harsh weather and other environmental stresses. Ozone causes noticeable foliar damage in many crops, trees, and ornamental plants (i.e., grass, flowers, shrubs, and trees) and causes reduced growth in plants. Studies indicate that current ambient levels of ozone are responsible for damage to forests and ecosystems (including habitat for native animal species). Ozone chemically attacks elastomers (natural rubber and certain synthetic polymers), textile fibers and dyes, and, to a lesser extent, paints. For example, elastomers become brittle and crack, and dyes fade after exposure to ozone.

VOC emissions are detrimental not only for their role in forming ozone, but also for their role as air toxics. Some VOCs emitted from motor vehicles are toxic compounds. At elevated concentrations and exposures, human health effects from air toxics can range from respiratory effects to cancer. Other health impacts include neurological, developmental and reproductive effects. Chapter III contains more information about air toxics.

Besides their role as an ozone precursor, NOx emissions produce a wide variety of health and welfare effects.[45] These problems are caused in part by emissions of nitrogen from motor vehicles. Nitrogen dioxide can irritate the lungs and lower resistance to respiratory infection (such as influenza). NOx emissions are an important precursor to acid rain and may affect both terrestrial and aquatic ecosystems. Atmospheric deposition of nitrogen leads to excess nutrient enrichment problems (“eutrophication”) in the Chesapeake Bay and several nationally important estuaries along the East and Gulf Coasts. Eutrophication can produce multiple adverse effects on water quality and the aquatic environment, including increased algal blooms, excessive phytoplankton growth, and low or no dissolved oxygen in bottom waters. Eutrophication also reduces sunlight, causing losses in submerged aquatic vegetation critical for healthy estuarine ecosystems. Deposition of nitrogen-containing compounds also affects terrestrial ecosystems. Nitrogen fertilization can alter growth patterns and change the balance of species in an ecosystem. In extreme cases, this process can result in nitrogen saturation when additions of nitrogen to soil over time exceed the capacity of plants and microorganisms to utilize and retain the nitrogen.

Elevated levels of nitrates in drinking water pose significant health risks, especially to infants. Studies have shown that a substantial rise in nitrogen levels in surface waters are highly correlated with human-generated inputs of nitrogen in those watersheds.[6] These nitrogen inputs are dominated by fertilizers and atmospheric deposition.

Nitrogen dioxide and airborne nitrate also contribute to pollutant haze, which impairs visibility and can reduce residential property values and tourism revenues. Section II.D. further describes information about visibility impairment and regional haze.

B. Particulate Matter

Particulate matter (PM) is the general term for the mixture of solid particles and liquid droplets found in the air. Particulate matter includes dust, dirt, soot, smoke, and liquid droplets that are directly emitted into the air from natural sources (such as windblown dust and fires) and manmade sources (such as motor vehicles, construction sites, factories, and driving on unpaved roads). Secondary PM is formed in the atmosphere through a number of physical and chemical processes that transform gases such as sulfur dioxide, NOx, and VOC into particles.

Particulate matter is distinguished between larger or "coarse" particles (larger than 2.5 micrometers) and smaller or "fine" particles (smaller than 2.5 micrometers). The characteristics, sources, and potential health effects of coarse and fine particles are very different. Coarse particles primarily come from natural sources, such as windblown dust and sea salt. They remain in the atmosphere a relatively short period of time. Fine particles primarily consist of secondary particles formed by gaseous emissions and often come from human sources, such as industrial and residential combustion, vehicle exhaust, and agriculture (including silvicultural prescribed burning). Fine PM consists primarily of sulfate-based particles (produced from sulfur oxides (SOx)), nitrate-based particles (produced from NOx), and carbon-based particles emitted directly from combustion processes and created through transformation of VOC emissions. Particles directly emitted from motor vehicles, and those formed by the transformation of motor vehicle gaseous emissions, tend to be in the fine particle range.

The formation and fate of secondary PM involves complex processes which are sensitive to sunlight, temperature, humidity, and other reactants. SOx, NOx, and VOC emissions are photochemically oxidized and react with water vapor to form sulfuric and nitric acids.[e] Sulfuric acid reacts with ammonia to form mostly ammonium sulfate and some ammonium bisulfate, while nitric acid reacts with ammonia to form ammonium nitrate. Ammonia gas is emitted from biogenic sources and biomass burning, both natural and anthropogenic. If ammonia is in limited supply, it will react to form sulfate rather than nitrate since sulfuric acid has a higher chemical affinity for ammonia than does nitric acid. Furthermore, ammonium nitrate reacts with ammonia and nitric acid in an equilibrium reaction, so nitric acid removal processes such as dry deposition will also lower the concentration of nitrate PM.

[e]Sulfuric acid is a particulate, while nitric acid is a gas at ambient conditions.

As a result, a much higher fraction of SOx is converted to PM than is the case for NOx. Conversion rates vary depending on local meteorology and the amount of ammonia, NOx, and SOx in the local atmosphere. However, mobile sources reasonably can be estimated to contribute to ambient secondary sulfate and nitrate in proportion to their contribution to total NOx and SOx emissions in a given area geographically.

Mobile sources are significant producers of carbonaceous PM, which consists largely of elemental carbon directly emitted by diesel vehicles and poorly maintained gasoline vehicles. Secondary carbonaceous PM results when VOCs or their photochemical reaction products adsorb to existing particles.

In the eastern U.S., based on limited monitoring data, sulfate is the largest single component of fine PM, closely followed by carbonaceous PM. Nitrate is the third-largest component of fine PM, accounting for roughly 10 percent of the total. Most of the rest is soil dust. In the West, again based on limited monitoring data, carbonaceous PM is generally the largest fraction of fine PM. Sulfate forms a smaller fraction of fine PM than in the East, probably because SOx emissions are lower. Sulfate still comprises a larger fraction of the total than nitrate, however, except in parts of California. Soil dust is a more important component of fine PM in the West than in the East, but is still smaller than nitrate in most places. Throughout the U.S., rural areas have lower fine PM levels than urban areas.

1. Health and Welfare Effects of Particulate Matter

Scientific studies have linked particulate matter (alone or in combination with other air pollutants) with a series of health effects.[7] Coarse particles can accumulate in the respiratory system and aggravate health problems such as asthma. Fine particles penetrate deeply into the lungs and are more likely than coarse particles to contribute to a number of the health effects. These health effects include premature death and increased hospital admissions and emergency room visits, increased respiratory symptoms and disease, decreased lung function, and alterations in lung tissue and structure and in respiratory tract defense mechanisms. Children, the elderly, and people with cardiopulmonary disease, such as asthma, are most at risk from these health effects. Chapter III contains a discussion of the toxic health effects from particulate matter in diesel fuel exhaust.

Particulate matter also causes a number of adverse effects on the environment. Fine particulate matter is the major cause of reduced visibility in parts of the U.S., including many of our national parks and wilderness areas. (Section II.D. further describes visibility impairment and regional haze). Other environmental impacts occur when particles deposit onto soil, plants, water, or materials. For example, particles containing nitrogen and sulfur that deposit onto land or water bodies may change the nutrient balance and acidity of those environments, leading to changes in species composition and buffering capacity.

Particles that are deposited directly onto leaves of plants can, depending on their chemical composition, corrode leaf surfaces or interfere with plant metabolism. When deposited in

sufficient quantities, such as near unpaved roads, tilled fields, or quarries, particles block sunlight from reaching the leaves, stressing or killing the plant. Finally, particulate matter causes soiling and erosion damage to materials, including culturally important objects, such as carved monuments and statues.

C. Carbon Monoxide

Carbon monoxide (CO) is a colorless, odorless gas produced though the incomplete combustion of carbon-based fuels. Carbon monoxide enters the bloodstream through the lungs and reduces the delivery of oxygen to the body's organs and tissues. The health threat from CO is most serious for those who suffer from cardiovascular disease, particularly those with angina or peripheral vascular disease. Healthy individuals also are affected, but only at higher CO levels. Exposure to elevated CO levels is associated with impairment of visual perception, work capacity, manual dexterity, learning ability and performance of complex tasks.

Several recent epidemiological studies have shown a link between CO and premature mortality and morbidity (including angina, congestive heart failure, and other cardiovascular diseases). EPA currently is in the process of reviewing these studies as part of the CO Criteria Document process.

Since 1979, the number of areas in the nation violating the CO NAAQS has decreased by a factor of almost ten, from 48 areas in 1979 to five areas (covering seven counties) in 1995 and 1996. In 1997, three counties, with a total population of nine million people, failed to meet the CO standard.

In addition to the substantial decrease in the number of areas where the NAAQS is exceeded, the severity of the exceedances also has decreased significantly. Nationally, CO concentrations decreased 38 percent during the past 10 years.[f] From 1979 to 1996, the measured atmospheric concentrations of CO during an exceedance decreased from 20-25 ppm at the beginning of the period to 10-12 ppm at the end of the period. Expressed as a multiple of the standard, atmospheric concentration of CO during an exceedance was two to almost three times the standard in 1979. By 1996, the CO levels present during an exceedance decreased to 10-30 percent over the nine ppm standard.

Unlike the case with ozone and PM, EPA has not made any recent comprehensive projections of future ambient CO levels and attainment and maintenance of the CO NAAQS. However, section 202(j) of the CAA requires a separate study of the need for more stringent cold CO standards. EPA is currently conducting this study.

[f]This value of the CO concentration decrease is measured by the composite average of the annual second highest 8-hour concentration.

D. Visibility and Regional Haze

Visibility impairment is the haze that obscures what we see, and is caused by the presence of tiny particles in the air. These particles cause light to be scattered or absorbed, thereby reducing visibility. Visibility impairment, also called regional haze, is a complex problem that relates to several pollutants. Visibility in our national parks and monuments, and many urban areas of the country, continues to be obscured by regional and local haze.

The principle cause of visibility impairment is fine particles, primarily sulfates, but also nitrates, organics, and elemental carbon and crustal matter. Particles between 0.1 and one micrometers in size are most effective at scattering light, in addition to being of greatest concern for human health. Of the pollutant gases, only NO_2 absorbs significant amounts of light; it is partly responsible for the brownish cast of polluted skies. However, it is responsible for less than ten percent of visibility reduction.

In the eastern U.S., reduced visibility is mainly attributable to secondary particles, particularly those less than a few micrometers in diameter. Based on data collected by the Interagency Monitoring of Protected Visual Environments (IMPROVE) network for visibility monitoring, sulfate particles account for about 50-70 percent of annual average light extinction in eastern locations. Sulfate plays a particularly significant role in the humid summer months, most notably in the Appalachian, northeast, and mid-south regions. Nitrates, organic carbon, and elemental carbon each account for between 10–15 percent of total light extinction in most eastern locations. Rural areas in the eastern U.S. generally have higher levels of impairment than most remote sites in the western U.S., generally due to the eastern U.S.'s higher levels of man-made pollution, higher estimated background levels of fine particles, and higher average relative humidity levels.

The relative contribution of individual pollutants to visibility impairment vary geographically. While secondary particles still dominate in the West, direct particulate emissions from sources such as woodsmoke contribute a larger percentage of the total particulate load than in the East. In the rural western U.S., sulfates also play a significant role, accounting for about 25–40 percent of total light extinction in most regions. In some areas, such as the Cascades region of Oregon, sulfates account for over 50 percent of annual average light extinction. Organic carbon typically is responsible for 15–35 percent of total light extinction in the rural western U.S. and elemental carbon (absorption) accounts for about 15–25 percent, so the total carbonaceous contribution is between 30 and 60 percent. Soil dust (coarse PM) accounts for about 10–20 percent. Nitrates typically account for less than 10 percent of visibility impairment.[8]

The CAA requires EPA to protect visibility, or visual air quality, through a number of programs. These programs include the national visibility program under sections 169a and 169b of the Act, the Prevention of Significant Deterioration program for the review of potential impacts from new and modified sources, and the secondary NAAQS for PM_{10} and $PM_{2.5}$. The national visibility program established in 1980 requires the protection of visibility in 156 mandatory Federal Class I areas across the country (primarily national parks and wilderness

areas). The CAA established as a national visibility goal, "the prevention of any future, and the remedying of any existing, impairment of visibility in mandatory Federal class I areas in which impairment results from manmade air pollution." The Act also calls for state programs to make "reasonable progress" toward the national goal. In July 1997, EPA proposed a program to address regional haze in the nation's most treasured national parks and wilderness areas (see 62 FR 41137, July 31, 1997).

Since mobile sources contribute to visibility-reducing PM, control programs that reduce the mobile source emissions of direct and indirect PM will have the effect of improving visibility. Western Governors, in commenting on the Regional Haze Rule and on protecting the 16 Class I areas on the Colorado Plateau, stated that, "...the federal government must do its part in regulating emissions from mobile sources that contribute to regional haze in these areas..." and called on EPA to make a "binding commitment to fully consider the Commission's recommendations related to the ... federal national mobile source emissions control strategies", including Tier 2 vehicle emissions standards.[9] The Grand Canyon Visibility Transport Commission's report found that reducing total mobile source emissions is an essential part of any program to protect visibility in the Western U.S.[10] The Commission identifies mobile source pollutants of concern as VOC, NO_X, and elemental and organic carbon.

Chapter II. References

1. U.S. EPA, 1996, Review of National Ambient Air Quality Standards for Ozone, Assessment of Scientific and Technical Information, OAQPS Staff Paper, EPA-452/R-96-007.

2. U.S. EPA, 1996, Air Quality Criteria for Ozone and Related Photochemical Oxidants, EPA/600/P-93/004aF.

3. U.S. EPA, 1997, Regulatory Impact Analysis for the Ozone NAAQS, Appendix J, "Assessment and Synthesis of Available Epidemiological Evidence of Mortality Associated with Ambient Ozone from Daily Time-series Analyses".

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5. U.S.EPA, 1993, Air Quality Criteria for Oxides of Nitrogen, EPA/600/8-91/049aF.

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7. U.S. EPA, 1996, Air Quality Criteria for Particulate Matter, EPA/600/P-95/001aF.

8. "National Air Quality and Emissions Trends Report, 1996", EPA Document Number 454/R-97-013.

9. Letter from Governor Michael Leavitt of Utah, on behalf of the Western Governors' Association, to EPA Administrator Carol Browner, dated June 29, 1998.

10. "Report of the Grand Canyon Visibility Transport Commission to the United States Environmental Protection Agency", June 1996.

Chapter III: Environmental Impact

A. Inventory Impacts of Tier 2/Sulfur

Today's proposal, if adopted, would reduce NOx, VOC, particulate, SOx, carbon monoxide, and hazardous air pollutant emissions from cars and light trucks by lowering the VOC, NOx, and PM emission standards for these vehicles and requiring that gasoline sulfur levels be reduced. Over time, the projected benefits of today's proposal would grow as vehicles meeting the new standards replace older, higher-emitting vehicles and as total VMT continues to grow. The results of our analysis of light-duty inventory levels with and without today's action are presented and discussed for each pollutant in the following sections. In all cases, "without Tier 2/Sulfur" refers to continuation of National LEV on in-use fuel as currently specified; sulfur levels for Conventional Gasoline are estimated at 330 ppm, summertime Phase 2 RFG levels are estimated at 150 ppm (i.e., baseline case). "With Tier 2/Sulfur" refers to implementation of a 30 ppm sulfur standard nationwide in 2004 and the phase-in of NOx, VOC, and PM standards proposed under today's action (i.e., control case).[g]

For this proposal, EPA developed new inventory projections for the United States excluding California, Alaska, and Hawaii.[h] These inventory projections can be divided into three major types of sources for the purpose of describing the methodologies used: stationary and area sources, nonroad mobile sources, and highway motor vehicles. To assess air quality need and the impact of today's proposal on urban areas, separate inventory analyses were also performed on four high ozone cities: New York, Chicago, Atlanta and Charlotte. Inventory estimates for each city were developed using the same data sources as the 47-state inventory discussed below, except where noted. Comprehensive inventories (47-state and four city) are presented in Appendix A with and without Tier 2/sulfur control, in 2005 (47-state only), 2007, 2010, 2015, 2020 and 2030.

These 47-state inventory projections are described more fully in this section. These projections differ in some respects from the inventory projections used for the ozone analyses described in Section B.1. and the inventory projections used for the benefit/cost analyses

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[g]Today's proposal includes a provision for the averaging, banking and trading (ABT) of sulfur levels which would allow average sulfur levels to be higher than 30 ppm in 2004/2005 in exchange for sulfur control prior to 2004 (See Section IV.C.3.c.i of the preamble for a detailed discussion of this program). We expect that overall emission reductions from the ABT program between 2001 and 2005 would be consistent with implementation of 30 ppm in 2004 without prior sulfur reduction, and hence assumed the latter schedule for the control case results presented here.

[h]The 47-state region comprised of the U.S. minus California, Alaska and Hawaii is interchangeably referred to as "nationwide" throughout this section. Although excluded from this analysis, emission reductions will be realized in each of these states. Today's action applies fully to Alaska, Hawaii, and U.S. territories; California, although subject to a separate vehicle and fuel control program, will benefit from lower-emitting Federal vehicles migrating to and/or traveling within the state, as well as California vehicles operating on cleaner non-California fuel.

described in Chapter VII. The methods used to develop the inventory projections presented in this section are described below. Subsequently, the differences between those methods and the methods used to develop the inventories used for the ozone analyses and benefit/cost analyses are described.

The 47-state inventory projections include updated emission estimates for the stationary, area, nonroad, and highway mobile source sectors.[1] For stationary and area sources, we relied on a set of 47-state projection inventories developed for this analysis by E.H. Pechan and Associates. Pechan used state inventories developed for the Regional Ozone Transport Rule (ROTR, 63 FR 57356, October 27, 1998) and Trends inventories for the non-OTAG states to develop a base year stationary and area source inventory. For sources not covered by emissions caps, the total emissions were grown using BEA-based growth factors. Emissions for large electric utilities were held constant at projected 2005 levels, consistent with emissions cap requirements in OTAG states and projections of shifts in types of fuel used in other states.

For nonroad mobile sources (except locomotives, aircraft, and commercial marine), we developed 47-state emission inventories using EPA's Draft NONROAD emissions model. This model is a significant update in data sources and methodologies compared to the NEVES inventories which have been the basis for nonroad emission estimates since 1992. Although NONROAD has only been released in draft form, the emissions estimation data and methods incorporated in it represent our most recent analysis of nonroad emission levels. For this reason, we chose to use the draft NONROAD model to develop our nonroad mobile source emission estimates used to evaluate the impact of the Tier 2/Sulfur proposal on emission inventories. The methods and data used in NONROAD are also consistent with the methods and data used in recent EPA proposed and final rules on nonroad engine standards and the nonroad emissions projections used here reflect all final and proposed standards for nonroad engines and equipment. Growth estimates in NONROAD are based on a linear projection of historical populations of nonroad equipment.

Because NONROAD does not yet include locomotives, aircraft, or commercial marine vessels, we had to use different sources to project emission inventories for these sources. Estimates of projected locomotive emissions were based on estimates in EPA's Final Rule on locomotive standards, adjusted to reflect the 47-state basis of the inventory described above. Commercial marine emissions were based on estimates in EPA's proposed commercial marine rule. Aircraft emissions estimates were based on Trends estimates adjusted to reflect a 47-state basis and grown using FAA growth estimates.

The most critical piece of our 47-state inventory analysis is the light-duty on-highway vehicle inventory. We are in the process of updating the on-highway mobile source emission factor models MOBILE (NOx, VOC and CO) and PART (PM and SOx), and the latest versions of these models (MOBILE6 and PART6) are not yet available. However, many of the modified inputs and assumptions which will be used in these models have at least been developed in draft form; thus, we were able to develop an up-to-date assessment of light-duty vehicle and truck emission inventory for today's proposal using a model which incorporated available elements which have or will be proposed as part of the MOBILE6 and PART6 models. This model,

referred to as the Tier 2 Model[i], reflects updated assessments of in-use emission deterioration and off-cycle emissions, fuel sulfur impacts, and the increase in truck sales relative to cars. The model also reflects existing national and local motor vehicle control programs including National LEV (NLEV), Supplemental Federal Test Procedure (SFTP), On-Board Diagnostics (OBD), reformulated gasoline (RFG) and Inspection/Maintenance (I/M) programs. We used this model to develop baseline emission estimates assuming that NLEV program continued in perpetuity (.e., that there would be no Tier 2/Sulfur standards implemented) and to develop emission estimates for various control scenarios.[2]

The 47-state nonexhaust VOC emission inventory was developed using MOBILE5b, since MOBILE6 estimates of evaporative emissions were not available at the time of the analysis. However, we incorporated available elements of MOBILE6 where possible, including mileage accumulation, VMT mix, and age distribution.[3] A modified version of MOBILE5b was also developed to estimate the benefits of today's proposed evaporative standards.[4]

47-state inventory estimates for heavy-duty gasoline, heavy-duty diesel and motorcycles also incorporated available aspects of MOBILE6 and PART6, including new base emission rates, defeat device emissions for heavy-duty diesel vehicles, off-cycle emissions, mileage accumulation and age distribution. New standards recently finalized for heavy-duty diesel vehicles were accounted for in these inventories, as were standards expected to be proposed for heavy-duty gasoline vehicles.[5,6]

To generate inventory projections, we needed to combine the on-highway emission factors generated using the Tier 2 Model or other means described above with estimates of on-highway vehicle miles traveled (VMT). For our 47-state inventory analysis, VMT estimates through 2010 were based on EPA's Trends Report through 2010. Beyond 2010, we developed VMT estimates for light-duty cars and trucks based on current trends in VMT growth as reported by NHTSA. From 2010 through 2015, we project that 47-state light-duty VMT will grow at a rate of 2.1 percent per year compounded; beyond 2015, we estimate VMT growth will be reduced to a linear 2.1 percent per year (i.e, 2.1 percent of 2015 VMT added incrementally in successive years). Projected 47-state VMT levels for heavy-duty gasoline and diesel vehicles were developed based on data from EPA's Trends Report.

Consistent with EPA's Trends Report, the 47-state inventory estimates were developed on the basis of annual tons emitted. Annual VMT estimates were used in conjunction with emission factors which reflected seasonal fuel control (i.e., low sulfur RFG in the summer only). Because of limitations in the Tier 2 Model, however, seasonal temperature adjustments were not made.

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[i] The Tier 2 Model is the next generation of Modified MOBILE5b (T2AT), the inventory model used in the Tier 2 Study. Since the study, the model has been transferred to a Microsoft Excel platform, updated extensively and expanded to include SOx and PM emissions. The development of this model and generation of light-duty inventory results presented in this section are outlined in the technical report "Development of Light-Duty Emissions Inventory Estimates in the Notice of Proposed Rulemaking for Tier 2 and Sulfur Standards" contained in Docket No. A-97-10. The Tier 2 Model is being made available in concurrence with the publication of today's proposal.

Thus, the annual tonnages developed for the 47-state inventories are annual tonnages assuming summertime temperatures year-round. The effect of using summertime conditions to estimate year-round emissions is to understate annual NOx emissions by about seven percent. Estimates of NOx emission reductions from changes in standards will be similarly underestimated. EPA does not consider this small error to be material.

The urban (four-city) analysis was performed on the basis of summertime (May through September) emissions. Stationary and area source inventories were provided by E.H. Pechan and Associates and were based on state inventories developed for the Regional Ozone Transport Rule (ROTR). Emissions from nonroad equipment were estimated using the NONROAD model, which includes the capability to allocate emissions to the county level. For nonroad equipment not included in the NONROAD model (locomotives, aircraft, and commercial marine) we did not have enough information to directly allocate the 47 inventories described above down to the county level for these urban areas. However, E.H. Pechan has calculated national and local inventories for these categories and areas using older assumptions about future emissions standards. We used those older inventories to calculate the proportion of national emissions from locomotives, aircraft, and commercial marine engines in the four urban areas. We then applied those proportions to the our newer national inventories for the three categories to estimate emissions for locomotives, aircraft, and commercial marine engines in the four urban areas using our latest assumptions about the effects of new standards.

Summertime VMT estimates for each area used in generation of OTAG inventories were provided by Pechan for 1995 and 2007; in order to more closely match localized VMT growth trends, the values were linearly interpolated between these years, and extrapolated linearly beyond 2007. Emission factors for highway vehicles were derived using the same methods described above for the 47-state inventories, but with local specific inputs, such as I/M programs or reformulated gasoline, where applicable.

The emission inventories used for the ozone analyses described in Section B.1. of this chapter and the benefit/cost analyses described in Chapter VII were developed prior to the 47-state inventory described in this section. The ozone analysis and benefit/cost analysis inventories differ from one another and from the 47-state inventories in several respects. It should be noted, however, that we used the emission inventory analyses described in this section to determine the change in emissions from the proposed Tier 2/Sulfur standards for both of these analyses.

The inventories used for the ozone modeling are described more fully in Section B.1. To develop the car and light truck baseline inventories (the inventories that would result if the Tier 2/Sulfur proposal were not adopted), we used the car and light truck inventories developed for the ROTR; these inventories were based on MOBILE5 inputs and emission factors. To estimate the change in emissions from cars and light trucks that would occur if the proposed Tier 2/Sulfur standards were implemented, we used the same methods used to develop the 47-state emission inventories (as described in this section). The inventories for highway heavy-duty engine emissions and nonroad emissions were based on the emission modeling tools that were available to the Ozone Transport Assessment Group (OTAG) and were used during that process and the

subsequent rulemaking process that resulted in promulgation of the ROTR. The highway heavy-duty engine emissions were based on MOBILE5 inputs and emission factors; the nonroad emissions were based on NEVES inputs.

The benefit/cost analyses described in Chapter VII used an even earlier set of estimates for highway, nonroad, and stationary and area source emissions that was developed before the ROTR was proposed or promulgated. These estimates were developed using the emission modeling tools available at the time the Regulatory Impact Analyses for the revised ozone and PM NAAQS rules were developed.[7] The inventories used in the benefit/cost analyses are described more fully in Chapter VII.

1. NOx

a. Light-Duty NOx Trends Without Tier 2/Sulfur

Total NOx emissions produced annually in the 47 states by cars and trucks without Tier 2/Sulfur controls are shown in Table III-1 and Figure III-1, broken down by relative contribution of cars (light-duty vehicles, or LDVs), LDT1s and 2s (light pickup trucks, minivans and most sport utility vehicles), and LDT3s and 4s (heavier pickup trucks and sport utility vehicles). As shown, total light-duty emissions decline from approximately 3.9 million tons to 3.0 million tons between 2000 and 2010 due to turnover of Tier 1 and NLEV vehicles and the phase in of off-cycle standards (SFTP). By 2014, however, the effect of these control programs begins to be offset by increases in overall VMT, in conjunction with the shift of VMT from cars to trucks. Light-duty emissions increase to 3.2 million tons by 2020 and 3.8 million tons by 2030, such that the gains from the Tier 1, NLEV and SFTP control programs are almost completely eradicated by VMT growth.

Table III-1. 47-State Light Duty NOx Emissions Without Tier 2/Sulfur (Annual Tons)

Year	*Light-Duty Emissions*	*Contribution by Vehicle Class*		
		LDV	*LDT1/2*	*LDT3/4*
2000	3,869,383	48.0%	35.6%	16.4%
2004	3,539,655	41.4%	39.9%	18.7%
2007	3,218,530	36.3%	42.2%	21.5%
2010	3,041,639	32.0%	43.6%	24.4%
2015	3,020,806	27.7%	44.3%	28.0%
2020	3,221,151	25.9%	44.8%	29.3%
2030	3,790,840	25.4%	45.1%	29.5%

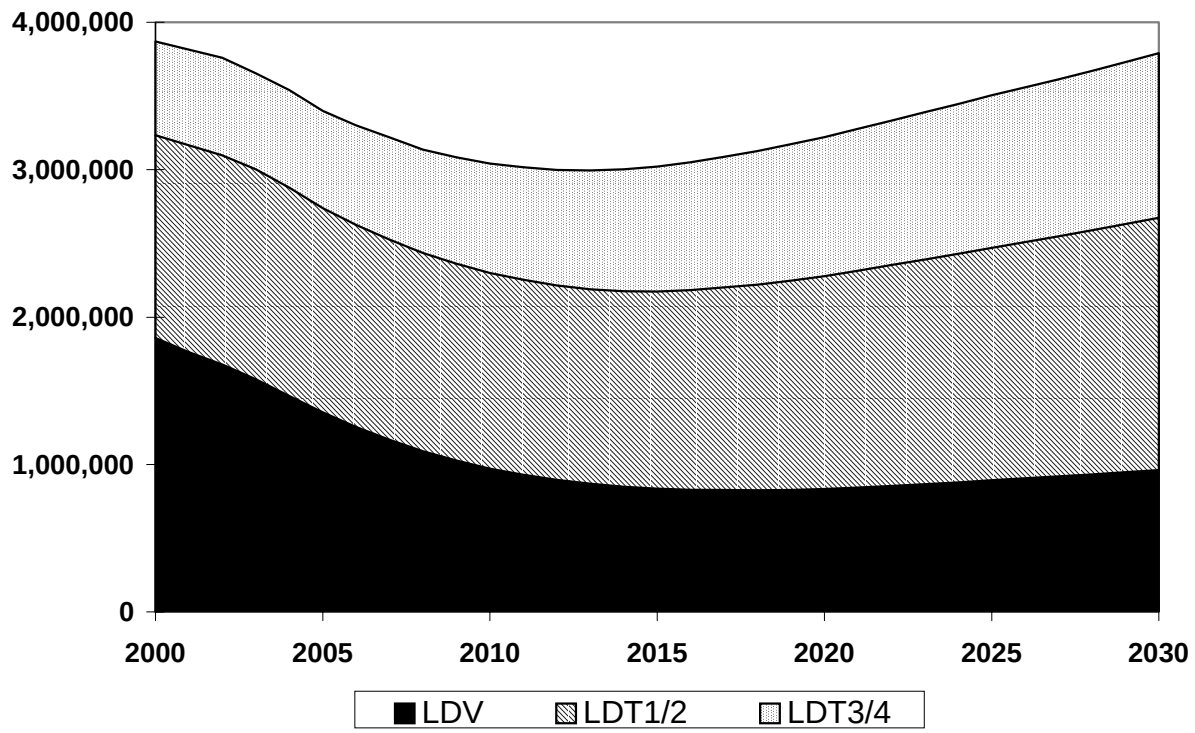

Figure III-1. 47-State Light-Duty NOx Emissions Without Tier 2/Sulfur (Annual Tons)

The impact of steady truck growth on overall light-duty NOx emissions is clearly

demonstrated in the preceding figure. In 2000, we project that trucks will produce 50 percent of overall NOx emissions. Over the next 30 years, trucks will grow to dominate light-duty NOx emissions due to the combined effects of sales migration, higher mileage accumulation rates, longer lifespan, and more relaxed emission standards relative to LDVs. By 2010, we project trucks will make up two-thirds of light-duty NOx emissions; by 2020, nearly three-quarters of all light-duty NOx emissions will be produced by trucks. As shown in Figure III-1, the decrease in overall light-duty emission levels is due solely to reductions in LDV emissions. The benefits from Tier 1, NLEV and SFTP are not as pronounced for trucks, and are offset almost immediately by growth in truck VMT. As a result, truck emissions are stable through 2010 and begin increasing steadily beyond this as VMT growth overtakes the gains from existing control programs.

The emission trends for the four urban areas we analyzed show similar behavior. Although the presence of localized control programs (I/M and in some cases, RFG) do serve to delay the upturn in light-duty emissions, they are not sufficient to counteract the effects of VMT growth. As shown in Table III-2, light-duty emissions decrease steadily in each city through 2010. Emission trends beyond 2010 depend on the rate of VMT growth in each city. In New York, which is projected to have relatively low VMT growth, emissions continue to decrease steadily through 2015 before leveling off and then turning upwards by 2017. In Chicago, Atlanta, and Charlotte, emissions begin to level off by 2010. Emissions start to increase in 2017 in Chicago, 2015 in Atlanta, and 2013 in Charlotte. For the latter two cities, emissions increase at a rapid rate beyond these years. We project that Atlanta's emission reductions achieved from programs currently in place will be almost fully offset by rapid VMT growth by 2030, while we project Charlotte's rapid VMT growth to cause emissions in 2030 to be over 10 percent higher than in 2000.

Table III-2. Four-City Light-Duty NOx Emissions Without Tier 2/Sulfur (Summer Tons)

Year	*New York*	*Chicago*	*Atlanta*	*Charlotte*
2000	78,287	37,037	33,267	4,714
2004	66,857	32,314	30,912	4,526
2007	57,753	28,399	28,313	4,230
2010	51,811	25,958	26,846	4,081
2015	47,634	24,440	26,384	4,109
2020	48,033	25,080	27,721	4,402
2030	52,280	28,165	32,018	5,239

Figures III-2 and III-3 show our projections of the contribution of light-duty vehicles and trucks to the total NOx inventory (i.e., NOx emission from all sources, including stationary, area,

nonroad) in the 47 states and in Atlanta, in 2020. Table III-3 shows this same contribution across the 47 states and all four cities from 2007 through 2030. Across the 47 states, cars and trucks produce nearly one-fifth of total NOx emissions across all years. In urban areas, however, this contribution can be significantly higher. Atlanta provides the most striking example of this; we project that roughly 40 percent of all NOx emissions will be produced by cars and trucks through 2030. While less than Atlanta, the light-duty contribution in New York is significantly higher than the national estimates; from 2007 through 2030, we project that 27 to 29 percent of all emissions in this area will be produced by light-duty cars and trucks. We estimate the contribution in Chicago and Charlotte to be slightly higher but comparable to the 47-state estimate of one-fifth of the total NOx inventory.

Light-duty NOx contribution in urban areas is generally higher than the 47-state region because of the increased concentration of VMT, in conjunction with the decreased prevalence of significant NOx contributors which are largely in non-urban areas (primarily utilities and agricultural nonroad sources). We expect that this trend will be consistent across many high-ozone urban areas.

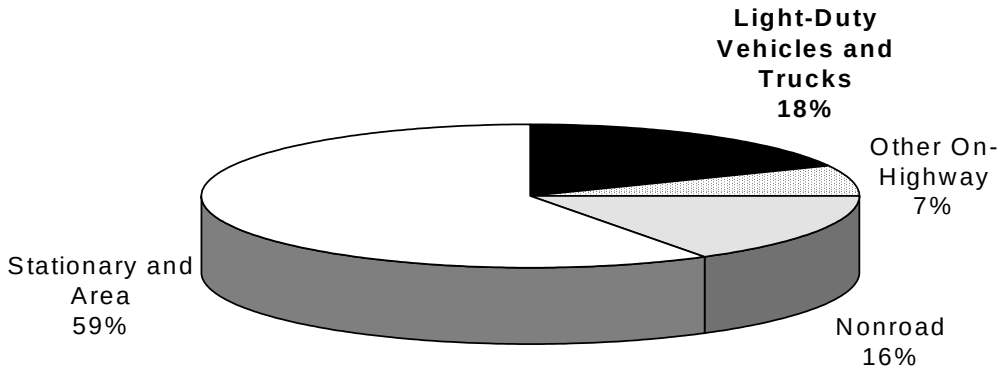

Figure III-2: Breakdown of Total 2020 47 State NOx Inventory Without Tier 2

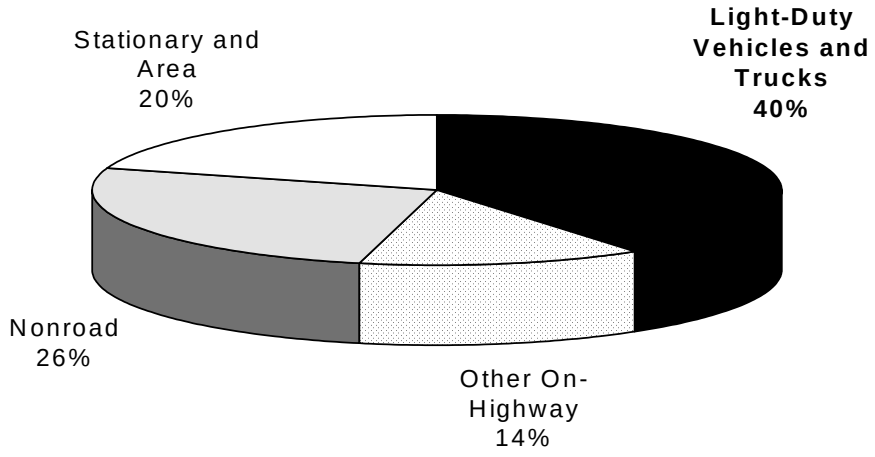

Figure III-3. Breakdown of Total 2020 Atlanta NOx Inventory Without Tier 2

Table III-3. Light-Duty Contribution to Total NOx Inventory Without Tier 2/Sulfur

Year	*47-state*	*New York*	*Chicago*	*Atlanta*	*Charlotte*
2007	17%	29%	19%	38%	18%
2010	17%	28%	18%	38%	19%
2015	17%	27%	18%	39%	19%
2020	18%	27%	19%	40%	21%
2030	20%	28%	19%	42%	22%

b. NOx Reductions Due To Tier 2/Sulfur

Today's proposal would provide substantial reductions in NOx emissions from cars and trucks. The implementation of low sulfur fuel in 2004 would afford an immediate drop in NOx emissions, while the phase-in of tighter vehicle standards would continue to reduce emissions over time, serving to mitigate through at least 2030 the projected upward trend in light-duty NOx emissions that would occur with no control. Table III-4 contains annual tons of NOx we project would be reduced by today's proposal, encompassing benefits of low sulfur fuel and the introduction of Tier 2 light-duty vehicle and light-duty truck standards. Figure III-4 shows annual 47-state light-duty NOx emissions with implementation of the Tier 2/Sulfur program, broken down by LDV, LDT1/2 and LDT3/4 categories.

Table III-4. 47-State Light-Duty NOx Reductions Due To Tier 2/Sulfur (Annual Tons)

Year	*Light-Duty Emissions Without Tier 2/Sulfur*	*Light-Duty Emissions With Tier 2/Sulfur*	*Emissions Reduced*	*Percent Reduction in Baseline Inventory*	
				Light-Duty	*All Sources**
2004	3,539,655	3,037,144	502,511	14%	-
2007	3,218,530	2,422,796	795,734	25%	4%
2010	3,041,639	1,859,316	1,182,323	39%	7%
2015	3,020,806	1,241,925	1,778,881	59%	10%
2020	3,221,151	1,023,038	2,198,113	68%	12%
2030	3,790,840	1,004,495	2,786,345	74%	15%

* Includes emission reductions from Heavy-Duty Gasoline Vehicles due to sulfur control

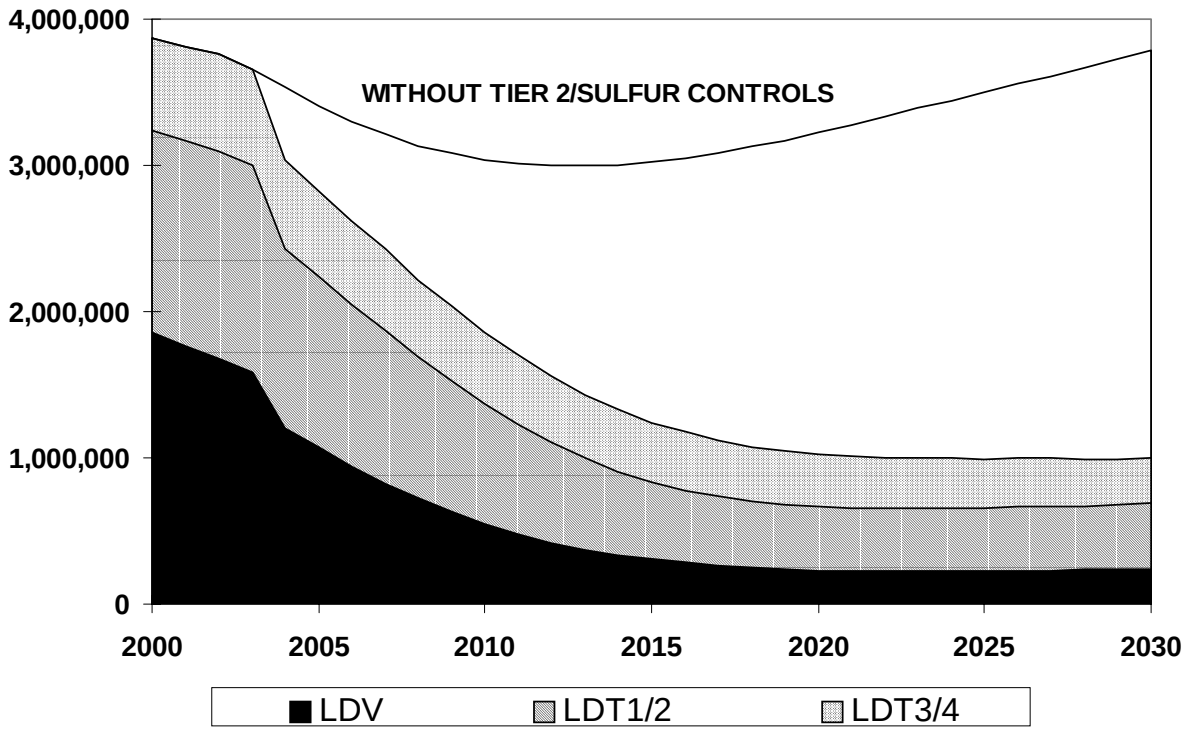

Figure III-4. 47-State Light-Duty NOx Emissions With Tier 2/Sulfur (Annual Tons)

As shown, the implementation of reduced sulfur levels in 2004 would result in an immediate benefit of over one-half million tons, a 14 percent drop in uncontrolled 2004 light-duty emissions; this is the equivalent of emissions produced by over 26 million pre-Tier 2 cars and trucks.[d,8] In 2004, nearly all of the benefits would be due to reduced emissions from Tier 0, Tier 1 and NLEV vehicles.

After 2004, emission are reduced further as the fleet turns over to predominantly Tier 2 vehicles operating on low sulfur fuel, versus NLEVs and Tier 1 trucks operating on current in-use sulfur levels. By 2020, the projected benefit represents a two-thirds reduction in 2020 light-duty emissions without Tier 2/Sulfur, equivalent to the emissions from over 166 million pre-Tier 2 cars and trucks. NOx emissions from all sources would be reduced by 12 percent.

We project that light-duty emissions would continue to decrease beyond 2020, reversing the upward emissions trend in the baseline case brought on by VMT growth. By 2030, essentially the entire fleet would consist of Tier 2 vehicles. The projected benefit of 2.8 million tons in this year represents a nearly three-quarters reduction in 2030 light-duty emissions without Tier 2/Sulfur, equivalent to the emissions from 213 million pre-Tier 2 cars and trucks. These emission reductions would amount to 15 percent of total man-made NOx emissions in that year

[d] i.e., vehicles that would be on the road in the absence of Tier 2/Sulfur control.

in the absence of today's proposal.

The estimated percentage reductions in total inventory presented in Table III-4 include benefits that would be realized on heavy-duty gasoline vehicles due to sulfur control. We estimate these heavy-duty emission reductions to be on the order of approximately 30,000 tons per year for every year starting in 2004, as shown in Appendix A.

NOx reductions due to today's proposal would be of a similar scope in urban areas. Table III-5 shows NOx emissions reduced due to Tier 2/Sulfur control, and light-duty highway vehicle emissions remaining, for each of the four cities. Table III-6 presents these reductions in terms of the percentage of baseline light-duty and total inventory reduced.

Table III-5. Four-City Light-Duty NOx Emissions With Tier 2/Sulfur (Summer Tons)

Year	*New York*		*Chicago*		*Atlanta*		*Charlotte*	
	Reduced	*Remain*	*Reduced*	*Remain*	*Reduced*	*Remain*	*Reduced*	*Remain*
2004	7,368	59,489	3,062	29,252	4,550	26,362	666	3,860
2007	12,139	45,614	5,546	22,853	7,346	20,967	1,098	3,133
2010	18,432	33,380	8,915	17,043	10,975	15,871	1,668	2,413
2015	27,544	20,089	14,020	10,421	16,483	9,901	2,567	1,542
2020	33,177	14,857	17,296	7,784	20,188	7,534	3,206	1,196
2030	39,488	12,792	21,259	6,906	25,160	6,857	4,117	1,122

Table III-6. Percent Reduction From Light-Duty and Total Baseline NOx Emissions in Four Cities

Year	*New York*		*Chicago*		*Atlanta*		*Charlotte*	
	Light-Duty	*All Sources**	*Light-Duty*	*All Sources**	*Light-Duty*	*All Sources**	*Light-Duty*	*All Sources**
2004	11%	-	9%	-	15%	-	15%	-
2007	21%	6%	20%	4%	26%	10%	26%	5%
2010	36%	10%	34%	6%	41%	16%	41%	8%
2015	58%	16%	57%	10%	62%	25%	62%	12%
2020	69%	19%	69%	13%	73%	30%	73%	15%
2030	76%	21%	75%	15%	79%	33%	79%	18%

* Includes emission reductions from Heavy-Duty Gasoline Vehicles due to sulfur control

The magnitude of reductions in urban areas reflect those nationally. An immediate reduction in light-duty emission would result from sulfur control, even in RFG areas (New York and Chicago). Over one-third of baseline light-duty emissions would be reduced by 2010 in each city. Light-duty emissions would be reduced by roughly 70 percent in 2020 and over 75 percent in 2030. Reductions in Atlanta and Charlotte are consistently larger in percentage terms than in New York and Chicago because they are not RFG areas; emission reductions in non-RFG urban areas would be particularly large since these areas would tend to have higher-sulfur fuel than RFG areas in the absence of today's proposal. We project that emissions would continue to decrease through at least 2028 in all four cities, indicating that today's program would be successful in reducing light-duty NOx emissions in the face of high VMT growth rates.

The impact on total inventory would also be significant, particularly in New York and Atlanta. By 2020, we project that the total NOx inventory would be reduced by nearly one-fifth in New York and one-third in Atlanta due to Tier 2/Sulfur control.

Concurrently, we project that the light-duty contribution to total NOx emissions would drop significantly. Figures III-5 and III-6 show our 2020 projections of this contribution in the 47 states and in Atlanta with Tier 2/Sulfur control. Table III-7 shows this same contribution across the 47 states and all four cities from 2007 through 2030. In 2020, we project that the light-duty contribution would drop to seven percent nationally, from 18 percent without Tier 2/Sulfur control. This trend is similar across the four cities, depending on the level of contribution without Tier 2/Sulfur control. We project that with Tier 2/Sulfur control, car and truck emissions would contribute 10 percent of total emissions in New York (down from 27 percent), seven percent in Chicago and Charlotte (down from 19 percent and 21 percent), and 16 percent in Atlanta (down from 40 percent) in 2020.

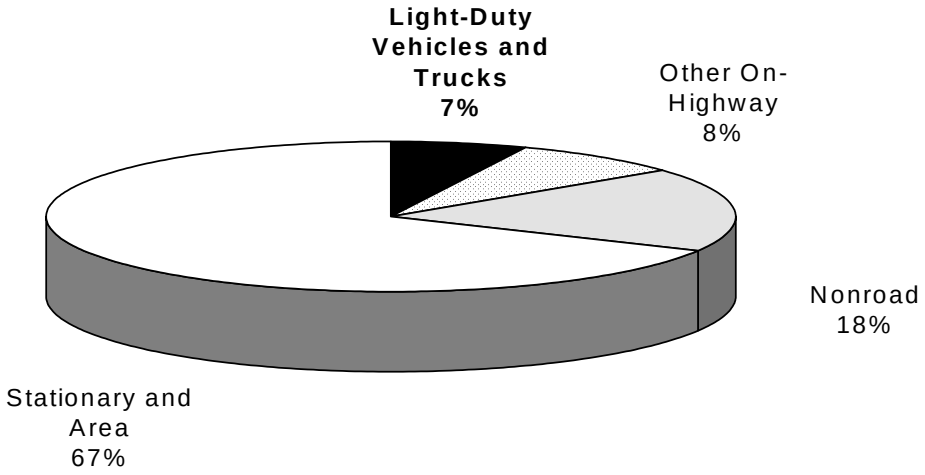

Figure III-5. Breakdown of Total 2020 47-State NOx Inventory With Tier 2/Sulfur

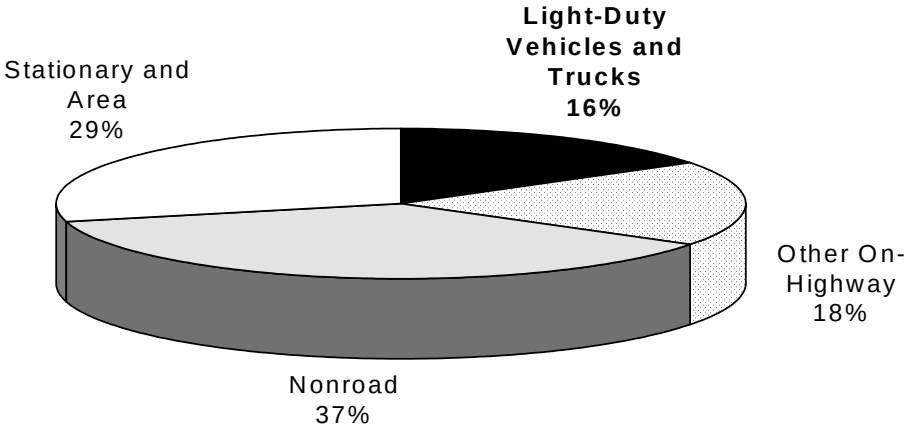

Figure III-6. Breakdown of Total 2020 Atlanta NOx Inventory With Tier 2/Sulfur

Table III-7. Light-Duty Contribution to Total NOx Inventory With Tier 2/Sulfur

Year	*47 State*	*New York*	*Chicago*	*Atlanta*	*Charlotte*
2007	14%	24%	16%	31%	14%
2010	11%	20%	13%	27%	12%
2015	8%	14%	9%	20%	8%
2020	7%	10%	7%	16%	7%
2030	6%	9%	6%	13%	6%

c. NOx Emission Reductions From Other Options

We developed 47-state light-duty emission inventory projections for three alternative vehicle/fuel control options to allow comparison with the emission reductions projected to result from today's action. These alternative options are:

1) Car and truck emission standards and implementation schedule as proposed in today's action in conjunction with sulfur control proposed to EPA by the American Petroleum Institute (API) and National Petroleum Refiners Association (NPRA). Under this plan, sulfur would be reduced in 2004 to 150 ppm in the eastern half of the U.S., referred to as the "API NOx Control Region", and 300 ppm in the remainder of the 49-state region.[e]

2) Option (1) above with implementation of a "rebuttable" element of the API/NPRA proposal in which sulfur would be reduced to 30 ppm in 2010 in the API NOx Control Region, while the remainder of the country remains at 300 ppm.

3) Sulfur control as proposed in today's action in conjunction with the default Tier 2 car and truck emission standards contained in the Clean Air Act. Under this alternative, LDVs and LDT1s would be required to meet full useful life emission standards of 0.125 g/mi NMHC and 0.20 g/mi NOx, assumed for this analysis to follow the implementation schedule for Tier 2 standards contained in today's proposal. LDT2s would be subject to California's applicable LEV I standards in 2004, while LDT3s and LDT4s would remain at Tier 1 levels.

For Options 1 and 2, the effects of sulfur irreversibility were accounted for using the methodology described in detail in Appendix B. In short, all cars and trucks complying with the Supplemental Federal Test Procedure (SFTP) were assigned an irreversibility effect of 50

[e]The API/NPRA fuel proposal is discussed in detail in the Preamble, Section IV.C.1

percent, meaning that vehicles within the API NOx Control Region exposed to higher sulfur levels outside the region would experience a permanent degradation in emissions performance equivalent to the average of emissions generated on fuel in and outside of the API Region. It was assumed that at any given time 25 percent of cars and trucks in the API NOx Control Region fleet would have traveled outside of the region, and hence been exposed to higher sulfur fuel.[f]

47-state light-duty NOx emissions projected for these options are shown in Tables III-8, in comparison with today's proposal. Table III-9 provide a direct comparison to today's proposal in terms of shortfall (i.e., emission reductions "lost" by the three options compared to today's proposal) and total benefits relative to the Tier 2/Sulfur proposal.

Table III-8. 47-State Light-Duty NOx Reductions From Alternative Control Options (Annual Tons)[g]

Option:	*Today's Proposal*	*1*	*2*	*3*
Vehicle Program:	*Proposed Tier 2*	*Proposed Tier 2*	*Proposed Tier 2*	*Clean Air Act Default*
Fuel Program:	*Proposed Tier 2*	*API No 30 ppm*	*API 30 ppm API Region 2010*	*Proposed Tier 2*
2007	795,733	397,886	397,886	611,020
2010	1,182,323	750,100	1,020,812	740,258
2020	2,198,113	1,713,531	2,000,129	1,026,690

[f]The baseline emission inventory estimates presented here do not account for sulfur irreversibility effects in RFG areas. Although vehicles in these areas will likely experience irreversibility effects due to exposure to higher sulfur levels during winter months, the overall impact on baseline emissions are expected to be small because a) LDT2/3/4s are less sensitive to sulfur under NLEV than expected under the standards proposed in today's action, and b) vehicles operating on summertime RFG make up a relatively small portion (less than 15%) of annual VMT in the 47-state region. Accounting for this effect would serve to increase the estimated benefits of today's proposal.

[g]Although not shown, Options 1 and 2 will also increase emissions from heavy-duty gasoline vehicles relative to today's action due to higher sulfur levels.

Table III-9. NOx Reduction Shortfall From Alternative Control Options Relative to Today's Proposal

Option:	*1*		*2*		*3*	
Vehicle Program:	*Proposed Tier 2*		*Proposed Tier 2*		*Clean Air Act Default*	
Fuel Program:	*API No 30 ppm*		*API 30 ppm API Region 2010*		*Proposed Tier 2*	
Year	*Shortfall (Annual Tons)*	*Benefit Relative to Tier 2/Sulfur Proposal*	*Shortfall (Annual Tons)*	*Benefit Relative to Tier 2/Sulfur Proposal*	*Shortfall (Annual Tons)*	*Benefit Relative to Tier 2/Sulfur Proposal*
2007	397,848	50%	397,848	50%	184,713	77%
2010	432,223	63%	162,012	86%	442,066	63%
2020	484,582	78%	197,984	91%	1,171,423	47%

2. VOC

a. Light-Duty VOC Trends Without Tier 2/Sulfur

Total VOC emissions produced nationwide by cars and trucks without Tier 2/Sulfur control are shown in Table III-10 and Figure III-7, broken down by relative contribution of evaporative emissions (across all cars and trucks), and exhaust emissions for LDVs, LDT1/2s and LDT3/4s. We project VOC emissions from light-duty vehicles will decline from approximately 3.8 million tons to 2.0 million tons between 2000 and 2015 as the fleet becomes increasingly dominated by cars and trucks complying with NLEV, Enhanced Evaporative control and SFTP requirements. Beginning in 2016, however, light-duty VOC emissions are projected to begin an upward trend due to VMT and vehicle fleet growth, increasing to 2.1 million tons by 2020 and 2.5 million tons by 2030.

Table III-10. 47-State Light-Duty VOC Emissions Without Tier 2/Sulfur (Annual Tons)

Year	*Light-Duty Emissions*	*Contribution by Emission Source / Vehicle Class*			
		Evaporative (All LDV/LDT)	*Exhaust*		
			LDV	*LDT1/2*	*LDT3/4*
2000	3,771,569	44.3%	22.6%	20.1%	13.0%
2004	2,969,912	46.8%	18.3%	21.1%	13.7%
2007	2,503,855	50.4%	15.3%	20.4%	14.0%
2010	2,227,593	52.1%	12.6%	19.8%	15.5%
2015	2,080,284	54.1%	9.9%	18.2%	17.8%
2020	2,132,070	54.7%	9.1%	18.0%	18.2%
2030	2,475,783	54.8%	8.8%	18.1%	18.2%

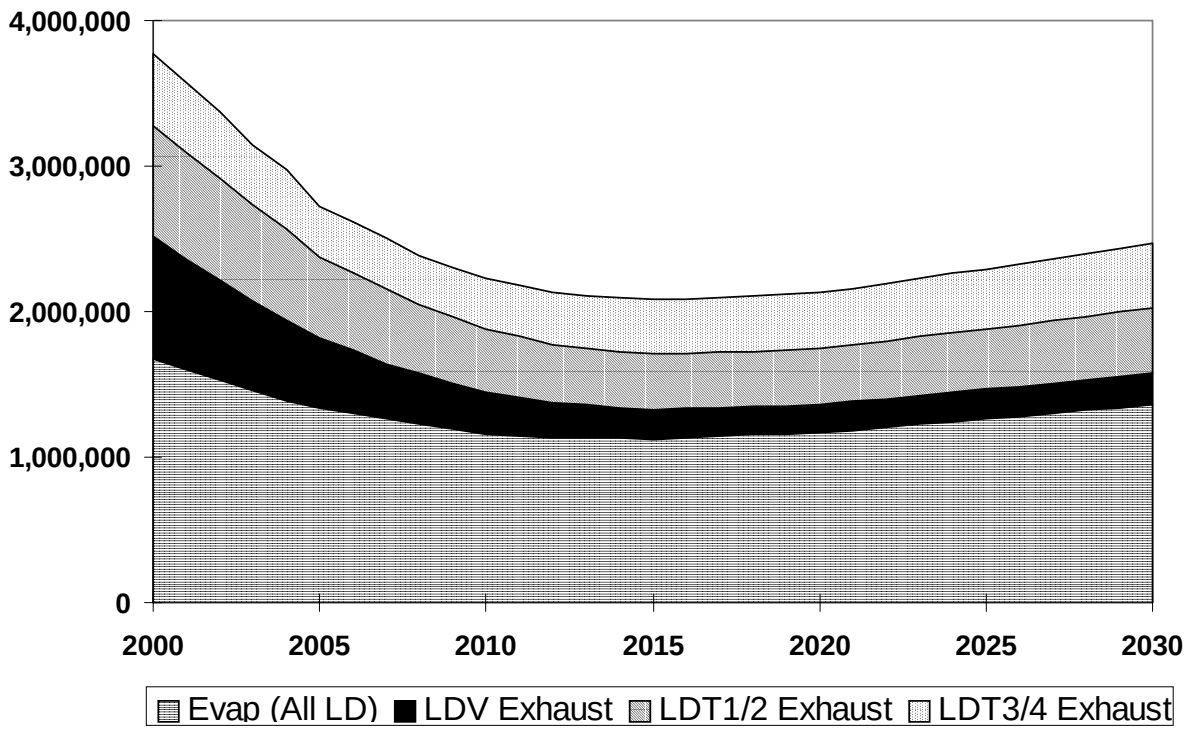

Figure III-7. 47-State Light-Duty VOC Emissions Without Tier 2/Sulfur (Annual Tons)

Although evaporative emissions are projected to grow to over half of the light-duty inventory, exhaust emissions from trucks play an increasingly significant role in shaping the overall VOC trend. In 2000, we project that trucks will produce approximately 60 percent of exhaust VOC emissions; by 2020, trucks account for 80 percent of these emissions, while overall emissions produced by trucks increase steadily. The benefits from Tier 1, NLEV and SFTP are not as pronounced for trucks relative to cars, and are offset almost immediately by growth in truck VMT. As a result, exhaust VOC emissions from trucks see only modest initial reductions due to these programs before being offset by VMT growth.

The emission trends for the four urban areas we analyzed show similar behavior to the national trends. As shown in Table III-11, light-duty emissions decrease steadily in each city through 2010. In all cities, the decline in emissions due to existing vehicle standards essentially ends by 2020, after which VOC emissions are projected to increase if today's proposal is not adopted.

Table III-11. Four-City Light-Duty VOC Emissions Without Tier 2/Sulfur (Summer Tons)

Year	*New York*	*Chicago*	*Atlanta*	*Charlotte*
2000	56,782	27,145	28,791	4,080
2004	40,063	19,768	22,166	3,245
2007	30,609	15,404	18,139	2,710
2010	25,732	13,151	15,869	2,412
2015	22,062	11,386	14,239	2,217
2020	21,124	11,061	14,195	2,254
2030	22,744	12,264	16,149	2,642

Figures III-8 and III-9 show our projections of the contribution of light-duty vehicles and trucks to the total anthropogenic (i.e., human-caused) 2020 VOC inventory in the 47 states and in Atlanta. Table III-12 shows this same contribution across the 47 states and all four cities from 2007 through 2030. Nationally, cars and trucks produce nearly one-fifth of total VOC emissions in 2007; this percentage declines subsequent years before stabilizing at 14 percent by 2015 and increasing after 2020. The light-duty contribution in New York, Chicago, and Charlotte are slightly lower than the national average, but significantly higher in Atlanta, where we project that one-fourth of all VOC emissions will be produced by cars and trucks in 2020.

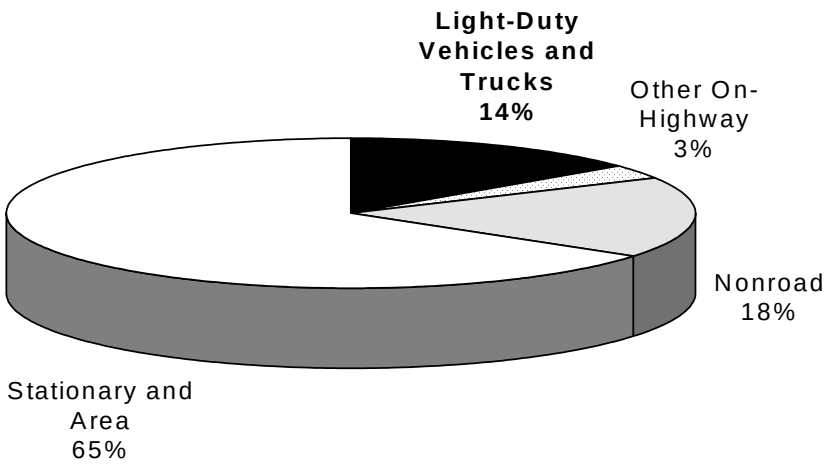

Figure III-8. Breakdown of Total 2020 47-State VOC Inventory Without Tier 2/Sulfur

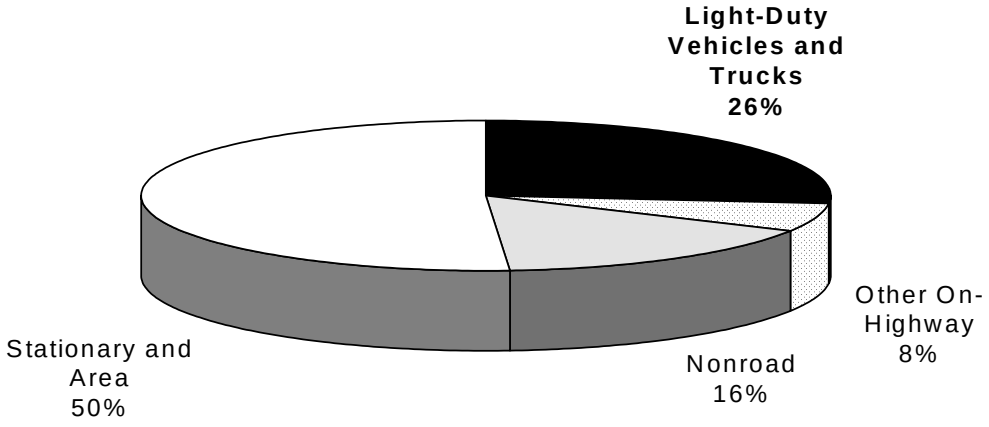

Figure III-9. Breakdown of Total 2020 Atlanta VOC Inventory Without Tier 2/Sulfur

Table III-12. Light-Duty Contribution to Total VOC Inventory Without Tier 2/Sulfur

Year	*47 State*	*New York*	*Chicago*	*Atlanta*	*Charlotte*
2007	18%	15%	12%	33%	15%
2010	16%	13%	11%	31%	14%
2015	14%	11%	10%	28%	12%
2020	14%	10%	9%	26%	12%
2030	15%	10%	9%	26%	12%

b. VOC Reductions Due To Tier 2/Sulfur

Table III-13 contains annual nationwide tons of VOC we project would be reduced due to today's proposal, encompassing the effects of low sulfur fuel and the introduction of Tier 2 light-duty vehicle and light-duty truck standards for both exhaust and evaporative emissions. Figure III-10 shows projected 47-state emissions with Tier 2/Sulfur control, broken down by light-duty evaporative emissions and exhaust emissions from LDVs, LDT1/2s and LDT3/4s.

Table III-13. 47-State Light-Duty VOC Reductions Due to Tier 2/Sulfur (Annual Tons)

Year	*Light-Duty Emissions Without Tier 2/Sulfur*	*Light-Duty Emissions With Tier 2/Sulfur*	*Emissions Reduced*	*Percent Reduction in Baseline Inventory*	
				Light-Duty	*All Sources**
2004	2,969,912	2,865,843	104,069	4%	-
2007	2,503,855	2,372,427	131,428	5%	1.0%
2010	2,227,593	2,050,465	177,128	8%	1.3%
2015	2,080,284	1,821,904	258,380	12%	1.8%
2020	2,132,070	1,800,394	331,676	16%	2.3%
2030	2,475,783	2,039,802	435,981	18%	2.7%

* Includes emission reductions from Heavy-Duty Gasoline Vehicles due to sulfur control

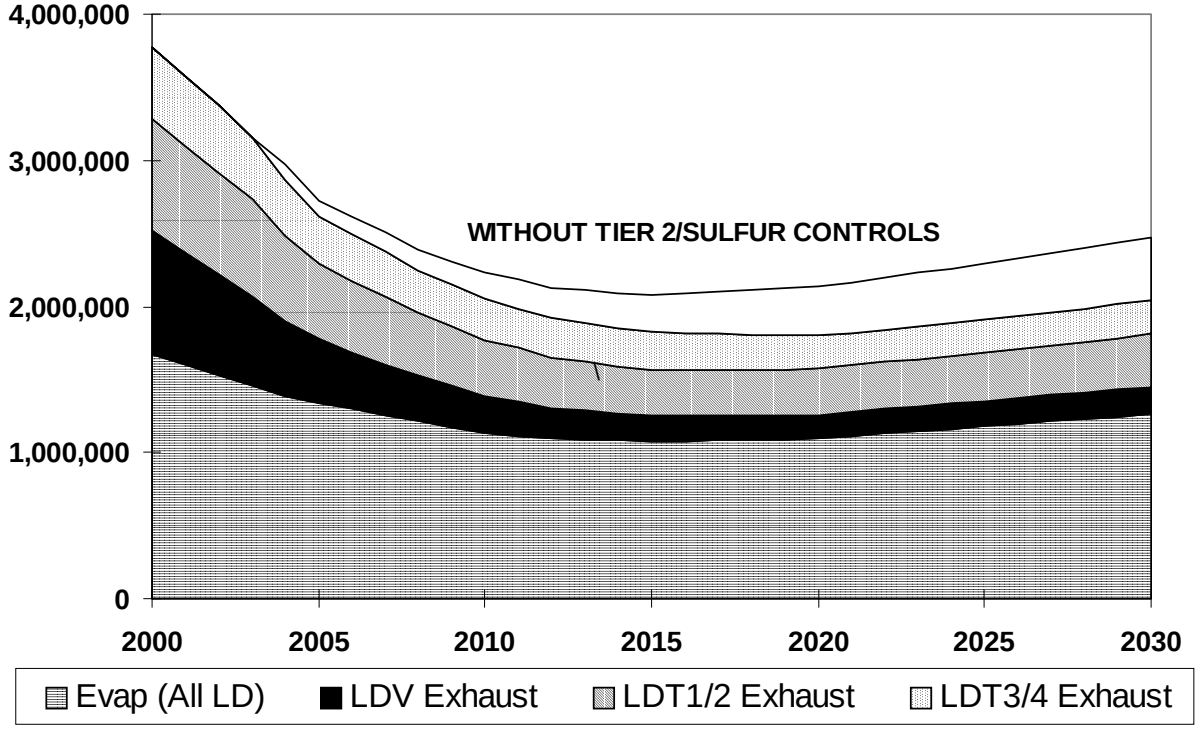

Figure III-10. 47-State Light-Duty VOC Emissions With Tier 2/Sulfur (Annual Tons)

We project that lower sulfur levels in 2004 would reduce light-duty emissions four percent, due almost entirely to reduced emission from Tier 0, Tier 1 and NLEV vehicles; this is the equivalent of emissions produced by 6.5 million pre-Tier 2 cars and trucks. After 2004, the introduction of LDT2s, LDT3s, and LDT4s complying with the Tier 2 NMOG standard and operating on low sulfur fuel reduce emission further. By 2020, baseline light-duty VOC emissions are reduced 16 percent due to Tier 2/Sulfur control, the equivalent of emissions from 38 million pre-Tier 2 cars and trucks. This represents a 2.3 percent reduction of the total anthropogenic VOC inventory. With Tier 2/Sulfur, we project that the upturn in light-duty VOC emissions will begin in 2021, five years later than the baseline case.

In addition to emission benefits on light-duty vehicles and trucks, we project that heavy-duty gasoline vehicles would decrease emissions by approximately 7,000 tons per year beginning in 2004, growing to 12,000 tons in 2030. These reductions are shown in Appendix A, and are included in the estimates of mobile source and all source percent reduction contained in Table III-13.

Tables III-14 and III-15 show VOC reductions in the four cities in both tonnage and percentage terms; the percentage reductions are expressed relative to light-duty emissions and total anthropogenic emissions if today's proposal were not adopted. VOC reductions would be larger in these areas in percentage terms than is the average throughout the 47 states. In 2020,

we project that 23 percent of light-duty VOC emissions would be reduced in these cities, versus 16 percent for the 47-state region. This difference is driven by the presence of I/M in each area and RFG in some of these areas. As modeled, vehicles with malfunctioning emission control systems do not realize the full benefit of the proposed Tier 2 vehicle standards. With I/M, it is assumed that a good portion of these vehicles are identified and repaired, thus increasing the relative benefit of the Tier 2/Sulfur program.[h] The reductions in total anthropogenic VOC inventory are generally consistent with the 47-state results, although in Atlanta the reductions are larger; by 2020, we project that 6.1 percent of Atlanta's total VOC emission would be reduced by today's action, versus 2.3 percent nationally.

Table III-14. Four-City Light-Duty VOC Reductions Due To Tier 2/Sulfur (Summer Tons)

Year	*New York*		*Chicago*		*Atlanta*		*Charlotte*	
	Reduced	*Remain*	*Reduced*	*Remain*	*Reduced*	*Remain*	*Reduced*	*Remain*
2004	1,282	38,781	611	19,157	1,110	21,056	163	3,083
2007	1,870	28,739	913	14,490	1,462	16,677	218	2,492
2010	2,675	23,057	1,333	11,818	1,860	14,009	283	2,130
2015	3,919	18,143	2,007	9,380	2,592	11,648	404	1,814
2020	4,919	16,205	2,568	8,493	3,240	10,955	515	1,740
2030	6,031	16,713	3,247	9,017	4,184	11,965	685	1,958

[h]The approach used for developing I/M benefits for Tier 2 vehicles is discussed in detail in the technical report "Development of Light-Duty Emission Inventory Estimates in the Notice of Proposed Rulemaking for Tier 2 and Sulfur Standards"

Table III-15. Percent Reduction From Light-Duty and Total Baseline VOC Emissions in Four Cities

Year	*New York*		*Chicago*		*Atlanta*		*Charlotte*	
	Light-Duty	*All Sources**	*Light-Duty*	*All Sources**	*Light-Duty*	*All Sources**	*Light-Duty*	*All Sources**
2004	3%	-	3%	-	5%	-	5%	-
2007	6%	0.9 %	6%	0.8%	8%	2.8%	8%	1.3%
2010	10%	1.4%	10%	1.1%	12%	3.7%	12%	1.7%
2015	18%	2.0%	18%	1.7%	18%	5.1%	18%	2.3%
2020	23%	2.4%	23%	2.1%	23%	6.1%	23%	2.8%
2030	27%	2.8%	26%	2.4%	26%	6.9%	26%	3.3%

* Includes emission reductions from Heavy-Duty Gasoline Vehicles due to sulfur control

Figures III-11 and III-12 show the contribution of light-duty cars and trucks to total 2020 VOC inventory in the 47 states and in Atlanta with Tier 2/Sulfur control. Table III-16 shows this same contribution across the 47 states and all four cities from 2007 through 2030. In 2020, the light-duty contribution would drop to 12 percent nationally, from 14 percent without Tier 2/Sulfur control. This trend would be similar across the four cities, depending on the level of light-duty contribution without Tier 2/Sulfur control. We project that with Tier 2/Sulfur control, car and truck emissions would contribute eight percent of total emissions in New York (down from 10 percent), seven percent in Chicago (down from nine percent), ten percent in Charlotte (down from 12 percent), and 22 percent in Atlanta (down from 26 percent).

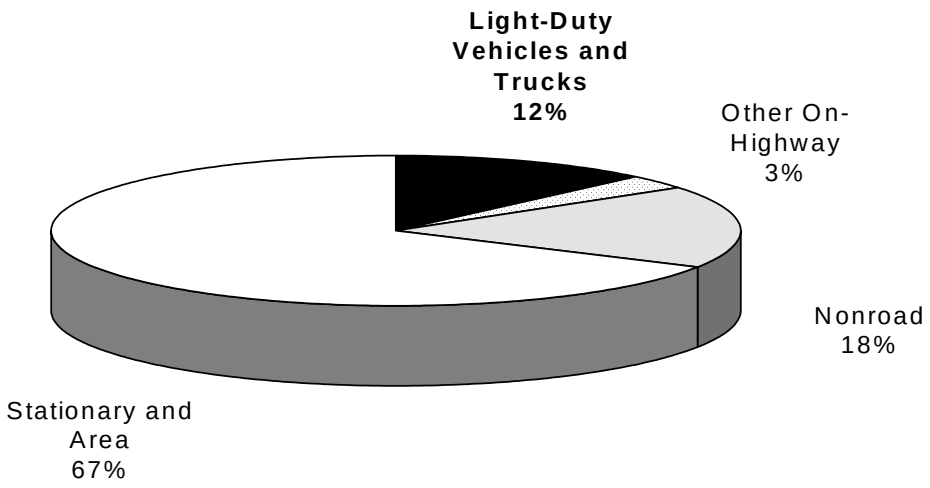

Figure III-11. Breakdown of Total 2020 47 State VOC Inventory With Tier 2/Sulfur

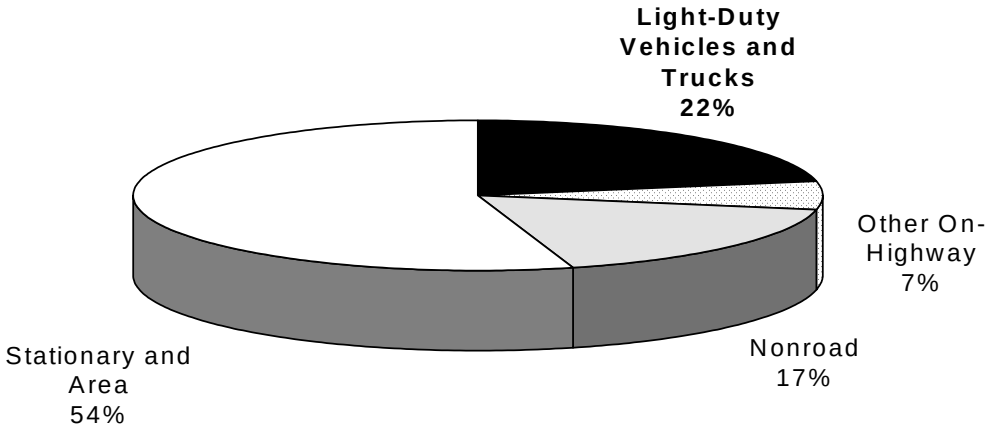

Figure III-12. Breakdown of Total 2020 Atlanta VOC Inventory With Tier 2/Sulfur

Table III-16. Light-Duty Contribution to Total VOC Inventory With Tier 2/Sulfur

Year	*47 State*	*New York*	*Chicago*	*Atlanta*	*Charlotte*
2007	17%	14%	12%	32%	14%
2010	15%	12%	10%	28%	12%
2015	13%	9%	8%	24%	10%
2020	12%	8%	7%	22%	10%
2030	13%	8%	7%	21%	10%

c. VOC Emission Reductions From Other Options

VOC reductions for the three alternative options discussed under Section III.A.1.c above are shown in Tables III-17 and III-18, in comparison to reductions projected from today's proposal. It it assumed for this analysis that the evaporative controls contained in today's action would be included in each option.

Table III-17. 47-State Light-Duty VOC Reductions From Alternative Control Options (Annual Tons)

Option:	*Today's Proposal*	*1*	*2*	*3*
Vehicle Program:	*Proposed Tier 2*	*Proposed Tier 2*	*Proposed Tier 2*	*Clean Air Act Default*
Fuel Program:	*Proposed Tier 2*	*API No 30 ppm*	*API 30 ppm API Region 2010*	*Proposed Tier 2*
2007	131,428	74,331	74,331	101,706
2010	177,128	118,809	155,750	107,955
2020	331,676	264,220	305,361	131,552

Table III-18. VOC Reduction Shortfall From Alternative Control Options Relative to Today's Action

Scenario:	*1*		*2*		*3*	
Vehicle Program:	*Proposed Tier 2*		*Proposed Tier 2*		*Clean Air Act Default*	
Fuel Program:	*API No 30 ppm*		*API 30 ppm API Region 2010*		*Proposed Tier 2*	
Year	*Shortfall (Annual Tons)*	*Benefit Relative to Tier 2/Sulfur Proposal*	*Shortfall (Annual Tons)*	*Benefit Relative to Tier 2/Sulfur Proposal*	*Shortfall (Annual Tons)*	*Benefit Relative to Tier 2/Sulfur Proposal*
2007	57,097	57%	57,097	57%	29,722	77%
2010	58,319	67%	21,378	88%	69,173	61%
2020	67,456	80%	26,315	92%	200,123	40%

3. SOx

a. Light-Duty SOx Trends Without Sulfur Control

Gaseous SOx emissions are formed by the combustion of fuel sulfur, and hence depend entirely on the level of sulfur in the fuel. SOx emissions without sulfur control are shown in Table III-19 and Figure III-13, broken down by LDV, LDT1/2 and LDT3/4. As shown, we project that SOx emission levels will increase unabated through 2030 in conjunction with VMT growth in the absence of any action to reduce fuel sulfur levels. In 2000, we project light-duty vehicles and trucks will emit 194,000 tons of SOx; by 2020, this level is projected to be nearly 300,000 tons, an increase of 55 percent.

Table III-19. 47-State SOx Emissions Without Sulfur Control (Annual Tons)

Year	*Emissions From All Sources*	*Light-Duty Emissions*	*Light-Duty Contribution to All Sources*	*Contribution by Vehicle Class*		
				LDV	*LDT1/2*	*LDT3/4*
2000	-	193,467	-	48%	39%	13%
2004	-	211,072	-	41%	44%	15%
2005	18,045,277	215,659	1.2%	40%	45%	15%
2010	18,350,974	240,694	1.3%	33%	50%	17%
2015	18,773,428	270,174	1.4%	29%	53%	18%
2020	19,161,564	299,959	1.6%	28%	54%	18%
2030	20,099,769	357,611	1.8%	27%	55%	18%

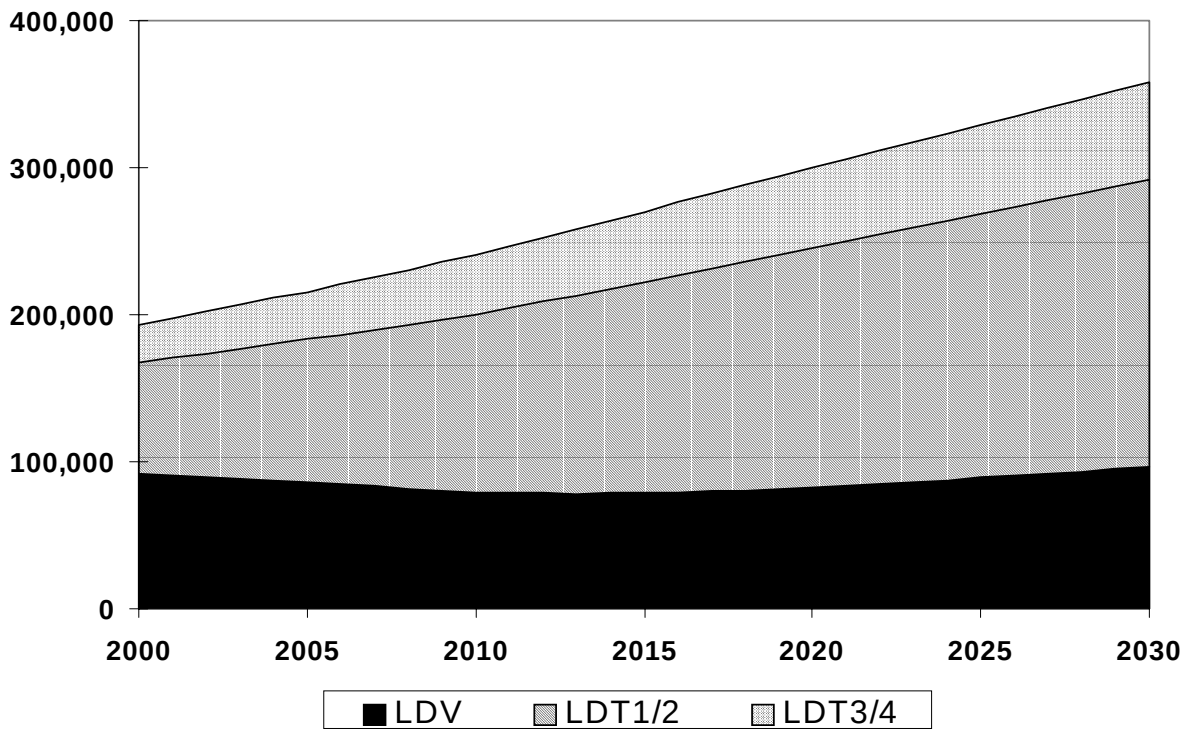

Figure III-13. 47-State Light-Duty SOx Emissions Without Sulfur Control (Annual Tons)

Trucks, primarily LDT1s and LDT2s, are responsible for the steady increase in light-duty SOx emissions. While LDV SOx emissions are relatively stable, SOx emissions from trucks (and hence the contribution to light-duty inventory produced by trucks) are projected to increase

steadily. In 2000, trucks account for roughly half of light-duty SOx emissions, growing to over 70 percent by 2020.

b. SOx Reductions Due To Sulfur Control

We project that today's proposal would immediately and substantially reduce SOx emissions from cars and trucks once its fuel sulfur provisions take effect. Table III-20 contains annual nationwide tons of gaseous SOx we project will be reduced from light-duty vehicles and trucks due to sulfur control. Figure III-14 shows SOx emissions after sulfur control, broken down by LDV, LDT1/2 and LDT3/4.

Table III-20. 47-State Light-Duty SOx Reductions Due To Sulfur Control (Annual Tons)

Year	*Light-Duty Emissions Without Sulfur Control*	*Light-Duty Emissions With Sulfur Control*	*Emissions Reduced*	*Percent Reduction in Baseline Inventory*	
				Light-Duty	*All Sources**
2004	211,072	21,426	189,646	90%	-
2005	215,659	21,899	193,760	90%	1.3%
2010	240,694	24,257	216,437	90%	1.4%
2015	270,174	27,210	242,964	90%	1.5%
2020	299,959	30,203	269,756	90%	1.6%
2030	357,611	36,002	321,609	90%	1.8%

* Includes reductions from Heavy-Duty Gasoline Vehicles, Motorcycles and Nonroad Sources

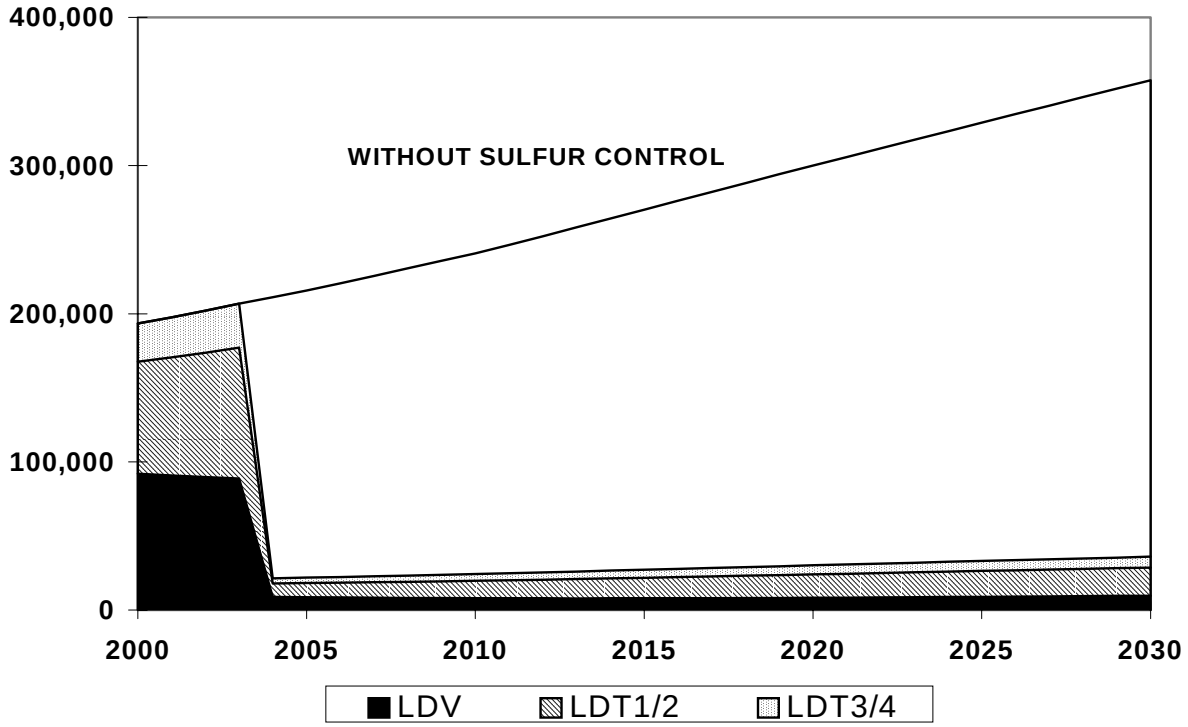

Figure III-14. 47-State Light-Duty SOx Emissions With Tier 2/Sulfur (Annual Tons)

As shown, a 90 percent reduction in light-duty SOx emissions would be realized beginning in 2004. This relative reduction remains constant beyond 2004, since SOx emissions are not reduced further as new Tier 2 VOC, NOx, and PM standards are phased in. The absolute level of emission reductions would become larger with time, however, due to VMT growth.

SOx emission reductions will also occur from heavy-duty gasoline vehicles and motorcycles due to sulfur control; we estimate this reduction to be approximately 10,000 tons in 2005, growing to 14,000 tons by 2020. In addition, emissions from all gasoline-powered nonroad equipment would be reduced due to sulfur control. Based on our NONROAD model, we estimate this benefit would be approximately 25,000 tons per year on average between 2005 and 2020. These reductions, shown in Appendix A, are included in the percent reductions from all sources in Table III-20.

4. Particulate Matter

Trends in particulate matter emissions will depend very strongly on the prevalence of diesel vehicles in the light-duty fleet. Currently, diesels make up a very small portion (less than one percent) of overall car and truck sales. However, sharp increases in diesel sales are a reasonable possibility given the focus on diesel technology for improving fuel economy under

the Partnership for a New Generation of Vehicles (PNGV). Thus, we assessed PM emissions under two sales scenarios: a "no growth" scenario, for which current diesel sales trends were assumed to continue, and an "increased growth" scenario, for which diesels grow to 50 percent of light-duty truck sales by 2010. The effects of Tier 2/Sulfur control were assessed for both scenarios. The results presented here are for direct exhaust PM, comprising carbonaceous PM and sulfate emitted directly from the tailpipe and a subset of Total PM (which also includes direct non-exhaust PM from tire and brake wear, and indirect PM caused by secondary reactions to emitted NOx and SOx in the atmosphere). Direct $PM_{2.5}$ and PM_{10} emissions are presented separately for the "no growth" scenario.

a. "No Growth" Diesel Sales Scenario

i. Light-Duty Direct Exhaust $PM_{2.5}$ Trends Without Tier 2/Sulfur

In general, gasoline vehicles emit PM at rates much lower than their diesel counterparts. Under the no growth scenario, direct PM emissions are driven largely by sulfate emissions from gasoline vehicles, which depend primarily on gasoline fuel sulfur level. Without Tier 2/Sulfur control, these emissions increase at a steady rate in conjunction with VMT, as shown in Tables III-21 and Figure III-15. In 2005, we project that approximately 35,000 tons will be emitted annually by light-duty cars and trucks. This level is projected to exceed 47,000 tons in 2020 and 56,000 tons in 2030.

Table III-21. 47 State Light-Duty Direct Exhaust $PM_{2.5}$ Emissions Without Tier 2/Sulfur No Growth in Diesel Sales (Annual Tons)

Year	*Emissions From All Sources**	*Light-Duty Exhaust Emissions*	*Light-Duty Contribution to All Sources*	*Contribution by Fuel Type / Vehicle Class*			
				Diesel LDV/LDT	*Gas LDV*	*Gas LDT1/2*	*Gas LDT3/4*
2000	-	34,072	-	5%	45%	34%	17%
2004	-	34,612	-	3%	42%	41%	14%
2005	2,071,897	35,051	1.7%	3%	40%	42%	15%
2010	2,108,058	38,409	1.8%	2%	34%	48%	16%
2015	2,217,074	42,724	1.9%	2%	30%	51%	17%
2020	2,318,805	47,397	2.0%	2%	28%	53%	17%
2030	2,544,434	56,505	2.2%	2%	28%	53%	17%

* Excludes natural and miscellaneous sources (e.g., fugitive dust), but includes indirect sources such as tire and brake wear.

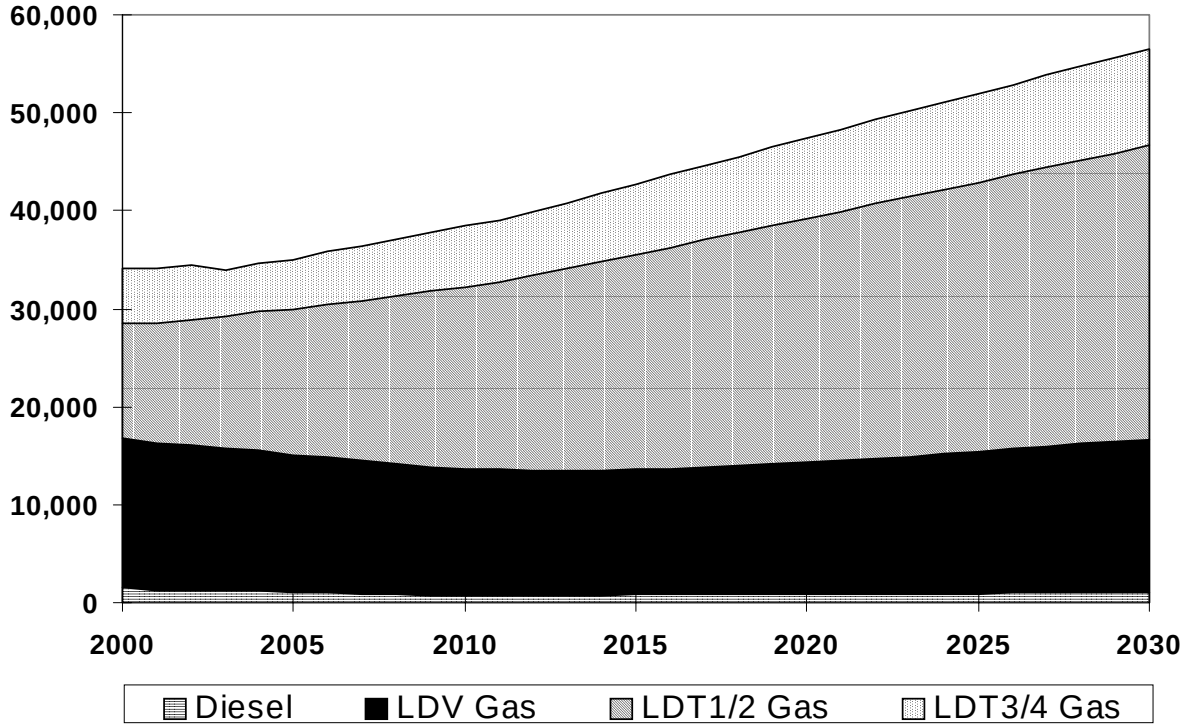

Figure III-15. 47-State Light-Duty Direct Exhaust $PM_{2.5}$ Emissions Without Tier 2/Sulfur -No Diesel Growth (Annual Tons)

As expected, the diesel contribution to overall emissions in the no growth scenario is relatively small. Rather, gasoline trucks (primarily LDT1s and LDT2s) are responsible for the steady increase in PM emissions. Under this scenario, we project the contribution of gasoline trucks to light-duty $PM_{2.5}$ inventory to grow to 70 percent by 2020.

ii. Direct Exhaust $PM_{2.5}$ Reductions Due To Tier 2/Sulfur Control

Under the no growth scenario, today's proposal would provide an immediate and substantive reduction in direct PM emissions from cars and trucks, due primary to sulfur control. Table III-22 contains annual nationwide tons of direct exhaust $PM_{2.5}$ we project would be reduced from light-duty vehicles and trucks due to Tier 2/Sulfur control. Figure III-16 shows $PM_{2.5}$ emissions after Tier 2/Sulfur control broken down by diesel (all light-duty cars and trucks) and gasoline LDV, LDT1/2 and LDT3/4.

Table III-22. 47-State Light-Duty Direct Exhaust $PM_{2.5}$ Reductions Due To Tier 2/Sulfur No Growth in Diesel Sales (Annual Tons)

Year	*Light-Duty Emissions Without Tier 2/Sulfur*	*Light-Duty Emissions With Tier 2/Sulfur*	*Emissions Reduced*	*Percent Reduction in Baseline Inventory*	
				Light-Duty	*All Sources**
2004	34,612	14,703	19,909	58%	-
2005	35,051	14,509	20,542	59%	1.0%
2010	38,409	14,999	23,410	61%	1.1%
2015	42,724	16,129	26,595	62%	1.2%
2020	47,397	17,690	29,707	63%	1.3%
2030	56,505	20,956	35,549	63%	1.4%

* Includes emission reductions from Heavy-Duty Gasoline Vehicles due to sulfur control

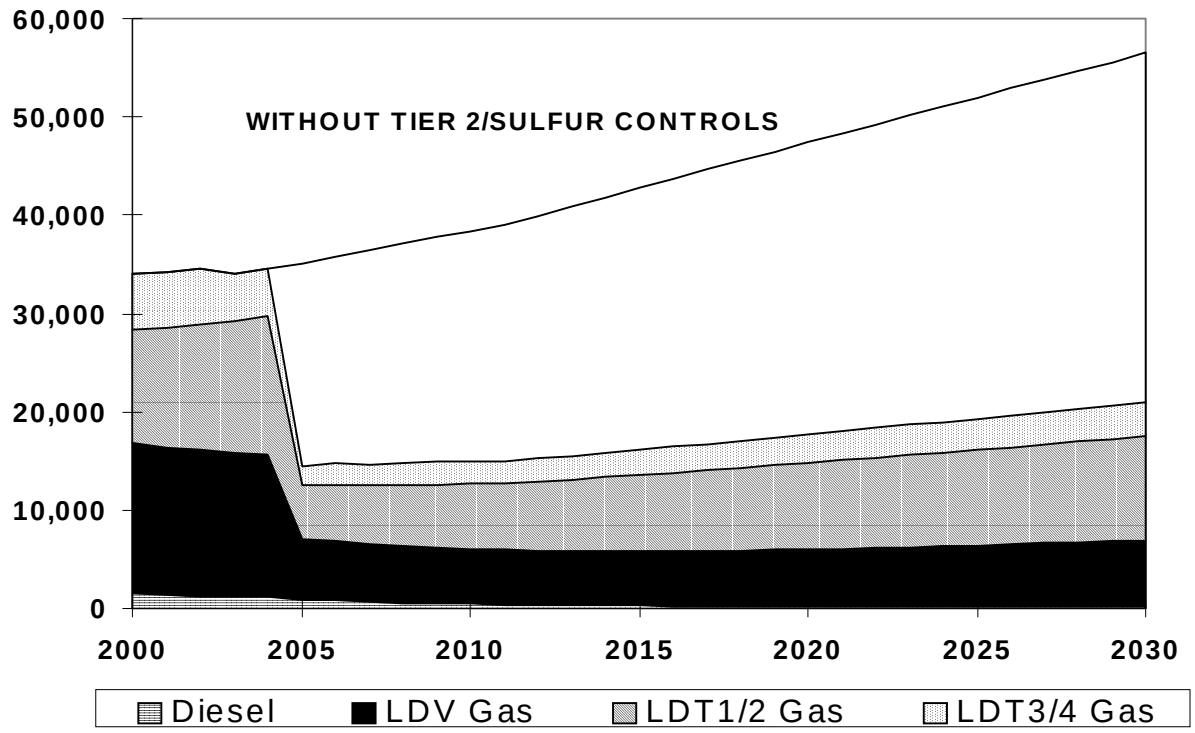

Figure III-16. 47-State Light-Duty Direct Exhaust $PM_{2.5}$ Emissions With Tier 2/Sulfur - No Diesel Growth (Annual Tons)

Reductions from gasoline vehicles would result almost entirely from sulfur control, rather than the proposed $PM_{2.5}$ exhaust standards. $PM_{2.5}$ emissions on current technology gasoline vehicles are much lower than diesel vehicles, and gasoline vehicle emissions are not expected to be reduced in response to the $PM_{2.5}$ standards contained in today's proposal. As such, we project that an immediate emission reduction of 58 percent from baseline levels would be realized due to sulfur control, increasing to 63 percent by 2020.

In addition to light-duty PM benefits, sulfur control would reduce $PM_{2.5}$ emissions from heavy-duty gasoline vehicles. We estimate these benefits would be approximately 700 tons per year beginning in 2004, increasing to 1,000 tons by 2020. Across all sources, we project Tier 2/Sulfur control would reduce direct $PM_{2.5}$ from all non-natural sources by about one percent.

iii. Direct Exhaust PM_{10} Reductions Due To Tier 2/Sulfur Control

Direct exhaust PM_{10} emissions exhibit similar trends to $PM_{2.5}$, and are thus shown here only for the no growth diesel case; PM_{10} emissions with and without Tier 2/Sulfur control are shown in Table III-23.

Table III-23. 47-State Light-Duty PM_{10} Emissions With and Without Tier 2/Sulfur Control No Growth in Diesel Sales (Annual Tons)

Year	*Emissions From All Sources Without Tier 2/Sulfur***	*Light-Duty Exhaust Emissions Without Tier 2/Sulfur*	*Light-Duty Contribution to All Sources*	*Light-Duty Exhaust Emissions With Tier 2/Sulfur*	*Emissions Reduced*	*Percent Reduction in Baseline Inventory*	
						Light-Duty	*All Sources**
2004	-	37,323	-	15,861	21,462	58%	-
2005	2,985,623	37,794	1.3%	15,649	22,145	59%	0.8%
2010	3,060,154	41,412	1.4%	16,173	25,239	61%	0.9%
2015	3,207,687	46,064	1.4%	17,390	28,674	62%	0.9%
2020	3,345,810	51,102	1.5%	19,071	32,031	63%	1.0%
2030	3,659,928	60,922	1.7%	22,591	38,331	63%	1.1%

* Includes emission reductions from Heavy-Duty Gasoline Vehicles due to sulfur control
** Excludes natural and miscellaneous sources (e.g., fugitive dust), but includes indirect sources such as tire and brake wear.

b. "Increased Growth" Sales Scenario

The "increased growth" scenario was developed with the intent of analyzing an upper

bound for diesel growth. We developed this scenario by assuming that the percent of diesels making up total light-duty truck sales increase to five percent in 2001, adding five percentage points per subsequent year until diesels represent 50 percent of light-duty truck sales in 2010; beyond 2010, the diesel engine share of the light truck market was assumed to stay at 50 percent. Within the period of diesel sales growth, we assumed that light duty truck classes were "converted" to diesels in a sequential manner starting with the heaviest trucks; i.e., LDT4s became diesels first, then LDT3s, etc. This methodology resulted in the diesel sales penetrations shown in Table III-24.

Table III-24. Diesel LDT Sales Penetration Under Increased Growth Scenario

Model Year	*Diesel Sales Penetration*			
	All LDT	*LDT2*	*LDT3*	*LDT4*
2001	5%	0%	0%	63%
2002	10%	0%	12%	100%
2003	15%	0%	41%	100%
2004	20%	0%	71%	100%
2005	25%	0%	100%	100%
2006	30%	9%	100%	100%
2007	35%	18%	100%	100%
2008	40%	26%	100%	100%
2009	45%	35%	100%	100%
2010 and later	50%	44%	100%	100%

i. Light-Duty Direct Exhaust $PM_{2.5}$ Trends Without Tier 2/Sulfur

Our projections for light-duty direct exhaust $PM_{2.5}$ under the increased diesel sales scenario are down in Table III-25 and Figure III-17. As expected, this scenario is projected to result in dramatic increases in light-duty $PM_{2.5}$ emissions. 2005 baseline emissions are approximately 43,000 tons, 23 percent higher than the 35,000 tons projected in the no growth diesel case from Table III-21. However, by 2020, we project this scenario would result in direct PM emissions of 138,000 tons, nearly three times the emissions projected for the no growth scenario in the same year.

Table III-25. 47 State Light-Duty Direct Exhaust $PM_{2.5}$ Emissions Without Tier 2/Sulfur Increased Diesel Growth Scenario (Annual Tons)

Year	*Light-Duty Emissions Without Tier 2/Sulfur*	*Contribution by Fuel Type*	
		Diesel LDV/LDT	*Gasoline LDV/LDT*
2000	34,072	5%	95%
2004	39,932	19%	81%
2005	43,439	25%	75%
2010	72,626	56%	44%
2015	109,622	72%	28%
2020	138,177	77%	23%
2030	175,068	80%	20%

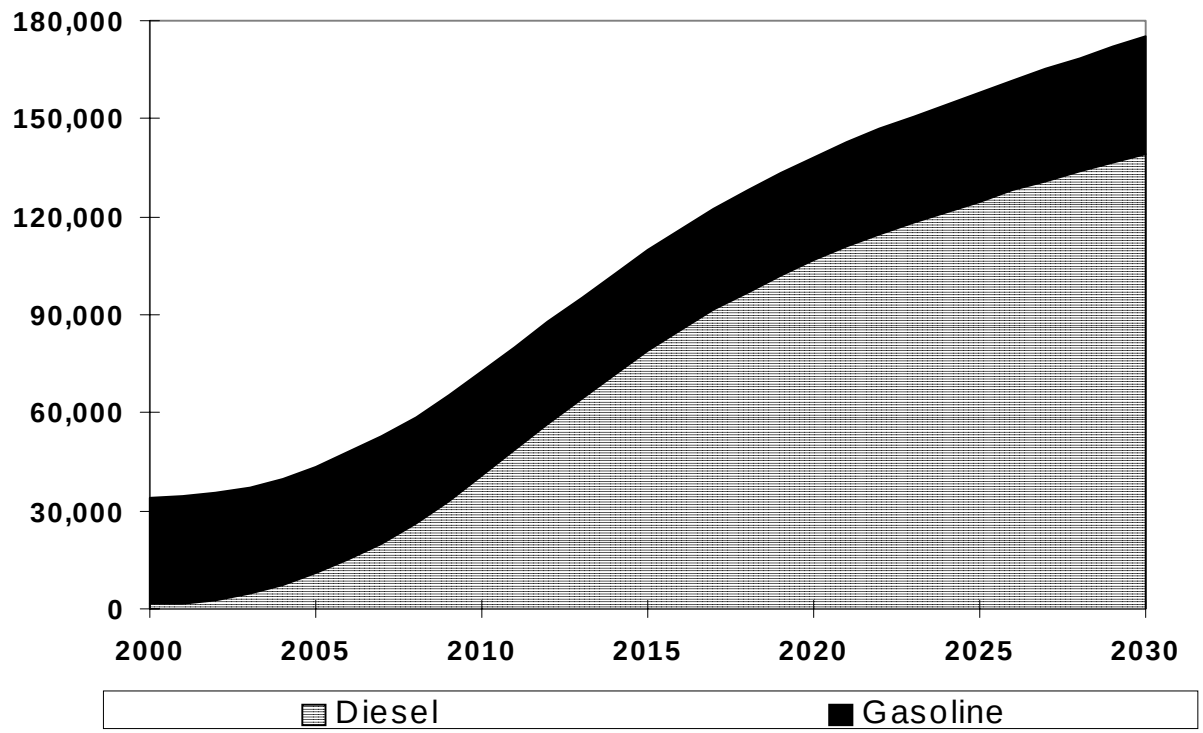

Figure III-17. 47-State Light-Duty Direct Exhaust $PM_{2.5}$ Without Tier 2/Sulfur - Increased Diesel Sales (Annual Tons)

As shown, the rapid growth of diesels in conjunction with high per-vehicle PM emissions from diesels drive overall direct PM emissions under this scenario. In 2005, we project diesels would already account for 25 percent of all light-duty emissions. Diesel contribution grows to over 50 percent by 2010 and over 75 percent by 2020.

ii. Direct Exhaust $PM_{2.5}$ Reductions Due To Tier 2/Sulfur

Tier 2/Sulfur control would effectively neutralize excess PM emissions generated under our increased diesel penetration scenario. Table III-26 contains reductions in direct exhaust $PM_{2.5}$ emissions due to Tier 2/Sulfur standards for the increased diesel sales penetration case. Figure III-18 shows these emissions with Tier 2/Sulfur control, broken down by diesel and gasoline.

Table III-26. 47-State Light-Duty Direct Exhaust $PM_{2.5}$ Reductions Due To Tier 2/Sulfur Increased Diesel Growth Scenario (Annual Tons)

Year	*Light-Duty Emissions Without Tier 2/Sulfur*	*Light-Duty Emissions With Tier 2/Sulfur*	*Emissions Reduced*	*Percent Reduction in Baseline Inventory*	
				Light-Duty	*All Sources**
2004	39,932	19,700	20,232	51%	-
2005	43,439	20,696	22,743	52%	1.1%
2010	72,626	22,542	50,084	69%	2.4%
2015	109,622	23,275	86,347	79%	3.8%
2020	138,177	24,754	113,423	82%	4.7%
2030	175,068	28,393	146,675	84%	5.6%

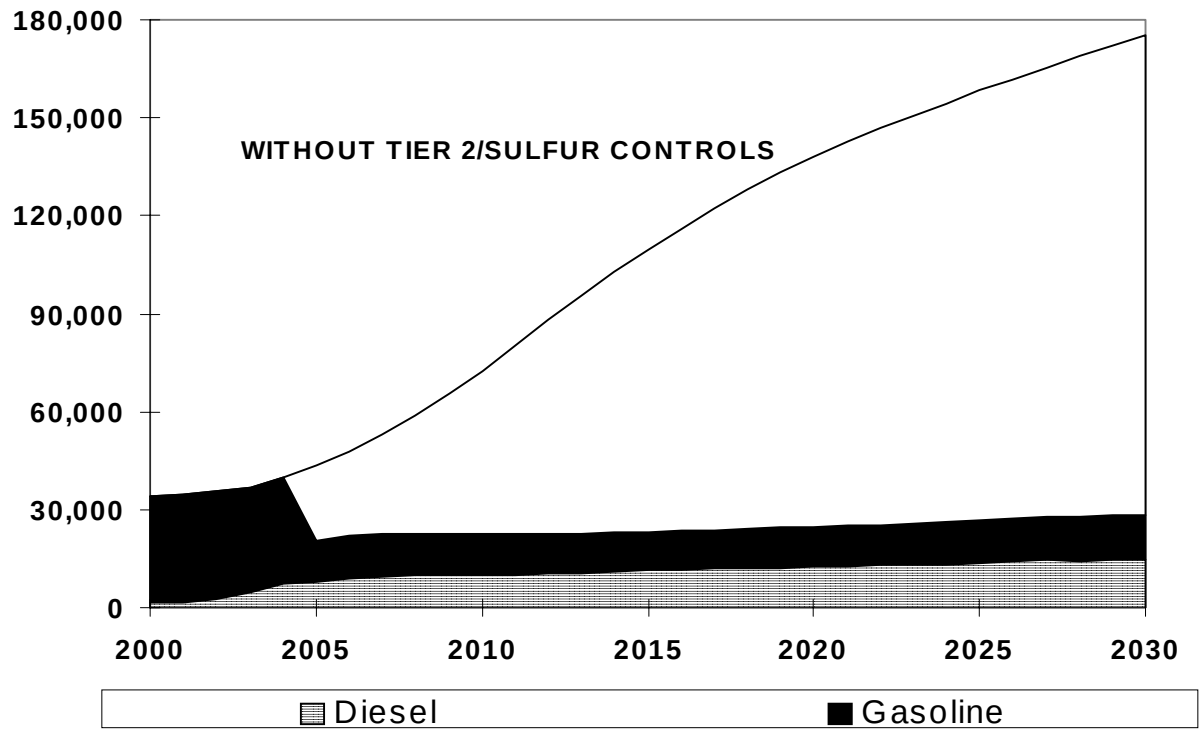

Figure III-18. 47-State Light-Duty Direct Exhaust $PM_{2.5}$ Emissions With Tier 2/Sulfur Increased Diesel Growth (Annual Tons)

In 2005, the fleet would still be comprised primarily of gasoline vehicles under this scenario; thus, significant benefits from gasoline sulfur control would be realized immediately, as with the no growth case. The rapid growth of diesel market penetration in conjunction with implementation of the proposed Tier 2 PM standards would result in a diesel fleet comprised almost exclusively of vehicles compliant with Tier 2. Thus, a large share of the baseline inventory would be reduced very soon after implementation of the Tier 2/Sulfur standards. In 2010, nearly 70 percent of baseline light-duty exhaust $PM_{2.5}$ inventory is reduced; by 2020, we project 82 percent of baseline emissions would be reduced. Today's proposal would serve to mitigate the large increases in direct PM emissions which would occur without control due to increased growth in diesel penetration, effectively stabilizing these emissions through at least 2030.

B. Air Quality Measures

This section describes the analyses performed to evaluate the impact of the Tier 2/Sulfur proposal on ozone and visibility levels, as discussed in Section III of the preamble. These analyses were performed using different emission inventories, control assumptions, ozone and visibility models, and analysis years than the air quality modeling we conducted for the benefit/cost analysis described in Chapter VII. As a result, the ozone and visibility modeling results presented in Section III of the preamble and described more fully in this section are not

directly comparable to the ozone and visibility modeling results used for the benefit/cost analysis.

This section does not discuss the impact of the Tier 2/Sulfur proposal on PM levels, since the PM air quality modeling we performed was conducted for the benefit/cost analysis described in Chapter VII. This section also does not discuss the impact of the Tier 2/Sulfur proposal on CO levels since we have not quantified the proposal's impact on CO emission levels at this time.

1. Ozone

Current air quality with respect to ozone can be expressed in terms of formal designation of attainment or nonattainment of the 1-hour standard (there is as yet no such designation for the 8-hour standard) and in terms of measured ambient design values (defined below) for both the 1-hour and 8-hour standards. Estimates of the ozone impact of today's proposal and the expected future ozone concentrations after its implementation can be obtained by modeling a base case (before control measures) and a control case (after control measures). The outputs of these and other model runs are used in combination with measured design values to project future design values. Other metrics described in this section are also used to compare one model run to another. The structure of this section is as follows:

- Subsection B.1.a. presents the data supporting the discussion in the preamble of current nonattainment status, including an explanation of design values.
- Subsection B.1.b. describes in general terms the ozone modeling that we used to estimate the effects of Tier 2/Sulfur controls and the way we used that modeling to estimate the resulting design values.
- Subsection B.1.c. explains the "rollback method," used to estimate future design values based on measured historical ozone levels and ozone modeling results.
- Subsection B.1.d. describes the ozone modeling simulations used to evaluate the impact of Tier 2/Sulfur controls on future ozone levels.
- Subsection B.1.e. presents the results of two ozone simulations that were used to explore the relative effects of NO_X and VOC controls on ozone levels.
- Subsection B.1.f. describes two ozone simulations that were used to estimate the effects of today's proposal on ozone levels.

a. Measures of Current Attainment and Non-attainment

Measures of attainment and non-attainment consist of both the formal attainment and nonattainment designations and the most recent set of ambient design values, which are based on measurements from 1995 to 1997. Formal attainment/nonattainment status applies only to the 1-hour standard, since such designations have not yet been made for the 8-hour standard.

Outside of California, the 1990 census showed 72 million people living in areas that were formally designated as non-attainment for the 1-hour standard as of August 10, 1998. The

individual areas, their populations, and their nonattainment classifications are listed in Table C-1 in Appendix C.

Design values

An ozone design value is the concentration or average of concentrations that determines whether a monitoring site meets the NAAQS for ozone. Because of the way they are defined, design values can only be determined for three-year monitoring periods. We estimate the design values, and therefore the attainment effects, resulting from control programs by using a combination of modeling results and measured design values. Air quality model runs for a base year and a future year are used to determine the relative change in ozone levels produced by the controls that would be implemented between the base and future years. This relative change is used to adjust the measured historical design values in the region being analyzed, as described in detail below.[i]

A 1-hour design value is the fourth highest daily maximum 1-hour average ozone concentration measured over a three-year period at a given monitor. An 8-hour design value is the three-year average of the annual fourth highest daily maximum 8-hour average ozone concentration 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. As discussed in these appendices, design values are truncated to whole ppb. Due to the precision with which the standards are expressed (0.12 ppm for the 1-hour, 0.08 ppm for the 8-hour), nonattainment of the 1-hour standard is defined as a design value greater than or equal to 125 ppb and nonattainment of the 8-hour standard is defined as a design value greater than or equal to 85 ppb.

For the 1-hour standard, the design value for a county is the highest design value of the monitors within that county. Typically, there is one or zero monitors per county. If a county does not contain an ozone monitor, it cannot have a design value. For most of our analyses, county design values are consolidated where possible into design values for metropolitan areas. The design value for a metropolitan area is the highest design value among the included counties. Counties that are not in metropolitan areas are listed separately. For the purposes of the analyses described in this section, we have assumed that the definition of county and metropolitan area design values for the 8-hour standard will be the same as for the 1-hour standard. It should be noted, however, that we have not yet determined how county and metropolitan area design values will be defined for the 8-hour standard.

To simulate the air quality effects of today's proposal, design values are estimated or projected from measured 1995-1997 county design values by the method described in Subsection

[i] The procedure described in this paragraph can also be used to isolate the effects of a particular control program on design values. To do so, one needs to apply the procedure twice: once for a future year without applying the control program of interest, and once for a future year with the control program of interest applied. The impact of the control program on ozone design values is given by the difference between the design values calculated for the two different cases.

B.1.c. Projected design values are determined only for counties that have measured design values. The measured 1995-1997 design values that exceeded the 1-hour standard in metropolitan areas and rural counties in the 37 states that participated in OTAG are shown in Table C-2 in Appendix C. Similar measured design values for the 8-hour standard are shown in Table C-3.

b. General Description of Ozone Modeling in the OTAG Domain to Estimate the Effect of Tier 2/Sulfur Controls

We used the considerable development work done for the ROTR as a foundation to estimate the impact of the proposed Tier 2/Sulfur controls on ozone levels in the OTAG domain. A method for estimating the design values that result from a given control scenario was also developed for the ROTR and has been extended to estimate the effects of Tier 2/Sulfur controls. Further details of the modeling work are presented below and in a technical memorandum to Docket A-97-10, "Photochemical Air Quality Simulations in Support of Tier 2/Sulfur," by Harvey Michaels.

The basic method of using modeling

The modeling methodology requires running two simulations, a base case (without Tier 2/Sulfur controls) and a control case (with Tier 2/Sulfur controls). The effects of the control program are then evaluated by comparing the modeling results of the control case with those of the base case. The base case for our Tier 2/Sulfur ozone analysis is the 2007 post-ROTR scenario. We used two versions of this base case; the first was published with the ROTR's Supplemental Notice of Proposed Rulemaking (SNPR) and used the SNPR emission inventories, while the second used the ROTR Final Inventory (September 1998), which was updated based on public comments. Table III-27 indicates which of our Tier 2/Sulfur simulations correspond to which base case.

Emissions inventories and meteorology were developed for four historical ozone episodes, each about 10 days long, from 1988, 1991, 1993, and 1995. When the photochemical grid model was judged to satisfactorily reproduce the historical episodes, the meteorology was retained and emission inventories for the base and control cases were substituted for the historical emission inventories. The base and control cases were then run for all four episodes.

The model output is hourly average ozone concentrations in all grid cells of the modeling domain for all hours of the simulation. A large number of different metrics have been developed to compare the ozone concentrations in the base case with those in the control case. One of the most useful of these, because of its relationship to measured design values used to determine attainment and nonattainment, is projected design values. Design values were projected using

the modeling results from three episodes: 1991, 1993, and 1995.[j] The calculation of projected design values is described in the next section.

To facilitate the ozone modeling, the emission reduction due to Tier 2/Sulfur controls was expressed as a percentage reduction from the 2007 post-ROTR emission inventory for all highway mobile sources. The procedure used to do this is described in a technical memo to Docket No. A-97-10 ("Methodology for Developing Inventory Reductions Used in Ozone Modeling," by John Koupal). These percentage reductions were applied everywhere in the modeling domain to all on-highway emissions in the base case. The proposed Tier 2/Sulfur program would achieve almost all of its emission reductions from cars and light trucks, but converting these reductions to a percentage of all on-highway emissions greatly streamlined the process of modeling the proposed Tier 2/Sulfur controls.

The standard ozone metrics applied to the modeling results are relatively simple and self-explanatory. For example, "Grid Cell Days Above the Standard" is a count of all the grid cells on all simulation days (except for 2 or 3 startup days in each episode) that the daily maximum ozone concentration (either 1- or 8-hour average, depending on the specific metric) exceeded the standard. The "rollback method" of projecting design values is considerably more complicated, because it uses both measured design values and simulations. This method is described below.

c. The "Rollback Method" for Estimating Design Values Resulting from Control Measures

Because of the way they are defined, design values can only be determined for three-year monitoring periods. We estimate the design values resulting from a given control program by beginning with the measured design values and then using two model runs to determine the relative change produced by the control program. The first model run is the base year case and uses an emissions inventory that corresponds to the measured design values. For 1995-1997 design values, we used the 1995/96 Base Year emissions inventory. The second model run is the control case and employs the inventories for which we are projecting resulting design values. We projected design values for three control cases: 2007 ROTR, 2007 Tier 2/Sulfur (OMS4) and 2020 Tier 2/Sulfur (OMS3). The relative change between the base year case and control case is used to adjust the measured design values, as described in this section. This process, called the "rollback method," was used in the ROTR rulemaking and is more fully described in the document: "Procedures for Estimating the Impact of OTAG Strategy Run 5 on Attainment of the

[j] This method, and the reasons why 1991, 1993, and 1995 were used, are discussed in "Procedures for Estimating the Impact of the OTAG Strategy Run 5 on Attainment of the 8-Hr Ozone NAAQS." Draft: October 1997. Staff Report, Air Quality Modeling Group, Emissions, Monitoring and Analysis Division, Office of Air Quality Planning and Standards, U.S. EPA. EPA Air Docket A-96-56, II-A-24.

8-Hr Ozone NAAQS", Staff Report, Draft October 1997, (EPA Air Docket A-96-56, II-A-24).[k]

There are three ozone episodes that are used in the modeling. Each corresponds to the meteorological conditions of a historical air pollution episode and is approximately 10 days long. The actual episodes occurred in 1991, 1993, and 1995. When we refer to running those three episodes for the ROTR in 2007, for example, we mean using the meteorology of those three episode with the emissions inventory we expect in 2007 following the ROTR.

The following procedure, referred to as the rollback method, was used to estimate the effects of control strategies on 1-hr and 8-hr ozone design values. Note that, except for Step 1(a), the procedures for treating 1-hr and the 8-hr design values are the same. The base year case refers to the 1995/96 Base Year inventory, which corresponds to the 1995-1997 period used to determine measured design values. The control case refers to one of the three cases for which we are projecting design values: either the 2007 post-ROTR scenario or the 2007 Tier 2/Sulfur case or the 2020 Tier 2/Sulfur case.

Step 1: Calculate ambient design values

(a) For each monitor in a county determine the monitor-specific 1-hr design values by taking the 4th highest daily maximum value from ozone data collected at the monitoring site for the period 1995-1997. For determining an 8-hr design value, calculate the 3-year average of the 4th highest daily maximum 8-hr value in each year at the monitor.

(b) Select the highest design value from all monitors within the county as the county-specific design value.

Step 2: Generate model predictions for three OTAG episodes (July 1991, 1993 and 1995) for the base year case and for the control case.

(a) The base year case model predictions reflect emissions levels in the 1995-1997 time period.

(b) The control case model predictions reflect a future year control scenario.

Step 3: Calculate an adjustment factor for each grid cell

Notes:

(1) The adjustment factor is based on the percent difference in ozone predictions between the base year case and the control case. These factors will be used in

[k] In keeping with Appendices H and I of 40 CFR Part 50, projected design values are truncated to whole ppb. Nonattainment of the 1-hour standard is defined as a design value greater than or equal to 125 ppb. Nonattainment of the 8-hour standard is defined as a design value greater than or equal to 85 ppb.

Step 5 to "rollback" ambient design values to reflect the impacts of the control case.
(2) Step 3 must be followed separately for the base year case and the control case.

For each grid cell:

(a) Calculate daily maximum ozone concentrations for every day simulated (excluding the ramp up days for each episode) for the three OTAG episodes identified in Step 2. The ramp up days are one and two for the 1993 episode and one, two, and three for the other episodes.

(b) For each episode select the 1st, 2nd, and 3rd highest daily maximum values.

(c) For each of these "ranks" (i.e., 1st, 2nd, and 3rd ranked values), average the concentrations across the episodes (e.g., sum all 1st ranked values and divide by number of episodes). This yields an average value for each rank (i.e., the average of the highest, the average of the 2nd highest, and the average of the 3rd highest concentrations).

(d) For each of the average ranks, calculate the ratio of the control case to the base year case. This yields a set of three ratios, one for each rank.

(e) Average these three ratios to get the Adjustment Factor, which is multiplied times the 1995-1997 design value for a given grid cell to get the new design value for that grid cell.

Step 4: Assign a unique grid cell adjustment factor to each individual county

(a) The cell with the largest portion of its area in the county is assigned to that county. If more than one cell is completely contained in the county, the cell with the highest base year case value is assigned to the county. The 1990 Base Year OTAG model predictions were used in those cases where it was necessary to chose among multiple grid cells for assigning a grid cell to a county.

(b) The step of assigning a unique grid cell to each county yields the county-specific adjustment factor. Note that only one grid cell is assigned to a county. Thus, there is no spatial averaging or spatial weighting of adjustment factors using multiple grid cells in determining the county-specific factors.

Step 5: Calculate the rollback ambient design value

(a) This step adjusts the ambient design values in each county to reflect the ozone reductions estimated to result from the control case.

(b) Multiply the county-specific ambient design value from Step 1 times the

county-specific adjustment factor from Step 4.

d. Specific Simulations Used to Evaluate Tier 2/Sulfur

Four simulations were performed in support of the Tier 2/Sulfur rulemaking. They are listed in the following table with the percentage reduction in highway vehicle emissions that were modeled for each run.

Table III-27. Percent Reductions for Tier 2/Sulfur Ozone Modeling Runs

Run	*% Reduction from Base Case*		*Base Case*
	NO_X	*VOC*	
OMS1	0%	30.3%	2007 Post-ROTR published with SNPR
OMS2	54.2%	0%	
OMS3	50.2%	10.5%	2007 Post-ROTR Final Inventory, September 1998
OMS4	18.5%	4.3%	

OMS1 and OMS2 were intended to explore the relative effect on ozone of VOC and NO_X reductions. OMS3 was intended to model the effect of Tier 2/Sulfur in 2020, when it would affect a large portion of the fleet. OMS4 was intended to model Tier 2/Sulfur in 2007, which is an important year for ozone attainment and is also a year for which a large body of ROTR-related modeling results are available.

As mentioned previously, the percentage reductions in Table III-27 are those that when applied to the whole highway mobile source fleet will reproduce the reductions expected to result from Tier 2/Sulfur controls. The emissions modeling used to obtain the percent reductions from the base case are described in a technical memo to the Docket A-97-10 from John Koupal, titled “Methodology for Developing Inventory Reductions Used in Ozone Modeling.”

e. Results of the NO_X-only and VOC-only Runs (OMS1 and OMS2)

While today’s proposal decreases both NOx and VOC, NOx is decreased preferentially because it has a far greater effect on ozone. Most areas are NO_X-limited—their ozone concentrations respond more to decreases in NO_X than to decreases in VOCs. Only a few, highly localized areas are VOC-limited. For this reason, the Ozone Transport Assessment Group reached a broad consensus that regional ozone reductions in the eastern U.S. are best accomplished by reducing NO_X. This consensus is reflected in the ROTR, which only reduces NO_X.

We have demonstrated that this conclusion is still valid even after the large NOx reductions resulting from the ROTR are taken into account. The demonstration used two OTAG-domain modeling runs that simulated the separate effects of mobile source VOC and NO_X reductions. OMS2 simulated a 54 percent reduction in highway mobile source NO_X and OMS1 a 30 percent reduction in highway mobile source VOC.[1]

The results of the OMS1 and OMS2 runs demonstrate that mobile source NO_X reductions are much more effective at reducing ozone than are mobile source VOC reductions. The number of grid cell days on which the daily maximum 1-hour average ozone concentration exceeded 124 ppb fell 46% for the NO_X reductions but only 2% for the VOC reductions. The number of grid cell days on which the daily maximum 8-hour average ozone concentration exceeded 84 ppb fell 40% for the NO_X reductions but only 1% for the VOC reductions.

f. Details of the Tier 2/Sulfur Ozone Modeling Runs (OMS3 and OMS4)

The results of our modeling of Tier 2/Sulfur have been summarized in the preamble. In this section, we discuss the detailed methods and results that were not covered there. The design-value results for all counties are listed in Appendix C.

As stated above, OMS3 and OMS4 were intended to model Tier 2/Sulfur in 2020 and 2007, respectively. For these two runs, the emission inventory for the base case, to which they are compared, is the ROTR budget case. This base case inventory uses the OTAG nonroad, highway heavy-duty, and highway light-duty emission estimates, as updated for the ROTR final rule based on public comment as of September 1998. This inventory is a newer version than the base case inventory used for the OMS1 and OMS2 runs. For both base case inventories, the nonroad inventories are based on the NEVES study, and the highway mobile source inventories are based on MOBILE5 emission factors, vehicle distributions, and mileage accumulation patterns. The fact that these inventories do not reflect the more recent information incorporated in the emission inventory analyses presented in Section A. of this chapter creates some uncertainty as to the absolute values of design values and which counties are in attainment or nonattainment under the base case.

Emissions and ozone levels were modeled for 2007 and 2020. The 2007 case is straightforward because we produced a full emission inventory for 2007 for the ROTR. For 2020, we assumed that total emissions (under ROTR plus current vehicle standards and fleet turnover) would be the same as in 2007, i.e., that emission reductions from fleet turnover and emission increases from growth in all sectors balance each other. This assumption is not exactly correct, but is close. Our best estimate is that without Tier 2/Sulfur NOx emissions from all human sources actually would be about 3% lower in 2020, and VOC emissions would be about 5% higher. The details of these estimates are in Section A of this chapter, “Inventory Impacts of

[1] For comparison, we estimate that today’s proposal will actually reduce mobile source NO_X 50.0 percent and VOC 10.2 percent in 2020.

Tier 2/Sulfur."

A relatively minor caveat is that the Tier 2/Sulfur NO_X and VOC reductions were distributed evenly over all highway mobile sources, which have a different spatial distribution from light-duty vehicles.

After OMS3 and OMS4 had been run and design values calculated by the rollback method, our proposal was refined, resulting in slightly different percent reductions from the base case. These two sets of percent reductions are shown in Table III-28.

Table III-28. Percentage Reductions from the 2007 Post-ROTR Inventory of NO_x and NMHC for OMS3 (2020), OMS4 (2007), and for Today's Proposal in 2007, 2010, and 2020.

Year	*OMS3 and OMS4*		*Today's Proposal*	
	NMHC	*NO_X*	*NMHC*	*NO_X*
2007	4.3%	18.5%	4.0%	18.1%
2010	–	–	5.4%	26.9%
2020	10.5%	50.2%	10.2%	50.0%

Because OMS3 and OMS4 were so close to today's proposal, we obtained the design values for today's proposal by linearly interpolating or extrapolating slightly based on the differences in NO_X alone. Interpolations and extrapolations were also used to determine design values in 2010, which was not modeled, and to estimate design values in 2010 without Tier 2/Sulfur. The percentage reduction in total highway NO_X emissions between the 2007 baseline and 2010 without Tier 2/Sulfur was 4.3%.

For discussing the effects of today's proposal on one- and eight-hour design values, we projected county design values using the rollback method for three modeling runs: 2007 post ROTR, OMS3, and OMS4. All other projected design values have been linearly interpolated based on NO_X. As we have discussed previously, the primary effect on ozone has been produced by NO_X.

All measured and projected county design values are in Appendix C. In addition, the preamble indicates counts of metropolitan areas and rural counties whose measured or projected design values meet various criteria with respect to the one and eight-hour standards. Appendix C contains the lists of these metropolitan areas and counties together with their design values and populations.

2. Visibility/Regional Haze

The Northern Front Range Air Quality Study (NFRAQS) report collected numerous ambient $PM_{2.5}$ samples in various areas around Denver, including urban areas such as Welby and rural areas such as Brighton, during the winter of 1997. The samples were analyzed for their composition, including the contribution of carbon-based, sulfate, nitrate, and crustal matter particles to each sample. The results of that analysis are summarized in Table III-29.

Table III-29. NFRAQS Compositional Analysis of $PM_{2.5}$ Samples

Site	*Carbon-based $PM_{2.5}$*	*Sulfate-based $PM_{2.5}$*	*Nitrate-based $PM_{2.5}$*	*Crustal Matter $PM_{2.5}$*
Welby	49%	10%	25%	16%
Brighton	42%	15%	32%	11%

The study used a variety of techniques to determine how much of the carbon-based, sulfate, and nitrate PM found in the $PM_{2.5}$ samples came from gasoline vehicles. Organic tracer compounds were used to determine how much of the carbonaceous $PM_{2.5}$ came from gasoline vehicles and to separate the contribution of normal emitting vehicles and higher emitting vehicles. A combination of inventory analysis, dispersion modeling, atmospheric chemistry, and analysis of compositional variation over time were used to determine the contribution of gasoline vehicles to sulfate and nitrate $PM_{2.5}$. The study reported the following average percentages of sulfates and nitrates coming from gasoline vehicles. The proportion of each type of $PM_{2.5}$ determined to come from gasoline vehicles is shown in Table III-30.

Table III-30. Percentage of $PM_{2.5}$ Coming from Gasoline Vehicles

Site	*Carbon-Based*	*Sulfate-Based*	*Nitrate-Based*
Welby	57%	20%	36%
Brighton	62%	14%	38%

From these two sets of numbers, one can calculate the contribution of each type of $PM_{2.5}$ from gasoline vehicles to total $PM_{2.5}$, as shown in the middle three columns of Table III-34. The results can be summed to derive the contribution of gasoline vehicles to total $PM_{2.5}$, as shown in the last column in Table III-31.

Table III-31. Percentage of Total $PM_{2.5}$ From Gasoline Vehicles

Site	*Carbon-Based*	*Sulfate-Based*	*Nitrate-Based*	*Total*
Welby	28%	2%	9%	39%
Brighton	26%	2%	12%	40%

This section presents the analytic basis for the preamble discussion of the impact of mobile sources on visibility impairment in the U.S. In this context, "visibility impairment" refers to the reduction in the distance that one can see as the result of air pollution. As discussed in the preamble, fine particles suspended in the atmosphere are the primary cause of visibility impairment.

As discussed in the preamble, the Grand Canyon Visibility Transport Commission examined visibility impairment on the Colorado Plateau. Figures II-4 and II-5 in the Commission's June 10, 1996 report titled "Recommendations for Improving Western Vistas" contain estimates for the contribution of 11 different sources to the man-made visibility impairment at Hopi Point. Figure II-4 is for annual average light extinction[m] and Figure II-5 for the worst days. Each figure gives estimates for 1990, 2000, 2010, and 2040. In 2000, for both annual average and worst days, the contribution from "Mobile" to light extinction is about 10 percent. EPA understands this category to consist of highway vehicles only, since there is a separate category for "Non Road Diesel." Furthermore, the "Mobile" category must exclude dust caused by highway vehicle travel since there is a separate category for "Road Dust." The road dust category is estimated to be responsible for about 30 percent of light extinction at Hopi Point.

It is generally recognized that the traditionally-used emission factors and transport assumptions for road dust have considerable uncertainty. Therefore, the contribution of road dust may be overstated in these figures. If light extinction from highway vehicles is expressed as a percentage of all light extinction not attributable to road dust, the highway vehicle contribution is 14 percent. Hence efforts to reduce highway vehicle emissions that cause light extinction can contribute significantly to improved visibility on the Colorado Plateau.

The benefit/cost analysis in Chapter VII includes the visibility-related economic benefits that would result from implementation of the Tier 2/Sulfur proposal.

C. Air Toxics

This section summarizes our analysis of the impact of the proposed Tier 2/Sulfur standards on emissions of and exposure to air toxics. Section C.1. reviews the effects of selected air toxics emissions on human health. Section C.2. describes our analysis of air toxics emissions and exposure and the effect that the proposed Tier 2/Sulfur standards may have on air toxics emissions and exposure.

1. Health Effects

Our assessment of motor vehicle toxics focused on the following compounds with cancer

[m] Light extinction is a measure of visibility impairment.

potency estimates that have or could have significant emissions from cars and light trucks: benzene, 1,3-butadiene, formaldehyde, acetaldehyde, and diesel PM. It should be noted, however, that the EPA does not have an official quantitative estimate of diesel emissions potency at present. The current estimate is still draft, as discussed below. A brief summary of health effects information on these compounds follows. The information in this section is based on our preliminary study of motor vehicle toxics emissions. The study will be peer reviewed in the near future. We anticipate updating our estimates once the study completes peer review.

a. Benzene

Benzene is an aromatic hydrocarbon which is present as a gas in both exhaust and evaporative emissions from motor vehicles. Benzene in the exhaust, expressed as a percentage of total organic gases (TOG), varies depending on control technology (e.g., type of catalyst) and the levels of benzene and aromatics in the fuel, but is generally about three to five percent. The benzene fraction of evaporative emissions depends on control technology (i.e., fuel injector or carburetor) and fuel composition (e.g., benzene level and Reid Vapor Pressure, or RVP) and is generally about one percent.

The EPA has recently reconfirmed that benzene is a known human carcinogen by all routes of exposure.[9] Respiration is the major source of human exposure. At least half of this exposure is by way of gasoline vapors and automotive emissions (EPA 1998a). Long-term exposure to high levels of benzene in air has been shown to cause cancer of the tissues that form white blood cells. Among these are acute nonlymphocytic[n] leukemia, chronic lymphocytic leukemia and possibly multiple myeloma (primary malignant tumors in the bone marrow), although the evidence for the latter has decreased with more recent studies.[10,11] Leukemias, lymphomas, and other tumor types have been observed in experimental animals that have been exposed to benzene by inhalation or oral administration (EPA 1985, Clement 1991). Exposure to benzene and/or its metabolites has also been linked with genetic changes in humans and animals[12] and increased proliferation of mouse bone marrow cells.[13] Furthermore, the occurrence of certain chromosomal changes in individuals with known exposure to benzene may serve as a marker for those at risk for contracting leukemia.[14]

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[n]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 bloods cell 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 (AML) 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.

The latest assessment by EPA places the excess risk of developing acute nonlymphocytic leukemia at 2.2×10^{-6} to $7.7 \times 10^{-6}/\mu g/m^3$. In other words, there is a risk of two to eight excess acute nonlymphocytic leukemia cases in one million people exposed to $1\mu g/m^3$ benzene over a lifetime (70 years). These numbers represent the maximum likelihood (MLE) estimate of risk, not an upper confidence limit (UCL).

A number of adverse noncancer health effects, blood disorders such as preleukemia and aplastic anemia, have also been associated with low-dose, long-term exposure to benzene (EPA 1985, Clement 1991, [15]). People with long-term exposure to benzene may experience harmful effects on the blood-forming tissues, especially the bone marrow. These effects can disrupt normal blood production and cause a decrease in important blood components, such as red 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 for blood to clot). Chronic inhalation exposure to benzene in humans and animals results in pancytopenia[o],a condition characterized by decreased numbers of circulating erythrocytes (red blood cells), leukocytes (white blood cells), and thrombocytes (blood platelets).[16,17] Individuals that develop pancytopenia and have continued exposure to benzene may develop aplastic anemia,[p] whereas others exhibit both pancytopenia and bone marrow hyperplasia (excessive cell formation), a condition that may indicate a preleukemic state.[18,19] The most sensitive noncancer effect observed in humans is the depression of absolute lymphocyte counts in the circulating blood.[20] A draft reference concentration (RfC) has been developed for benzene. The reference concentration (RfC) is an estimate of a continuous inhalation exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious noncancer effects during a lifetime; these estimates frequently have uncertainty levels that span perhaps an order of magnitude. The benzene RfC is 9 $\mu g/m^3$, which means that long-term exposures to benzene should be kept below 9 $\mu g/m^3$ to avoid appreciable risks of these non-cancer effects.[21]

b. 1,3-Butadiene

1,3-Butadiene is formed in vehicle exhaust by the incomplete combustion of the fuel. It is not present in vehicle evaporative and refueling emissions, because it is not present in any appreciable amount in gasoline. 1,3-Butadiene accounts for 0.4 to 1.0 percent of total exhaust

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[o]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.

[p] Aplastic anemia is a more severe blood disease and occurs when the bone marrow ceases to function, i.e., these stem cells never reach maturity. The depression in bone marrow function occurs in two stages - hyperplasia, or increased synthesis of blood cell elements, followed by hypoplasia, or decreased synthesis. As the disease progresses, the bone marrow decreases functioning. This myeloplastic dysplasia (formation of abnormal tissue) without acute leukemia is known as preleukemia. The aplastic anemia can progress to AML (acute mylogenous leukemia).

TOG, depending on control technology and fuel composition.

EPA recently prepared a draft assessment that would determine sufficient evidence exists to consider 1,3-butadiene a known human carcinogen.[22] However, the Environmental Health Committee of EPA's Scientific Advisory Board (SAB), in reviewing the draft document, issued a majority opinion that 1,3-butadiene should instead be classified as a probable human carcinogen.[23] In the draft EPA assessment, the MLE estimate of a lifetime extra cancer risk from continuous 1,3-butadiene exposure is about $3.9 \times 10^{-6}/\mu g/m^3$. In other words, it is estimated that approximately 4 persons in one million exposed to 1 $\mu g/m^3$ 1,3-butadiene continuously for their lifetime (85 years in this case) would develop cancer as a result of their exposure. Lower exposures are expected to result in risks that are lower.

1,3-Butadiene also causes a variety of reproductive and developmental effects in mice and rats (no human data) when exposed to long-term, low doses of butadiene (EPA 1998c). The most sensitive effect was reduced litter size at birth and at weaning. These effects were observed in studies in which male mice exposed to 1,3-butadiene were mated with unexposed females. In humans, such an effect might manifest itself as an increased risk of spontaneous abortions, miscarriages, still births, or very early deaths. Long-term exposures to 1,3-butadiene should be kept below its reference concentration of 0.33 $\mu g/m^3$ to avoid appreciable risks of these reproductive and developmental effects (EPA 1998c).

c. Formaldehyde

Formaldehyde is the most prevalent aldehyde in vehicle exhaust. It is formed from incomplete combustion of both gasoline and diesel fuel and accounts for one to four percent of total exhaust TOG emissions, depending on control technology and fuel composition. It is not found in evaporative emissions.

Formaldehyde exhibits extremely complex atmospheric behavior.[24] It is present in emissions and is also formed by the atmospheric oxidation of virtually all organic species, including biogenic (produced by a living organism) hydrocarbons. Mobile sources contribute both primary formaldehyde (emitted directly from motor vehicles) and secondary formaldehyde (formed from photooxidation of other VOCs emitted from vehicles). The mobile source contribution is difficult to quantify, but it appears that at least 30 percent of formaldehyde in the ambient air may be attributable to motor vehicles (EPA 1993a).

EPA has classified formaldehyde as a probable human carcinogen[25] based on limited evidence for carcinogenicity in humans and sufficient evidence of carcinogenicity in animal studies, rats, mice, hamsters, and monkeys. Epidemiological studies in occupationally exposed workers suggest that long-term inhalation of formaldehyde may be associated with tumors of the nasopharyngeal cavity (generally the area at the back of the mouth near the nose), nasal cavity, and sinus (Clement 1991, EPA 1993a). Studies in experimental animals provide sufficient evidence that long-term inhalation exposure to formaldehyde causes an increase in the incidence of squamous (epithelial) cell carcinomas (tumors) of the nasal cavity (Clement 1991, EPA

1993a, EPA 1987). The distribution of nasal tumors in rats suggests that not only regional exposure but also local tissue susceptibility may be important for the distribution of formaldehyde-induced tumors (Clement 1991, EPA 1993a). Research has demonstrated that formaldehyde produces mutagenic activity in cell cultures.

The MLE estimate of a lifetime extra cancer risk from continuous formaldehyde exposure is about $1.3 \times 10^{-6}/\mu g/m^3$. In other words, it is estimated that approximately 1 person in one million exposed to 1 $\mu g/m^3$ formaldehyde continuously for their lifetime (70 years) would develop cancer as a result of their exposure. Lower exposures are expected to result in risks that are lower.

Formaldehyde exposure also causes a range of noncancer health effects. At low concentrations (0.05-2.0 ppm), irritation of the eyes (tearing of the eyes and increased blinking) and mucous membranes is the principal effect observed in humans. At exposure to 1-11 ppm, other human upper respiratory effects associated with acute formaldehyde exposure include a dry or sore throat, and a tingling sensation of the nose. Sensitive individuals may experience these effects at lower concentrations. Forty percent of formaldehyde-producing factory workers reported nasal symptoms such as rhinitis (inflammation of the nasal membrane), nasal obstruction, and nasal discharge following chronic exposure.[26] In persons with bronchial asthma, the upper respiratory irritation caused by formaldehyde can precipitate an acute asthmatic attack, sometimes at concentrations below 5 ppm;[27] formaldehyde exposure may also cause bronchial asthma-like symptoms in nonasthmatics.[28,29] However, it is unclear whether asthmatics are more sensitive than nonasthmatics to formaldehyde's effects.[30]

Immune stimulation may occur following formaldehyde exposure, although conclusive evidence is not available. Also, little is known about formaldehyde's effect on the central nervous system. Several animal inhalation studies have been conducted to assess the developmental toxicity of formaldehyde: The only exposure-related effect noted was decreased maternal body weight gain at the high-exposure level but no adverse effects on reproductive outcome of the fetuses that could be attributed to treatment were noted. An inhalation reference concentration (RfC), below which long-term exposures would not pose appreciable non-cancer health risks, is not available for formaldehyde at this time.

d. Acetaldehyde

Acetaldehyde is a saturated aldehyde that 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. Acetaldehyde comprises 0.4 to 1.0 percent of exhaust TOG, depending on control technology and fuel composition.

The atmospheric chemistry of acetaldehyde is similar in many respects to that of formaldehyde (Ligocki et al., 1991, [31]). Like formaldehyde, it can be both produced and destroyed by atmospheric chemical transformation, so mobile sources contribute to ambient acetaldehyde levels both by their primary emissions and by secondary formation resulting from

their VOC emissions. Data from emission inventories and atmospheric modeling indicate that roughly 40 percent of the acetaldehyde in ambient air may be attributable to mobile sources.

Acetaldehyde emissions are classified as a probable human carcinogen. The MLE estimate of a lifetime extra cancer risk from continuous acetaldehyde exposure is about $0.78 \times 10^{-6}/\mu g/m^3$. In other words, it is estimated that less than 1 person in one million exposed to 1 $\mu g/m^3$ acetaldehyde continuously for their lifetime (70 years) would develop cancer as a result of their exposure.

Non-cancer effects in studies with rats and mice showed acetaldehyde to be moderately toxic by the inhalation, oral, and intravenous routes.[32,33,34] The primary acute effect of exposure to acetaldehyde vapors is irritation of the eyes, skin, and respiratory tract. At high concentrations, irritation and pulmonary effects can occur, which could facilitate the uptake of other contaminants. Little research exists that addresses the effects of inhalation of acetaldehyde on reproductive and developmental effects. The *in vitro* and *in vivo* studies provide evidence to suggest that acetaldehyde may be the causative factor in birth defects observed in fetal alcohol syndrome, though evidence is very limited linking these effects to inhalation exposure Long-term exposures should be kept below the reference concentration of 9 $\mu g/m^3$ to avoid appreciable risk of these non-cancer health effects.[35]

e. Diesel Particulate Matter

The particulate matter (PM) from diesel exhaust typically consists of a solid core, composed mainly of elemental carbon, which has a coating of various organic and inorganic compounds. The diameter of diesel particles is very small with typically 75-95 percent of the particle mass having a diameter smaller than 1.0 µm. The characteristically small particle size increases the likelihood that the particles and the attached compounds will reach and lodge in the deepest and more sensitive areas of the human lung. Both the diesel particle and the attached compounds may be influential in contributing to a potential for human health hazard from long term exposure.

The heavy-duty highway and off-road diesel engines, as a group, account for most of the diesel particulate emissions currently released into ambient air.[36] Diesel particulate matter is mainly attributable to the incomplete combustion of fuel hydrocarbons, though some may be due to engine oil or other fuel components.

In two human studies on railroad workers, and one on truckers, occupationally exposed to diesel exhaust (EPA 1998d), it was observed that long-term inhalation of diesel exhaust produced an excess risk of lung cancer. Taken together, the human studies show a positive association between diesel exhaust exposure and lung cancer. Studies in experimental animals provide additional evidence that long-term inhalation exposure to high levels of diesel particulate may pose a significant cancer risk. Research has demonstrated that exposure to high diesel exhaust levels causes an increase in lung tumors in two strains of rats and two strains of mice (EPA 1998d). Also, as a result of extensive studies, the direct-acting mutagenic activity of

both the particle and gaseous fractions of diesel exhaust has been shown (EPA 1998d).

EPA's draft Diesel Health Assessment identifies both lung cancer as well as several other adverse respiratory health effects including respiratory tract irritation, immunological changes, and changes in lung function, as possible concerns for long term exposure to diesel exhaust. The evidence in both cases comes from the studies involving occupational exposures and or high exposure animal studies mentioned above, and the Health Assessment, when completed, will recommend how the data should be interpreted for lower environmental levels of exposure. The draft Health Assessment is currently being revised to address comments from a peer review panel of the Clean Air Science Advisory Committee. Based on human epidemiology studies, the draft MLE estimate of a lifetime extra cancer risk from continuous diesel exhaust particulate exposure ranges from 3.0 × 10-4 to 1.0 × 10-3/µg/m3. In other words, it is estimated that approximately 300 to 1000 persons in one million exposed to 1 µg/m3 diesel exhaust particulate continuously for their lifetime (70 years) would develop cancer as a result of their exposure.

The California Air Resources Board has identified diesel exhaust PM as a "toxic air contaminant" under the state's air toxics program, based on the information available on cancer and non-cancer health effects. California is in the process of determining the need for, and appropriate degree of, control measures for diesel exhaust particulate matter. Note that California limited its finding to diesel particulate matter, as opposed to diesel exhaust. EPA's assessment activities of diesel exhaust PM are coincident with, but independent from, California's evaluation.

Particulates (i.e, particulate matter, PM) are a prominent part of diesel exhaust and play a role in contributing to total ambient PM, especially $PM_{2.5}$ (PM less than 2.5 µm in diameter). This means that EPA's new National Ambient Air Quality Standard for $PM_{2.5}$ provides another health-based reference point. Diesel exhaust particles may pose a particularly serious health risk since more than 75 percent of the particles can be less than 1µm and the smaller diesel particles can be inhaled and deposited deeper in the lung. Diesel particles also have a large surface area per unit mass and carry a coating of organic compounds with them which may contribute to the health effects observed from particles. At the present time, EPA believes that for many people, keeping long term exposures to diesel particulate matter at or below 5 $\mu g/m^3$ provides an adequate margin of safety for the noncancer respiratory hazards.[37]

2. Assessment of Emissions and Exposure

In 1993, EPA released the "Motor Vehicle-Related Air Toxics Study" to meet the requirements of Section 202(l)(1) of the Clean Air Act, which required EPA to complete a study of the need for, and feasibility of, controlling emissions of toxic air pollutants associated with motor vehicles and motor vehicle fuels (EPA 1993a). In 1998, EPA updated the emissions and exposure analyses done for this study to account for new information[38,39] Base scenarios for 1990, 1996, 2007, and 2020 were included in the assessment, as well as several control scenarios in 2007 and 2020. Toxic emissions and exposure were modeled for the following urban areas: Chicago, Denver, Houston, Minneapolis, New York, Philadelphia, Phoenix, Spokane, and St.

Louis. Results for these urban areas were extrapolated nationwide. As mentioned previously, EPA has assessed emissions, and exposure from the following air toxics: benzene, formaldehyde, acetaldehyde, 1,3-butadiene, and diesel particulate matter. An assessment of the cancer and non-cancer effects of mobile source emissions of these compounds has not yet been completed as part of the updated analyses.

This subsection describes the analysis we have conducted to update our 1993 study. Subsection C.2.a. discusses the emission modeling conducted for mobile source gaseous air toxics (including both exhaust and nonexhaust air toxics) and diesel PM. Subsection C.2.b. describes how we calculated nationwide air toxic emissions for our baseline scenario, which assumed continuation of the National Low Emission Vehicle program indefinitely. Subsection C.2.c. describes our analysis of air toxics exposure for our baseline scenario. Subsection C.2.d. describes our analysis of the effects of various vehicle and fuel control scenarios on air toxics emissions and exposure. It also describes how we used those analyses to estimate the effect of the proposed Tier 2/Sulfur standards on air toxics emissions. This subsection also reviews our analysis of the potential impact of increased diesel engine use in light trucks on diesel PM emissions and exposure.

a. Emissions Modeling

i. Gaseous Air Toxics Emissions Modeling

In these analyses, emissions of benzene, formaldehyde, acetaldehyde, and 1,3-butadiene were estimated using a toxic emission factor model, MOBTOX5b. This model is based on a modified version of MOBILE5b, which estimates emissions of regulated pollutants, and essentially applies toxic fractions to TOG estimates. The TOG basic emission rates used in this modeling were similar, but not identical, to the rates used for previous modeling studies. The model accounted for differences in toxic fractions between technology groups, driving cycles, and normal versus high emitters. Impacts of fuel formulations were also addressed in the modeling. Motor vehicle toxic emissions were modeled for the following urban areas: Chicago, Denver, Houston, Minneapolis, New York, Philadelphia, Phoenix, Spokane, and St. Louis.

Exhaust Emissions

Analysis of speciation data from 1990 technology light-duty gasoline vehicles done for the EPA Complex Model for Reformulated Gasoline showed that the fraction of toxic emissions relative to TOG differs among eight technology groups within the Complex Model as well as between normal emitters and high emitters.[40] This difference is especially significant for 1,3-butadiene; its TOG fraction is about three times larger for high emitters than for normal emitters. If this difference is not taken into account, the impact of I/M programs and fleet turnover to vehicles with lower deterioration rates will be underestimated. Thus, the input format for exhaust toxic adjustment factors in MOBTOX5b was structured to allow input of high and normal emitter toxic emission rates for a given “target” fuel. These toxic emission rates were then weighted to come up with a composite toxic emission factor, based on a distribution of

normal and high emitters. This distribution is not supplied directly by the MOBILE model. Instead, this distribution was determined from the fleet average TOG emission rate on baseline fuel as determined by MOBILE and average normal and high TOG emission rates on baseline fuel derived from the Complex Model. Essentially, "toxic-TOG curves" were developed that plot the target fuel toxic emission rate against the base fuel TOG emission rate.

To construct these curves, the distribution of normal and high emitters was determined in the following manner for each model year. A TOG gram per mile emission rate for normal emitters (TOG-N) and a TOG emission rate for high emitters (TOG-H) on baseline fuel were input into MOBTOX5b. TOG-N from newer technology light-duty gasoline vehicles and trucks were obtained from an unconsolidated version of the Complex Model, which provides output for normal emitters in each of eight technology groups. The Complex Model provides estimates for mass of exhaust VOC, which is TOG minus the mass of methane and ethane. TOG was estimated by applying a conversion factor which accounts for the mass of these compounds. The conversion factor was derived by analysis of weight percent emissions of methane and ethane from available speciation data. Based on the distribution of technology groups in given model year, the individual TOG estimates were weighted appropriately to obtain a composite estimate for all normal emitters. Since the unconsolidated model's TOG-N emission rates are applicable only to Tier 0 light duty vehicles, they had to be adjusted for Tier 1 and later vehicles. This adjustment was performed by multiplying the unconsolidated model results by the ratio of the emission standard for these later vehicles to the Tier 0 emission standard. TOG-H was also obtained from the unconsolidated version of the Complex Model. TOG-H was assumed to be the same for all Tier 0 and later vehicles.

For benzene, 1,3-butadiene, formaldehyde, and acetaldehyde, milligram per mile toxic emission rates for normal and high emitters running on a given fuel formulation were also entered into MOBTOX5b, using output from the unconsolidated version of the Complex Model.

An example of the data file format is provided in Table III-32. Using the information in the data file, an overall FTP toxic emission rate for each vehicle class in a given model year is calculated. This overall rate takes into account the distribution of normal and high emitters by calculating the slope and intercept of a straight line (the "toxic-TOG" curve), where the FTP toxic emission rates for a vehicle class in a given model year are a linear function of the baseline fuel TOG emission rate:

$$TOX_{Flt,\ Fuel\ A,\ FTP} = A + B*TOG_{Baseline\ \ fuel,\ FTP} \qquad (1)$$

A and B are determined as follows:

$$A = (TOG\text{-}H*TOX\text{-}N - TOG\text{-}N*TOX\text{-}H)/(TOG\text{-}H - TOG\text{-}N) \qquad (2)$$

$$B = (TOX\text{-}H - TOX\text{-}N)/(TOG\text{-}H - TOG\text{-}N) \qquad (3)$$

where:

TOX-N = toxic emission rate for normal emitters derived from the Complex Model
TOX-H = toxic emission rate for high emitters derived from the Complex Model

Table III-32. Example of Data File Format for Toxic Adjustment Factors

IV	*MYA*	*MYB*	*TOG-N*	*TOG-H*	*BZ-N*	*BZ-H*	*AC-N*	*AC-H*	*FR-N*	*FR-H*	*BD-N*	*BD-H*
1	1965	1974	0.000	10.00	0.00	276.93	0.00	109.72	0.00	224.28	0.00	93.15
1	1975	1980	0.000	10.00	0.00	263.61	0.00	108.70	0.00	173.41	0.00	44.57
1	1981	1987	0.640	4.03	28.63	113.23	5.07	32.89	7.16	44.59	2.14	25.84
1	1988	1999	0.570	4.03	17.49	116.45	4.02	28.65	5.67	36.68	2.04	30.82

IV = vehicle class, MYA = initial model year, MYB = final model year, TOG-N = TOG for normal emitters running on baseline fuel in g/mi, TOG-H = TOG for high emitters on baseline fuel in g/mi, BZ = benzene in mg/mi for vehicles running on fuel A, AC = acetaldehyde in mg/mi on fuel A, FR = formaldehyde in mg/mi on fuel A, BD = 1,3-butadiene in mg/mi on fuel A

These relationships can be thought of graphically, as illustrated in Figure III-19, below.

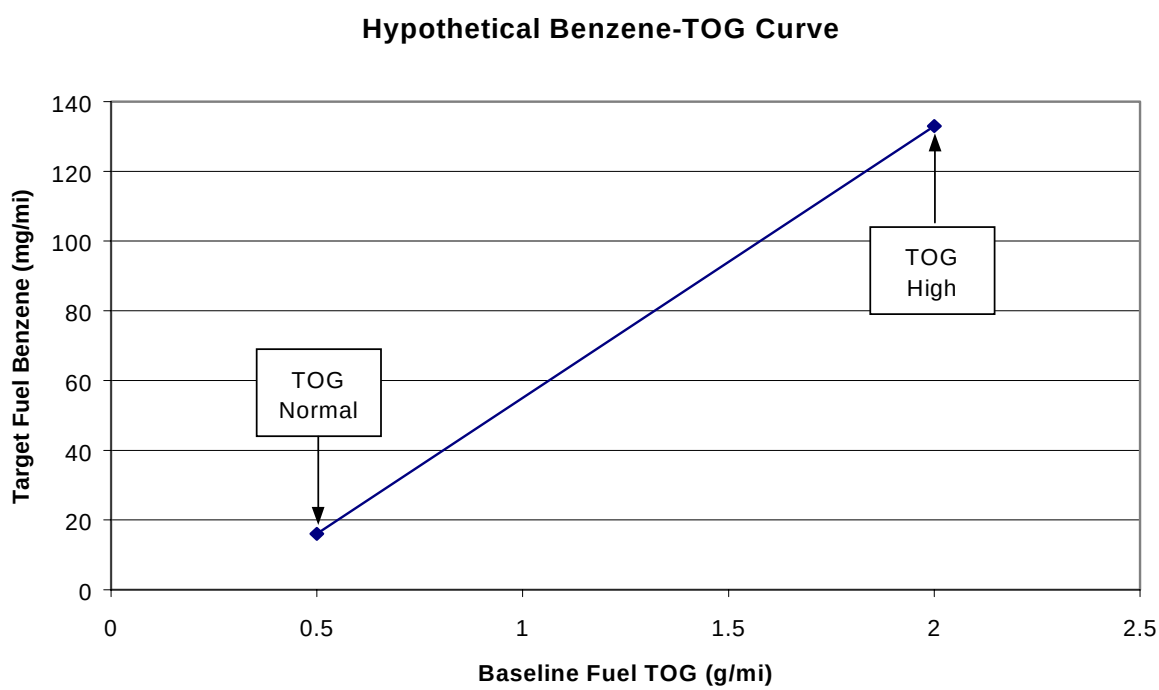

Figure III-19. Example Plot of Target Fuel Benzene Versus Baseline Fuel TOG under FTP Conditions

An issue related to the above methodology is whether the linear assumption is valid for baseline

TOG values above the high emitter point and below the normal emitter point. This is particularly relevant in cases where A and B values are determined from Tier 0 vehicles (e.g., the Complex model), but the results are applied to Tier 1 and LEV-category vehicles. For the simple example presented above, negative benzene emissions are estimated for the target fuel when the baseline fleet-average TOG emission rate falls below 0.295 g/mi. Thus, for fleet-average emission rates below (and above) the normal (and high) emitter values, a different methodology was needed. In those cases, it was assumed that the toxic emission rate was the same on a fractional basis. For the example above, the benzene emission rate for a baseline TOG value of 0.1 g/mi would be calculated as follows:

$$BZ_{(TOG=0.1\ g/mi)} = 0.1\ g/mi * (16\ mg/mi\ BZ / 0.5\ g/mi\ TOG) = 3.2\ mg/mi$$

This has the effect of forcing the toxic-TOG curve from the normal-emitter point back through the origin and thus avoids negative toxic emission rate estimates for Tier 1 and LEV-category vehicles. The same approach is used in cases where the fleet-average baseline TOG emission rate is above the high emitter point.

For non-light duty vehicle classes and older technology light-duty vehicles, such as non-catalyst and oxidation catalyst vehicles, adequate toxic emissions data were not available to distinguish between emission rates of normal and high emitters. In such cases, the toxic fraction was assumed to be constant.

Next, aggressive driving corrections were applied to the FTP toxic emission rates for light duty vehicles. These corrections were provided in an external data file and were multiplicative in form. Several recent studies suggest that toxic fractions of TOG differ between FTP and aggressive driving conditions[41,42,43] Thus, another adjustment to the toxic emission rates was applied to take into account this difference in toxic fractions. This adjustment took the form of the ratio of the toxic mass fraction over the unified cycle (FTP and off-cycle) to the toxic mass fraction over the FTP. The adjustment was obtained from an analysis of unpublished CARB data as described in Sierra Research et al. (Sierra 1998). The toxic emission rate under the unified cycle (FTP and off-cycle) was calculated in the model as follows:

$$TOX_{UC} = TOX_{FTP} * ADJ_{Aggressive\ Driving} * ADJ_{TOX\ UC/FTP} \quad (4)$$

where

TOX_{UC} = Unified Cycle toxic emission rate
TOX_{FTP} = FTP toxic emission rate
$ADJ_{Aggressive\ Driving}$ = Adjustment to TOG emissions for aggressive driving
$ADJ_{TOX\ UC/FTP}$ = Adjustment for difference in toxic mass fraction over the UC versus FTP

Next, toxic emission rates were adjusted in the model to take into account air conditioning effects on light duty vehicles. In the absence of data, we assumed that FTP-based toxic fractions will apply to the increased TOG mass as a result of air conditioning usage. Thus, the increase in TOG mass as a result of air conditioner usage was estimated from model year-specific corrections for air conditioner use on TOG emissions. The corrections were provided in

an external data file in the model. The model calculates the increase in toxic emissions as a result of air conditioner use as follows:

$$TOX_{A/C} = TOX_{FTP} * ADJ_{A/C} \quad (5)$$

where

$TOX_{A/C}$ = increase in toxic emissions as a result of air conditioning usage
TOX_{FTP} = toxic emission rate under FTP conditions
$ADJ_{A/C}$ = Air conditioner usage adjustment for TOG

This result was then added to the TOX_{UC} estimate for an overall in-use toxic emission rate. MOBTOX5b then applies temperature, speed, humidity and load corrections.

Evaporative, Refueling, Running Loss, and Resting Loss Emissions

MOBTOX5b estimated evaporative, refueling, running loss, and resting loss toxic emissions for benzene. (1,3-Butadiene, formaldehyde, and acetaldehyde are not found in fuel and hence are not found in nonexhaust emissions. Because their nonexhaust emissions are zero, they were not included in the portions of MOBTOX5b used to estimate nonexhaust emissions.) Benzene fractions of total hydrocarbons were entered in an external data file. Separate fractions were entered for hot soak, diurnal, refueling, running loss, and resting loss. Toxic fractions for evaporative, refueling and running loss benzene from gasoline vehicles were obtained from the Complex Model (EPA 1994). The Complex Model does not estimate resting loss emissions. EPA assumed that the benzene fractions of diurnal and resting loss emissions were the same.

ii. Diesel PM Emissions Modeling

To estimate diesel PM emissions, we used EPA's PART5 model. PART5 is similar in structure and function to the MOBILE series of models. It calculates exhaust and non-exhaust (e.g., road dust) particulate emissions for each vehicle class included in the MOBILE models. Only primary exhaust PM emission rates from diesel vehicles were included in these analyses since cancer potencies are not available for PM emissions such as tire and brake wear or for secondary PM formed through transformation of diesel engine emissions of SOx, NOx, and VOC. A particle size cut-off of 10 µm was specified in the model inputs since essentially all primary exhaust PM from diesel engines is smaller than 10 µm.

b. Nationwide Toxic Emissions Estimates – Baseline Scenario

Nationwide urban emission estimates were developed by mapping each county in the United States to one of the modeled urban areas, based primarily on geographic considerations (Sierra, 1998). The resulting county level emission rates were weighted by VMT estimates to come up with average nationwide rates. Average nationwide emission rates for baseline scenarios in 1990, 1996, 2007, and 2020 are given in Table III-33. The baseline scenario

assumed implementation of NLEV standards (0.09 g/mi) for light-duty gasoline vehicles and light duty trucks under 6000 lbs. gross vehicle weighting, Tier 1 standards for light-duty trucks over 6000 lbs., and a mix of conventional gasoline and Phase 2 reformulated gasoline with no additional sulfur control.

Table III-33. Average Nationwide Highway Vehicle Toxic Emission Rates (mg/mi) In 1990, 1996, 2007, and 2020, for Baseline Scenarios.

Toxic	*CY 1990*	*CY 1996*	*CY2007*	*CY2020*
Benzene	126	62	26	16
Acetaldehyde	19	14	6	3
Formaldehyde	61	35	14	8
1,3-Butadiene	17	9	3	2
Diesel PM	93	62	23	17

A number of rough approximations had to be made due to the small number of cities actually modeled. For instance, most of the South was mapped to Houston, a reformulated gasoline area, even though most Southern cities do not require reformulated gasoline. Also, all of California was mapped to Phoenix, which does not take into account the California LEV program. EPA plans to perform additional modeling prior to the final rulemaking to improve the national estimate. Despite these limitations, however, the nationwide exposure estimates should provide reasonable approximations.

c. Exposure – Baseline Scenario

Exposure modeling was done for 1990 using the Hazardous Air Pollutant Exposure Model for Mobile Sources, Version-3, or HAPEM-MS3.[44] This model uses CO as a tracer for toxics. Since most ambient CO comes from cars and light trucks, we believe CO exposure is an reasonable surrogate for exposure to other motor vehicle emissions, including toxics emissions. The HAPEM model links human activity patterns with ambient CO concentration to arrive at average exposure estimates for 22 different demographic groups (e.g., outdoor workers, children 0 to 17, working men 18 to 44, women 65+, etc.) and for the total population. The model simulates the movement of individuals between home and work and through a number of different microenvironments. The CO concentration in each microenvironment is determined by multiplying ambient concentration by a microenvironmental factor.

With the 1990 CO exposure estimates generated by HAPEM model for each urban area, EPA determined the fraction of exposure that was a result of on-road motor vehicle emissions. This calculation was accomplished by scaling the exposure estimates (which reflect exposure to

total ambient CO) by the fraction of the 1990 CO emissions inventory from on-road motor vehicles, determined from the EPA Emission Trends database.[45] Nationwide urban CO exposure from on-road motor vehicles was estimated by first calculating a population-weighted average CO exposure for the nine modeled areas. This number was adjusted by applying a ratio of population-weighted annual average CO for urban areas in the entire country versus average ambient CO concentration for the modeled areas. To estimate rural exposure, the urban estimate was scaled downward using rough estimates of urban versus rural exposure from the 1993 *Motor Vehicle-Related Air Toxics Study* (EPA 1993a).

Modeled onroad CO exposure for 1990 was divided by 1990 CO grams per mile emission estimates to create a conversion factor. The conversion factor was applied to modeled toxic emission estimates (in grams per mile terms) to determine exposure to onroad toxic emissions, as shown in Equation 6:

$$TOX_{Exposure(\mu g/m3)} = [CO_{Exposure(\mu g/m3)}/CO_{EF(g/mi)}]_{1990} \times TOX_{EF(g/mi)} \qquad (6)$$

where TOX reflects one of the six toxic pollutants considered in this study.

The exposure estimates for calendar years 1996, 2007, and 2020 were adjusted for VMT growth relative to 1990. 1,3-Butadiene exposure was adjusted for atmospheric transformation. The multiplicative factors used were 0.44 for summer, 0.70 for spring and fall, and 0.96 for winter.[46] In contrast, estimated exposure to formaldehyde and acetaldehyde was based on direct emissions. For these pollutants, removal of direct emissions in the afternoon was assumed to be offset by secondary formation. Table III-34 presents annual average exposure estimates for the entire population. Estimates were also developed for outdoor workers, and children 0 - 17 years of age. Exposure among outdoor workers was higher than for the entire population, and among children it was slightly lower.

Table III-34. Average Nationwide Highway Vehicle Toxic Exposure ($\mu g/m^3$) In 1990, 1996, 2007, and 2020, for Baseline Scenarios.

Toxic	*CY 1990*	*CY 1996*	*CY2007*	*CY2020*
Benzene	1.35	0.90	0.46	0.36
Acetaldehyde	0.20	0.20	0.10	0.08
Formaldehyde	0.66	0.51	0.26	0.20
1,3-Butadiene	0.14	0.09	0.04	0.04
Diesel PM	0.99	0.89	0.42	0.40

It should be noted that recent California-EPA studies estimated a population-weighted average outdoor diesel exhaust PM_{10} (particulate matter < 10 µm) exposure for 1995.[47]

California also estimated indoor and total exposure concentrations for 1995. The 1995 indoor and total air exposure concentrations were estimated to be 1.47 $\mu g/m^3$ and 1.54 $\mu g/m^3$, respectively. This estimate compares to the estimated annual average nationwide diesel PM 1996 exposure estimate of 0.89 $\mu g/m^3$ in Table III-37. The difference may be due to differences in estimates of emission rates, exposure patterns, the concentration of diesel vehicle traffic, or the spatial distribution of diesel engine emissions.

d. Impact of Potential Vehicle and Fuel Controls

The following control scenarios for 2007 and 2020 were assessed:

- base fuels and emissions with NLEV and a 40 ppm sulfur standard.
- NLEV, 40 ppm sulfur, and 0.055 NMHC standard in 2004 for light duty gasoline vehicles and trucks.
- NLEV, 40 ppm sulfur, 0.055 NMHC standard, and light duty diesel trucks 50 percent of light duty truck sales in 2004 (phased in starting in 2001)

Although none of these scenarios represent the standards actually being proposed, the assessment shows that VOC emission reductions would reduce the health risk posed by many of the hazardous air pollutants emitted by light-duty vehicles and trucks beyond what was projected under baseline conditions. Estimates of the impact of VOC reductions from a 0.055 gram per mile NMHC standard for the full useful life of the vehicle, combined with a 40 ppm sulfur standard, on toxics emissions and exposure, are provided in Tables III-35 through III-39. Actual reductions under the standards being proposed would be smaller, since the VOC emission standards being proposed are less stringent. Under the proposed standards, VOC emissions would be about 20 percent larger than under the 0.055 NMHC/40 ppm sulfur scenario modeled; thus a similar difference would be expected for gaseous toxics emissions and exposure.[q] Table III-39 presents gaseous toxics exposure under the proposed standards, assuming the impact on toxics exposure is equivalent to the impact on VOC emissions.

The 1998 revision to the 1993 *Motor Vehicle-Related Air Toxics Study* also evaluated the potential increase in diesel PM emissions and exposure due to increased use of diesel engines in light trucks. Diesel engines are used in a very small portion of the cars and light-duty trucks in service today. However, engine and vehicle manufacturers have projected that diesel engines are likely to be used in an increasing share of light trucks. Some manufacturers have announced capital investments to build such engines. The 1998 study evaluated the potential increase in diesel PM emissions and exposure associated with introducing more diesel engines into the light-duty fleet, absent any action by EPA to mitigate those risks. An extreme case was modeled, with light duty diesel trucks accounting for 50 percent of light-duty truck sales in 2004, phased

[q]The difference in toxic reductions would not be exactly the same, since fleet average toxic emissions are affected differently by such factors the distribution of normal and high emitters, and the mix of vehicle control technologies.

in starting in 2001.

The impact of such increased diesel penetration on emissions and exposure are provided in Tables III-35 through III-39. Based on the exposure estimates for 2020, the potential nationwide cancer risk from diesel particulate matter would increase by 137 percent under this scenario. Beyond 2020, the health risks would be even greater for two reasons. First, the proportion of light trucks equipped with diesel engines would continue to increase as the older, gasoline-powered trucks are replaced by a mix of gasoline and diesel trucks. Second, continued growth in the total number of miles driven would increase diesel PM emissions.

It should be noted that this increase in diesel sales is more rapid than the increase in diesel sales analyzed for its effect on direct and secondary PM levels, which assumes that diesel engines do not reach 50 percent of light truck sales until 2010. However, both analyses assume that diesel engines' share of light truck sales eventually reach the same level, and the two analyses' estimates of the total number of diesel trucks on the road tend to converge after 2010. Under this more gradual phase-in schedule, the increase in nationwide cancer risk would be slightly lower, about 128 percent. This estimate was developed by adjusting the estimated potential increase in risk for the more rapid phase-in to reflect the approximately four percent decrease in projected diesel PM emissions in 2020 that would result from the more gradual phase-in schedule.

Under both phase-in scenarios, we have estimated that the proposed Tier 2 standards for PM emissions from light-duty gasoline vehicles and trucks would reduce the potential increase in diesel PM cancer risk from cars and light trucks by over 85 percent. The potential number of cancers avoided would be even larger in future years as the proportion of diesel-powered light-duty trucks, and the number of miles they are driven, increased.

Table III-35. Average Nationwide Highway Vehicle Toxic Emission Rates (mg/mi) in 2007, for Various Scenarios

Toxic	*No New Controls Scenario*	*40 ppm Sulfur Scenario*	*0.055 NMHC Standard w/40 ppm Sulfur Scenario*	*0.055 NMHC Standard, 40 ppm Gasoline Sulfur, & High Diesel Sales Scenario (50% of 2004 Sales)*
Benzene	25.54	24.43	23.44	20.89
Acetaldehyde	5.54	5.43	5.29	5.23
Formaldehyde	14.30	14.38	14.04	14.15
1,3-Butadiene	3.26	2.96	2.86	2.82
Diesel PM	23.36	23.36	23.36	38.69

Table III-36. Average Nationwide Highway Vehicle Toxic Emission Rates (mg/mi) in 2020, for Various Scenarios

Toxic	*No New Controls Scenario*	*40 ppm Sulfur Scenario*	*0.055 NMHC Standard w/40 ppm Sulfur Scenario*	*0.055 NMHC Standard, 40 ppm Gasoline Sulfur, & High Diesel Sales Scenario (50% of 2004 Sales)*
Benzene	15.61	14.68	11.36	9.02
Acetaldehyde	3.39	3.29	2.82	2.77
Formaldehyde	8.42	8.45	7.29	7.45
1,3-Butadiene	2.29	2.04	1.69	1.53
Diesel PM	17.42	17.42	17.42	41.29

Table III-37. Average Nationwide Highway Vehicle Toxic Exposures for the Entire Population (µg/m^3) in 2007, for Various Scenarios

Toxic	*No New Controls Scenario*	*40 ppm Sulfur Scenario*	*0.055 NMHC Standard w/40 ppm Sulfur Scenario*	*0.055 NMHC Standard, 40 ppm Gasoline Sulfur, & High Diesel Sales Scenario (50% of 2004 Sales)*
Benzene	0.46	0.44	0.42	0.37
Acetaldehyde	0.10	0.10	0.095	0.094
Formaldehyde	0.26	0.26	0.26	0.26
1,3-Butadiene	0.044	0.040	0.038	0.038
Diesel PM	0.42	0.42	0.42	0.70

Table III-38. Average Nationwide Highway Vehicle Toxic Exposures for the Entire Population (µg/m^3) in 2020, for Various Scenarios

Toxic	*No Tier 2/Sulfur Scenario*	*40 ppm Sulfur Scenario*	*0.055 NMHC Standard w/40 ppm Sulfur Scenario*	*0.055 NMHC Standard, 40 ppm Gasoline Sulfur, & High Diesel Sales Scenario (50% of 2004 Sales)*
Benzene	0.36	0.34	0.26	0.21
Acetaldehyde	0.078	0.075	0.064	0.064
Formaldehyde	0.20	0.20	0.17	0.17
1,3-Butadiene	0.039	0.035	0.029	0.026
Diesel PM	0.40	0.40	0.40	0.96

Table III-39. Average Nationwide Highway Vehicle Gaseous Toxic Exposures for the Entire Population (µg/m^3) in 2020, under proposed Tier 2 standards.

Toxic	*Exposure (µg/m^3)*
Benzene	0.25
Acetaldehyde	0.077
Formaldehyde	0.21
1,3-Butadiene	0.031

e. Limitations

The analysis referenced above was conducted by Sierra Research for the Office of Mobile Sources. It will undergo formal scientific peer review in the near future. Once that review is complete and the peer review comments are addressed, OMS expects to conduct a formal risk assessment on health risk of toxic emissions from mobile sources for the final rule.

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Chapter IV: Technological Feasibility

A. Feasibility of Tier 2 Exhaust Emission Standards for LDVs and LDTs

1. NMOG and NOx Emissions from Gasoline-Fueled Vehicles

Emission control technology has evolved rapidly since the passing of the CAA Amendments of 1990. Emission standards applicable to 1990 model year vehicles required roughly 90 percent reductions in exhaust HC and CO emissions and a 75 percent reduction in NOx emissions compared to the uncontrolled emissions. Some vehicles currently in production show overall reductions in these three pollutants of more than 99 percent. These vehicles emissions are well below those necessary to meet the current federal Tier 1 and even California LEV standards.

A number of technological advances and breakthroughs have allowed these significant emission reductions to occur without the need for expensive, exotic equipment and fuels. For example, ARB originally projected that many vehicles would require electrically heated catalysts to meet their LEV program requirements. Today, no manufacturer is expected to use these devices to comply with the LEV program requirement. EPA projected that alternative fuels, such as methanol or natural gas, may be needed to meet these low emission levels. Today, while vehicles using these alternative fuels are capable of meeting the California LEV requirements, so are vehicles fueled with gasoline.

The most significant improvements which have facilitated these low emission levels have been to traditional catalysts, which now warm up very rapidly and are substantially more durable than past technology, and to fuel metering, which is more precise and accurate than previous systems. Improvements have also been made to base engine designs, which have resulted in lower engine-out emissions. Reduction of combustion chamber crevice volumes and oil consumption are examples of improvements to base engine designs.

Table IV-1 below lists specific types of emission controls which EPA projects will be needed in order for LDVs and LDTs to meet the proposed Tier 2 standards. It is important to point out that the use of all of the following technologies is not necessarily required to meet the proposed Tier 2 standards. The choices and combinations of technologies will depend on several factors, such as current engine-out emission levels, effectiveness of existing emission control systems, and individual manufacturer preferences. In some cases, such as projected increases in catalyst volume and precious metal loading, EPA believes that most, if not all, LDVs and LDTs will use the specified emission control technique.

Table IV-1. Emission Control Hardware and Techniques Projected to Meet Proposed Tier 2 Vehicle Standards

Emission Control Technologies	
Fast Light-Off Exhaust Gas Oxygen Sensor	Injection of Air into Exhaust
Universal Exhaust Gas Oxygen Sensor	Heat Optimized Exhaust Pipe
Retarded Spark Timing at Start-Up	Leak-Free Exhaust System
More Precise Fuel Control	Close-Coupled Catalyst
Faster Microprocessor	Improved Catalyst Washcoats
Individual Cylinder Air-Fuel Control	Increased Catalyst Volume and PGM Loading
Manifold with Low Thermal Capacity	Full Electronic Exhaust Gas Recirculation
Air-Assisted Fuel Injection	Engine Modifications

a. Technology Description

The following descriptions provide an overview of the latest technologies capable of reducing exhaust emissions. The descriptions will also discuss the state of development and current production usage of the various technologies. The technology descriptions are divided into four categories - base engine improvements, improved fuel control, improved fuel atomization, and improved catalyst performance.

i. Base Engine Improvements

There are several design techniques that can be used for reducing engine-out emissions, especially for HC and NOx. The main causes of excessive engine-out emissions are unburned HC's and high combustion temperatures for NOx. Methods for reducing engine-out HC emissions include the reduction of crevice volumes in the combustion chamber, reducing the combustion of lubricating oil in the combustion chamber and developing leak-free exhaust systems. Leak-free exhaust systems are considered to be base engine improvements because any modifications or changes made to the exhaust manifold can directly affect the design of the base engine. Base engine control strategies for reducing NOx include the use of "fast burn" combustion chamber designs, multiple valves with variable-valve timing, and exhaust gas recirculation.

Combustion Chamber Design

Unburned fuel can be trapped momentarily in crevice volumes (i.e., the space between the piston and cylinder wall) before being subsequently released. Since trapped and re-released fuel can increase engine-out HC, the reduction of crevice volumes is beneficial to emission performance. One way to reduce crevice volumes is to design pistons with reduced top "land heights" (The distance between the top of the piston and the first piston ring). The reduction of crevice volume is especially desirable for vehicles with larger displacement engines, since they typically produce greater levels of engine-out HC than smaller displacement engines.

Another cause of excess engine-out HC emissions is the combustion of lubricating oil that leaks into the combustion chamber, since heavier hydrocarbons in oil do not oxidize as readily as those in gasoline. Oil in the combustion chamber can also trap gaseous HC from the fuel and release it later unburned. In addition, some components in lubricating oil can poison the catalyst and reduce its effectiveness. To reduce oil consumption, vehicle manufacturers will tighten tolerances and improve the surface finishes of cylinders and pistons, improve piston ring design and material, and improve exhaust valve stem seals to prevent excessive leakage of lubricating oil into the combustion chamber.

As discussed above, engine-out NOx emissions result from high combustion temperatures. Therefore, the main control strategies for reducing engine-out NOx are designed to lower combustion temperature. The most promising techniques for reducing combustion temperatures, and thus engine-out NOx emissions, are the combination of increasing the rate of combustion, reducing spark advance, and adding a diluent to the air-fuel mixture, typically via exhaust gas recirculation (EGR). The rate of combustion can be increased by using "fast burn" combustion chamber designs. A fast burn combustion rate provides improved thermal efficiency and a greater tolerance for dilution from EGR resulting in better fuel economy and lower NOx emissions. There are numerous ways to design a fast burn combustion chamber. However, the most common approach is to induce turbulence into the combustion chamber which increases the surface area of the flame front and thereby increases the rate of combustion, and to locate the spark plug in the center of the combustion chamber. Locating the spark plug in the center of the combustion chamber promotes more thorough combustion and allows the ignition timing to be retarded, decreasing the dwell time of hot gases in the combustion chamber and reducing NOx formation. Many engine designs induce turbulence into the combustion chamber by increasing the velocity of the incoming air-fuel mixture and having it enter the chamber in a swirling motion (known as "swirl").

Improved EGR Design

One of the most effective means of reducing engine-out NOx emissions is exhaust gas recirculation. By recirculating spent exhaust gases into the combustion chamber, the overall air-fuel mixture is diluted, lowering peak combustion temperatures and reducing NOx. As discussed above, the use of high swirl, high turbulence combustion chambers can allow the amount of EGR to be increased from current levels of 15 to 17 percent to levels possibly as high

as 20 to 25[r] percent, resulting in a 15 to 20 percent reduction in engine-out NOx emissions.

Many EGR systems in today's vehicles utilize a control valve that requires vacuum from the intake manifold to regulate EGR flow. Under part-throttle operation where EGR is needed, engine vacuum is sufficient to open the valve. However, during throttle applications near or at wide-open throttle, engine vacuum is too low to open the EGR valve. While EGR operation only during part-throttle driving conditions has been sufficient to control NOx emissions for most vehicles in the past, more stringent NOx standards and emphasis on controlling off-cycle emission levels may require more precise EGR control and additional EGR during heavy throttle operation to reduce NOx emissions. Many manufacturers now use electronic EGR in place of mechanical back-pressure designs. By using electronic solenoids to open and close the EGR valve, the flow of EGR can be more precisely controlled.

While most manufacturers agree that electronic EGR gives more precise control of EGR flow rate, not all manufacturers are using it. Numerous LEV vehicles certified for the 1998 model year still use mechanical EGR systems, and in some cases, no EGR at all. Nonetheless, the use of EGR remains a very important tool in reducing engine-out NOx emissions, whether mechanical or electronic.

Multiple Valves and Variable-Valve Timing

Conventional engines have two valves per cylinder, one for intake of the air-fuel mixture and the other for exhaust of the combustion products. The duration and lift (distance the valve head is pushed away from its seat) of valve openings is constant regardless of engine speed. As engine speed increases, the aerodynamic resistance to pumping air in and out of the cylinder for intake and exhaust also increases. By doubling the number of intake and exhaust valves, pumping losses are reduced, improving the volumetric efficiency and useful power output.

In addition to gains in breathing, the multiple-valve (typically 4-valve) design allows the spark plug to be positioned closer to the center of the combustion chamber (as discussed above) which decreases the distance the flame must travel inside the chamber. In addition, the two streams of incoming gas can be used to achieve greater mixing of air and fuel, further increasing combustion efficiency which lowers engine-out HC emissions.

Even greater improvements to combustion efficiency can be realized by using valve timing and lift control to take advantage of the 4-valve configuration. Conventional engines utilize fixed-valve timing and lift across all engine speeds. Typically the valve timing is set at a level that is a compromise between low speed torque and high engine speed horsepower. At light engine loads it would be desirable to close the intake valve earlier to reduce pumping losses.

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[r] Some manufacturers have stated that EGR impacts the ability to control net air-fuel ratios tightly due to dynamic changes in exhaust back pressure and temperature, and that the advantages of increasing EGR flow rates are lost partly in losses in air-fuel ratio control even with electronic control of EGR. Higher EGR flow rates can be tolerated by modern engines with more advanced combustion chambers, but EGR cooling may be necessary to achieve higher EGR flow rates within acceptable detonation limits without significant loss of air-fuel control.

Variable valve timing can enhance both low speed torque and high speed horsepower with no necessary compromise between the two. Variable valve timing can allow for increased swirl and intake charge velocity, especially during low load operating conditions where sufficient swirl and turbulence tend to be lacking. By providing a strong swirl formation in the combustion chamber, the air-fuel mixture can mix sufficiently, resulting in a faster, more complete combustion, even under lean air-fuel conditions, thereby reducing emissions. Variable valve technology by itself may have somewhat limited effect on reducing emissions. Several vehicle manufacturers estimated emission reductions of 3 percent-10 percent for both NMHC and NOx, but reductions could be increased when variable valve timing is combined with optimized spark plug location and additional EGR.

Multi-valve engines already exist in numerous federal and California certified vehicles and are projected by ARB to become even more common. ARB also projects that in order to meet LEV II and ULEV II standards, more vehicles will have to make improvements to the induction system, including the use of variable valve timing.

Leak-Free Exhaust System

Leaks in the exhaust system can result in increased emissions, but not necessarily from emissions escaping from the exhaust leak to the atmosphere. With an exhaust system leak, ambient air is typically sucked into the exhaust system by the pressure difference created by the flowing exhaust gases inside the exhaust pipe. The air that is sucked into the exhaust system is unmetered and, therefore, unaccounted for in the fuel system's closed-loop feedback control. The excess air in the exhaust causes the computer to increase fuel to the engine, resulting in erratic and/or overly rich fuel control. This results in increased emission levels and potentially poor driveability. In addition, an air leak can cause an oxidation environment to exist in a three-way catalyst at low speeds that would hamper reduction of NOx and lead to increased NOx emissions.

Some vehicles currently use leak-free exhaust systems today. These systems consist of an improved exhaust manifold/exhaust pipe interface plus a corrosion-free flexible coupling inserted between the exhaust manifold flange and the catalyst to reduce stress and the tendency for leakage to occur at the joint. In addition, improvements to the welding process for catalytic converter canning could ensure less air leakage into the converter and further reduce emissions. ARB and MECA project that vehicle manufacturers will continue to incorporate leak-free exhaust systems as emission standards become more stringent.

ii. Improvements in Air-Fuel Ratio Control

Modern three-way catalysts require the air-fuel ratio (A/F) to be as close to stoichiometry (the amount of air and fuel just sufficient for nearly complete combustion) as possible. This is because three-way catalysts simultaneously oxidize HC and CO, and reduce NOx. Since HC and CO are oxidized during A/F operation slightly lean of stoichiometry, while NOx is reduced during operation slightly rich of stoichiometry, there exists a very small A/F window of

operation around stoichiometry where catalyst conversion efficiency is maximized for all three pollutants (i.e., less than 1 percent deviation in A/F or roughly ± 0.15). Contemporary vehicles have been able to maintain stoichiometry, or very close to it, by using closed-loop feedback fuel control systems. At the heart of these systems has been a single heated exhaust gas oxygen (HEGO) sensor. The HEGO sensor continuously switches between rich and lean readings. By maintaining an equal number of rich readings with lean readings over a given period, and by limiting the degree to which the exhaust is rich or lean at any point in time, the fuel control system is able to maintain stoichiometry. While this fuel control system is capable of maintaining the A/F with the required accuracy under steady-state operating conditions, the system accuracy is challenged during transient operation where rapidly changing throttle conditions occur. Also, as the sensor ages, its accuracy decreases.

Dual Oxygen Sensors

Many vehicle manufacturers have placed a second HEGO sensor(s) downstream of one or more catalysts in the exhaust system as a method for monitoring the catalyst effectiveness of the federally and California mandated on-board diagnostic (OBD II) system. In addition to monitoring the effectiveness of the catalyst, the downstream sensors can also be used to monitor the primary control sensor and adjust for deterioration, thereby maintaining precise A/F control at higher mileages. Should the front primary HEGO sensor, which operates in a higher temperature environment, begin to exhibit slow response or drift from its calibration point, the secondary downstream sensor can be relied upon for modifying the fuel system controls to compensate for the aging effects. By placing the second sensor further downstream from the hot engine exhaust, where it is also less susceptible to poisoning, the rear sensor is less susceptible to aging over the life of the vehicle. As a result, the use of a dual oxygen sensor fuel control system can ensure more robust and precise fuel control, resulting in lower emissions.

Currently, all vehicle manufacturers use a dual oxygen sensor system for monitoring the catalyst as part of the OBD II system. As discussed above, most manufacturers also utilize the secondary HEGO sensor for trim (i.e., adjustments to) of the fuel control system. It is anticipated that all manufacturers will soon use the secondary sensor for fuel trim.

Universal Oxygen Sensors

The universal exhaust gas oxygen (UEGO) sensor, also called a "linear oxygen sensor", could replace conventional HEGO sensors. Conventional HEGO sensors only determine if an engine's A/F is richer or leaner than stoichiometric, providing no indication of the exact level of the A/F. In contrast, UEGO's are capable of recognizing both the direction and magnitude of A/F transients since the voltage output of the UEGO is "proportional" with changing A/F (i.e., each voltage value corresponds to a certain A/F). Therefore, proportional A/F control is possible with the use of UEGO sensors, facilitating faster response of the fuel feedback control system and tighter control of A/F.

Although some manufacturers are currently using UEGO sensors, discussions with various manufacturers suggest that some manufacturers are of mixed opinion as to the future

applicability of UEGO sensors. Because of their high cost, manufacturers claim that it may be cheaper to improve HEGO technology rather than utilize UEGO sensors. An example of this is the use of a “planar” design for HEGO sensors. Planar HEGO sensors (also known as “fast light-off” HEGO sensors) have a thimble design that is considerably lighter than conventional designs. The main benefits are shorter heat-up time and faster sensor response.

Individual Cylinder A/F Control

Another method for tightening fuel control is to control the A/F in each individual cylinder. Current fuel control systems control the A/F for the entire engine or a bank of cylinders. By controlling A/F for the entire engine or a bank of cylinders, any necessary adjustments made to fuel delivery for the engine are applied to all cylinders simultaneously, regardless of whether all cylinders need the adjustment. For example, there is usually some deviation in A/F between cylinders. If a particular cylinder is rich, but the "bulk" A/F indication for the engine is lean, the fuel control system will simultaneously increase the amount of fuel delivered to all of the cylinders, including the rich cylinder. Thus, the rich cylinder becomes even richer having a potentially negative effect on the net A/F.

Individual cylinder A/F control helps diminish variation among individual cylinders. This is accomplished by modeling the behavior of the exhaust gases in the exhaust manifold and using sophisticated software algorithms to predict individual cylinder A/F. Individual cylinder A/F control requires use of an UEGO sensor in lieu of the traditional HEGO sensor, and requires a more powerful engine control computer.

Adaptive Fuel Control Systems

The fuel control systems of virtually all current vehicles incorporate a feature known as "adaptive memory" or "adaptive block learn." Adaptive fuel control systems automatically adjust the amount of fuel delivered to compensate for component tolerances, component wear, varying environmental conditions, varying fuel compositions, etc., to more closely maintain proper fuel control under various operating conditions.

For most fuel control systems in use today, the adaption process affects only steady-state operation conditions (i.e., constant or slowly changing throttle conditions). Because transient operating conditions have always provided a challenge to maintaining precise fuel control, the use of adaptive fuel control for transient operation would be extremely valuable. Accurate fuel control during transient driving conditions has traditionally been difficult because of inaccuracies in predicting the air and fuel flow under rapidly changing throttle conditions. Air and fuel dynamics within the intake manifold (fuel evaporation and air flow behavior), and the time delay between measurement of air flow and the injection of the calculated fuel mass, result in temporarily lean A/F during transient operation. Variation in fuel properties, particularly distillation characteristics, also increases the difficulty in predicting A/F during transients. These can all lead to poor driveability and an increase in NOx emissions.

Electronic Throttle Control Systems

As mentioned above, the time delay between the air mass measurement and the calculated fuel delivery presents one of the primary difficulties in maintaining accurate fuel control and good driveability during transient driving conditions. With the conventional mechanical throttle system (a metal linkage connected from the accelerator pedal to the throttle blade in the throttle body), quick throttle openings can result in a lean A/F spike in the combustion chamber. Although algorithms can be developed to model air and fuel flow dynamics to compensate for these time delay effects, the use of an electronic throttle control system, known as "drive-by-wire" or "throttle-by-wire," may better synchronize the air and fuel flow to achieve proper fueling during transients (e.g., the driver moves the throttle, but the fuel delivery is momentarily delayed to match the inertial lag of the increased airflow).

While this technology is currently used on several vehicle models, it is considered expensive and those vehicles equipped with the feature are expensive, higher end vehicles. Because of its high cost, it is not anticipated that drive-by-wire technology will become commonplace in the near future.

iii. Improvements in Fuel Atomization

In addition to maintaining a stoichiometric A/F ratio, it is also important that a homogeneous air-fuel mixture be delivered at the proper time and that the mixture is finely atomized to provide the best combustion characteristics and lowest emissions. Poorly prepared air-fuel mixtures, especially after a cold start and during the warm-up phase of the engine, result in significantly higher emissions of unburned HC since combustion of the mixture is less complete. By providing better fuel atomization, more efficient combustion can be attained, which should aid in improving fuel economy and reducing emissions. Sequential multi-point fuel injection and air-assisted fuel injectors are examples of the most promising technologies available for improving fuel atomization.

Sequential Multi-Point

Typically, conventional multi-point fuel injection systems inject fuel into the intake manifold by injector pairs. This means that rather than injecting fuel into each individual cylinder, a pair of injectors (or even a whole bank of injectors) fires simultaneously, sending fuel into several cylinders. Since only one of the cylinders is actually ready for fuel at the moment of injection, the other cylinder(s) gets too much or too little fuel. With this less than optimum fuel injection timing, fuel puddling and intake manifold wall wetting can occur, both of which can hinder complete combustion. Sequential injection, on the other hand, delivers a more precise amount of fuel that is required by each cylinder to each cylinder at the appropriate time. Because of the emission reductions and other performance benefits "timed" fuel injection offers, sequential fuel injection systems are very common on today's vehicles and are expected to be incorporated in all vehicles soon.

Air-Assisted Fuel Injectors

Another method to further homogenize the air-fuel mixture is through the use of air-assisted fuel injection. By injecting high pressure air into the fuel injector, and subsequently, the fuel spray, greater atomization of the fuel droplets can occur. Since achieving good fuel atomization is difficult when the air flow into the engine is low, air-assisted fuel injection can be particularly beneficial in reducing emissions at low engine speeds. In addition, industry studies have shown that the short burst of additional fuel needed for responsive, smooth transient maneuvers can be reduced significantly with air-assisted fuel injection due to a decrease in wall wetting in the intake manifold.

iv. Improvements to Exhaust Aftertreatment Systems

Over the last five years or so, there have been tremendous advancements in exhaust aftertreatment systems. Catalyst manufacturers are progressively moving to palladium as the main precious metal in automotive catalyst applications. Improvements to catalyst thermal stability and washcoat technologies, the design of higher cell densities, and the use of two-layer washcoat applications are just some of the advancements made to catalyst technology. There has also been much development in HC and NOx absorber technology. The advancements to exhaust aftertreatment systems are probably the single most important area of emission control development.

Catalysts

As previously mentioned, significant changes in catalyst formulation, size and design have been made in recent years and additional advances in these areas are still possible. Palladium (Pd) is likely to continue as the precious metal of choice for close-coupled applications and will start to see more use in underfloor applications. Some manufacturers, for example, have suggested that they will use Pd/Rh in lieu of tri-metal or conventional Pt/Rh catalysts for underfloor applications. Palladium catalysts, however, are less resistant to poisoning by oil-and fuel-based additives than conventional platinum/rhodium (Pt/Rh) catalysts. Based on current certification trends and information from vehicle manufacturers and catalyst suppliers, it is expected that Pd-only and Pd/Rh catalysts will be used in the close-coupled locations while conventional or tri-metal (Pd/Pt/Rh) catalysts will continue to be used in underfloor applications. As palladium technology continues to improve, it may be possible for a single close-coupled catalyst to replace both catalysts. If fact, at least one vehicle manufacturer currently uses a single Pd-only catalyst for one of their models. According to MECA, new Pd-based catalysts are now capable of withstanding exposure to temperatures as high as 1100EC and, as a result, can be moved very close to the exhaust manifold to enhance catalyst light-off performance.

In addition to reliance on Pd and tri-metal applications, catalyst manufacturers have developed “multi-layered” washcoat technologies. Automotive catalysts consist of a cylindrical or oval shaped substrate, typically made of ceramic or metal. The substrate is made up of hundreds of very small, but long cells configured in a shape similar to a honey-comb. The substrate is coated with a substance containing precious metals, rare earth metals, and base-metal oxides, that is known as the catalyst washcoat. Typical washcoat formulations consist of

precious metals which either oxidize or reduce pollutants, base-metal oxides, such as alumina, which provide the surface area support for the precious metals to adhere to, and base components (rare earth metals) such as lanthanum, ceria, and zirconia, which act as promoters, stabilizers, and encourage storage and reduction of oxygen. Conventional catalysts have a single layer of washcoat and precious metals applied to the catalyst substrate. More advanced catalysts use multi-layered washcoats with two or more layers of different combinations of washcoat and precious metals. The washcoat can be applied to the substrate such that one layer can be applied on top of another. The use of multi-layered washcoat technology allows precious metals that have adverse reactions together to be separated such that catalyst durability and emission reduction performance are significantly enhanced. For example, Pd and Rh can have adverse reactions when combined together in a single washcoat formulation. A multi-layer washcoat architecture that uses Pd and Rh could have the Pd on the bottom layer and the Rh on the top layer. Rh is particularly used at reducing NOx. It is generally preferable to reduce NOx in the top layer while CO and HC are still present and then oxidize CO and HC in the bottom layer. Figure IV-1 illustrates the impact coating architecture (multi-layered washcoat technology) can have on emission performance.

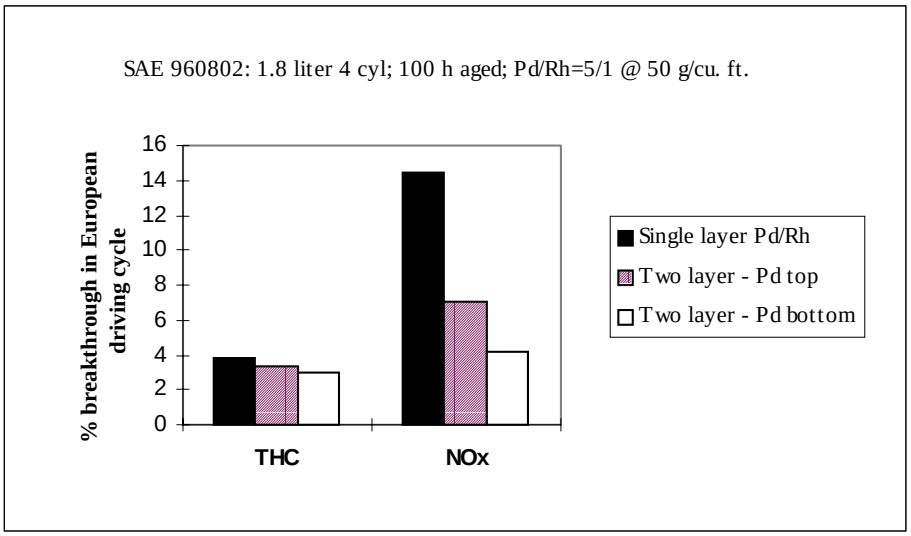

Figure IV-1. Impact of Coating Architecture on HC and NOx Emissions.

Manufacturers have also been developing catalysts with substrates which utilize thinner walls in order to design higher cell density, low thermal mass catalysts for close-coupled applications (improves mass transfer at high engine loads and increases catalyst surface area as well as speeding up light-off during cold starts). The greater the number of cells there are, the more surface area that exists for washcoat components and precious metals to adhere to, resulting in more precious metal sites available for oxidizing and reducing pollutants. Cell densities of 600 cells per square inch (cpsi) have already been commercialized, and research on 900 cpsi catalysts has been progressing. Typical cell densities for conventional catalysts are 400 cpsi.

We have projected that in order to meet the proposed Tier 2 emission standards catalyst volumes will increase. Current California LEV and ULEV passenger car catalyst volume to engine displacement ratios are approximately 0.7 to over 1.0 while many trucks only have ratios of 0.6 or less. We believe that in order to comply with proposed Tier 2 standards, most vehicle will likely need catalyst volumes equal to the displacement of the engine, or in some cases, even greater. As mentioned above, higher cell density substrates effectively provide more surface area for pollutant conversion, therefore catalyst volumes may not need to be increased as significantly if higher cell density substrates are used.

We have also projected that some level of increased catalyst loading will be necessary to meet proposed Tier 2 standards. Typical catalyst loading for current LEVs and ULEVs range from 50 g/cu ft to 300 g/cu ft. We believe that, based on input from catalyst suppliers and vehicle manufacturers, depending on the vehicle, catalysts meeting Tier 2 standards will need loadings in the 100 - 300 g/cu ft range. However, catalyst suppliers have also indicated to us that they and vehicle manufacturers are constantly working on ways to reduce the amount of precious metal loading (a process they refer to as “thrifting”). Thrifting is achieved in several ways. One of the most common is matching the catalyst to the attributes of the vehicle. By working in unison, vehicle manufacturers and catalyst suppliers are able to thrift or reduce the amount of precious metal used in a given application by attempting to optimize the vehicle fuel control strategy, exhaust mass flow rate, and exhaust temperature with various catalyst parameters, such as catalyst location, substrate design, cell density, oxygen storage capability, and precious metal and base metal dispersion, to name a few. Other methods of thrifting are the constant improvements being made to washcoat architecture - that is, constant improvement to the materials used in the washcoat formulation so that the precious metals and other components better adhere to the substrate surface. Finally, improvements to washcoat application processes can also significantly improve catalyst performance while allowing thrifting of precious metals. Improvements to processes consist of advancements to the process used to coat the substrate with washcoat materials - allowing precious metals, base metals, and ceria to better dispersed. Better dispersion means that rather than relatively large “clumps” of precious metals unevenly dispersed throughout the catalyst surface, many smaller precious metal sites are dispersed uniformly throughout the catalyst surface increasing the chance for pollutants to come into contact with the precious metal and react into a harmless emission. Therefore, as thrifting continues, it is possible that precious metal loading may actually decrease rather than increase.

The largest source of HC emissions continues to be cold start operation where the combination of rich A/F operation and the ineffectiveness of a still relatively cool catalyst result in excess HC emissions. One of the most effective strategies for controlling cold start HC emissions is to reduce the time it takes to increase the operating temperature of the catalyst immediately following engine start-up. The effectiveness or efficiency of the catalyst increases as the catalyst temperature increases. One common strategy is to move the catalyst closer to the exhaust manifold where the exhaust temperature is greater (e.g., a close-coupled catalyst). In addition to locating the catalyst closer to the engine, retarding the spark timing and increasing idle speed are other possible approaches. Retarding spark timing, causes combustion to occur later in the power stroke, allowing more heat to escape into the exhaust manifold during the exhaust stroke. Increased idle speed leads to a greater amount of combustion per unit time,

providing a greater quantity of heat for heating the exhaust manifold, headpipe, and catalyst.

Another strategy is to use an electrically-heated catalyst (EHC). The EHC consists of a small electrically heated catalyst placed directly in front of a conventional catalyst. Both substrates are located in a single can or container. The EHC is powered by the alternator, or solely from the vehicle's battery, or from a combination of the alternator and battery. The EHC is capable of heating up almost immediately, assisting the catalyst that directly follows it to also heat up and obtain light-off temperature (e.g., the catalyst temperature where catalyst efficiency is 50 percent) quickly. Manufacturers have indicated that EHC's will probably only be necessary for a limited number of LEV II/ULEV II engine families, mostly larger displacement V-8's where cold start emissions are difficult to control.

Adsorbers/Traps

Other potential exhaust aftertreatment systems that are used in conjunction with a catalyst or catalysts, are the HC and NOx adsorbers or traps. Hydrocarbon adsorbers are designed to trap HC while the catalyst is cold and unable to sufficiently convert the HC. They accomplish this by utilizing an adsorbing material which holds onto the HC. Once the catalyst is warmed up, the trapped HC are automatically released from the adsorption material and are converted by the fully functioning downstream three-way catalyst. There are three principal methods for incorporating an adsorber into the exhaust system. The first is to coat the adsorber directly on the catalyst substrate. The advantage is that there are no changes to the exhaust system required, but the desorption process cannot be easily controlled and usually occurs before the catalyst has reached light-off temperature. The second method locates the adsorber in another exhaust pipe parallel with the main exhaust pipe, but in front of the catalyst and includes a series of valves that route the exhaust through the adsorber in the first few seconds after cold start, switching exhaust flow through the catalyst thereafter. Under this system, mechanisms to purge the adsorber are also required. The third method places the trap at the end of the exhaust system, in another exhaust pipe parallel to the muffler, because of the low thermal tolerance of adsorber material. Again a purging mechanism is required to purge the adsorbed HC back into the catalyst, but adsorber overheating is avoided.

NOx adsorbers are also being developed, but according to MECA, are generally recognized as a control for NOx resulting from reduced EGR. They are typically used for lean-burn applications and are not applicable to engines that attempt to maintain stoichiometry all the time.

Secondary Air Injection

Secondary injection of air into exhaust ports after cold start (e.g., the first 40-60 seconds) when the engine is operating rich, coupled with spark retard, can promote combustion of unburned HC and CO in the exhaust manifold and increase the warm-up rate of the catalyst. By means of an electrical pump, secondary air is injected into the exhaust system, preferably in close proximity of the exhaust valve. Together with the oxygen of the secondary air and the hot exhaust components of HC and CO, oxidation ahead of the catalyst can bring about an efficient

increase in the exhaust temperature which helps the catalyst to heat up quicker. The exothermic reaction that occurs is dependent on several parameters (secondary air mass, location of secondary air injection, engine A/F ratio, engine air mass, ignition timing, manifold and headpipe construction, etc.), and ensuring reproducibility demands detailed individual application for each vehicle or engine design.

Insulated or Dual Wall Exhaust System

Insulating the exhaust system is another method of furnishing heat to the catalyst to decrease light-off time. Similar to close-coupled catalysts, the principle behind insulating the exhaust system is to conserve heat generated in the engine to aid the catalyst warm-up. Through the use of laminated thin-wall exhaust pipes, less heat will be lost in the exhaust system, enabling quicker catalyst light-off.

v. Improvements in Engine Calibration Techniques

Of all the technologies discussed above, one of the most important emission control strategies is not hardware-related. Rather, it is software related and, more specifically, involves the algorithms and calibrations contained within the software that are used in the power-train control module (PCM) which control how the various engine and emission control components and systems operate. Advancements in software along with refinements to existing algorithms and calibrations can have a major impact in reducing emissions. Confidential discussions between manufacturers and EPA have suggested that manufacturers believe emissions can be further reduced by improving and updating their calibration techniques. As computer technology and software continues to advance, so does the ability of the automotive engineer to use these advancements in ways to better optimize the emission control systems. For example, as processors become faster, it is possible to perform calculations quicker, thus allowing for faster response times for controlling engine parameters, such as fuel rate and spark timing. As the PCM becomes more powerful with greater memory capability, algorithms can become more sophisticated. Manufacturers have found that as computer processors, engine control sensors and actuators, and computer software become more advanced, and, in conjunction with their growing experience with developing calibrations, as time passes, their calibration skills will continue to become more refined and robust, resulting in even lower emissions.

Manufacturers have suggested to EPA that perhaps the single most effective method for controlling NOx emissions will be tighter A/F control which could be accomplished with advancements in calibration techniques without necessarily having to use advanced technologies, such as UEGO sensors. Manufacturers have found ways to improve calibration strategies such that meeting federal cold CO requirements, as well as, complying with LEV standards, have not required the use of advanced hardware, such as EHCs or adsorbers.

Since emission control calibrations are typically confidential, it is difficult to predict what advancements will occur in the future, but it is clear that improved calibration techniques and strategies are a very important and viable method for further reducing emissions.

b. Data Supporting Tier 2 Technical Feasibility

Automobile manufacturers generally design vehicles to meet emission targets which are 50-70 percent of the emission standards, even after the catalytic converter has been aged to full useful life (e.g., 100,000-120,000 miles). The manufacturer desires this 30-50 percent safety margin in order to reduce the probability that in-use vehicles will exceed the standard to an acceptable level. Thus, the emission design targets for proposed Tier 2 standards for full useful life would be 0.045-0.063 g/mi NMOG and 0.035-0.049 g/mi NOx at full useful life.

With this in mind, we will present data from several sources that establish our proposed Tier 2 standards to be feasible. The data ranges from certification emission levels to feasibility evaluation programs undertaken in the last year by ARB and MECA. Even though these programs were directed towards the LEV II program, the data and information resulting from these programs are useful to EPA in establishing feasibility of Tier 2 emission standards since our proposed Tier 2 standards are the same as the LEV II standards.

i. Certification Emission Levels

Manufacturers report certification results for engine families. Those engine families are used in a variety of vehicle models and configurations. Manufacturers are required to report certification test results for at least two vehicle configurations and often report results for five or six or more models or configurations within an engine family. Manufacturers, for example, will report certification test results for both automatic and manual transmission versions of a vehicle. Table IV-2 below indicates the number of engine families with at least one vehicle configuration at or below full-life NOx levels of 0.04, 0.07, and 0.1 g/mile. Of those at or below 0.04 and 0.07 g/mile NOx, 16 and 35, respectively, also have HC levels below 0.09 g/mile. There are approximately 400 engine families total.

Table IV-2. Number of Engine Families with One or More Engine/Vehicle Configurations with Low Full-life NOx Levels

NOx level	*Vehicles Below 6,000 pounds (LDVs, LDT1s, LDT2s)*	*Vehicles Above 6,000 pounds (LDT3s, LDT4s)*
# 0.04	20	2
# 0.07	45	3
# 0.1	150	11

Table IV-3 provides a listing of engine families with one or more vehicle configurations at or below 0.07 g/mile NOx. The table also provides the HC certification levels for those configurations. Where a range is shown, there is more than one configuration within the engine

family with full-life NOx certification levels at or below 0.07. The same vehicle models appear in the table more than once because multiple engine families are often certified for the same vehicle models. EPA assembled this list by reviewing 1999 model year certification data for engine families certified to nationwide Tier 1 standards, NLEV program standards, and the California program standards.

Table IV-3. 1999 Engine Families with One or More Vehicle Configurations with Full-life NOx Certification Levels at or below 0.07 g/mile NOx

Manufacturer	*Models*	*NOx level*	*HC level*	*Standard*
LDVs (passenger cars)				
Hyundai	Elantra Wagon, Tiburon	0.01 - 0.02	0.05	LEV
Ford	Contour, Mystique, Cougar	0.02 - 0.05	0.12 - 0.17	Tier 1
Ford	Contour, Mystique, Cougar	0.02*	0.12	Tier 1
Volkswagon, Audi	Passat, Passat wagon A4	0.03 - 0.07*	0.06 - 0.07	TLEV
Volvo	V70, S70	0.03	0.06 - 0.08	TLEV
Volvo	S70, V70, C70	0.03 - 0.04	0.05 - 0.07	LEV
Hyundai	Elantra, Tiburon	0.03 - 0.04*+	0.04 - 0.06	Tier 1
Daimler Chrysler	Cirrus, Stratus, Breeze	0.04*+	0.06	LEV
Mitsubishi	Diamante	0.04*+	0.05	LEV
Mitsubishi	Gallant, Mirage	0.04 +	0.03	LEV
Suzuki	Metro	0.04	0.03	TLEV
Ford	Mustang	0.04	0.17 - 0.21	Tier 1
Ford	Contour, Mystique, Cougar	0.04 - 0.05	0.07 - 0.08	TLEV
Daimler Chrysler	S320	0.04 +	0.07	Tier 1
Hyundai	Sonata	0.04 - 0.06*	0.07	TLEV
Volkswagon	Jetta, Golf, Cabriolet	0.04 - 0.06	0.04 -0.07	TLEV
Nissan	Altima	0.05	0.03	LEV
Ford	Sable, Taurus	0.05 - 0.06	0.13 - 0.14	Tier 1
Ford	Mustang	0.05 - 0.06	0.07	TLEV
Ford	Contour, Mystique, Cougar	0.06	0.07	Tier 1
Daimler Chrysler	E430, SL500	0.06 - 0.07	0.02	LEV
Daimler Chrysler	SL600	0.06	0.12	Tier 1
Hyundai	Accent	0.06*	0.08 - 0.1	TLEV
Hyundai	Sonata	0.06*	0.04 - 0.05	TLEV
Volkswagon	New Beetle, New Golf, New Jetta	0.06*	0.06	LEV
Mazda	MX-5 Miata	0.07	0.07	TLEV

Mitsubishi	Mirage	0.07	0.05	LEV
Volvo	S80	0.06 - 0.07*	0.07 - 0.08	TLEV
Volvo	S80	0.04 - 0.05	0.11	TLEV
Daimler Chrysler	C230 Kompressor	0.07	0.03	TLEV
Honda	Accord	0.07*	0.04 - 0.05	LEV
Honda	Civic HX	0.07*	0.09	TLEV
Honda	Civic	0.07*	0.07 - 0.08	TLEV
Infiniti	Q45	0.07*	0.11	Tier 1
LDT 1				
Daimler Chrysler	Jeep Cherokee 2WD, 4WD	0.03*+	0.06	Tier 1
Ford	Ranger	0.04 - 0.07	0.09 - 0.18	Tier 1
Mazda	B2500, B3000	0.04 - 0.06	0.08 - 0.13	Tier 1
Ford	Ranger	0.05*	0.11	Tier 1
LDT2				
Ford	Explorer	0.03 - 0.04	0.07 - 0.10	Tier1
Ford, Mazda	Ranger, B3000	0.04 - 0.07	0.12 - 0.15	Tier 1
Ford	F-150	0.05*	0.08 - 0.10	Tier 1
Mazda	B3000	0.05*	0.06 - 0.07	Tier 1
Ford, Mazda	Ranger, B3000	0.05 - 0.07	0.07 - 0.12	Tier 1
Daimler Chrysler	Caravan, Voyager	0.07		LEV
Nissan	Frontier	0.07*	0.07	LEV
LDT3				
Ford	F-150	0.04 - 0.06	0.07 - 0.08	Tier 1
Ford	F-150	0.05 - 0.06	0.11 - 0.12	Tier 1
LDT4				
Ford	Expedition, Navigator, F-250	0.04*	0.16 - 0.17	Tier 1

* Other model configurations have NOx certification levels above 0.07 g/mile
+ The official NOx certification result reported was 0 for these vehicles due to rounding. The values shown are the unrounded results.

A review of the Table above shows that most of the engine families with configurations

certified at 0.07 g/mile NOx or less are passenger cars and lighter weight LDTs . This is understandable since all LDT classes except LDT1 have emission standards considerably higher than LDVs. Thus, to this point, there has been no motivation for vehicle manufacturers to design and produce light-duty trucks with emission control systems on par with light-duty vehicle systems. Even so, there are several light-duty trucks with certification levels at or very close to the proposed Tier 2 requirements.

ii. Industry Sulfur Test Program

The Coordinating Research Council (CRC), automobile manufacturers and the American Petroleum Institute (API) all tested a number of vehicles capable of complying with the California LEV or ULEV standards. The primary purpose of these test programs was to estimate how higher fuel sulfur levels affected emissions. However, the test results with low sulfur fuel (i.e., 30-40 ppm sulfur) provide an indication of the emission control potential of these vehicles. Of the 20 unique vehicle models tested in these programs, four models met both of the Tier 2 NMOG and NOx design targets mentioned above. An additional three models had NMOG levels below the design targets and NOx levels above the design targets, but below the proposed NOx standard. All of these low emitting models were LDVs with 100K catalyst systems.

iii. MECA Test Program

The Manufacturers of Emission Controls Association (MECA) sponsored vehicle emission testing at the Southwest Research Institute (SwRI)[1] for the purpose of demonstrating the performance of advanced emission control systems in meeting proposed California LEV II and our proposed Tier 2 light-duty vehicle standards. SwRI took two LDVs (a 1997 3.8L Buick LeSabre and a 1997 4.6L Ford Crown Vic) and one LDT2 (3.4L Toyota T100) certified to the federal Tier 1 standards and replaced the original catalytic converters with more advanced catalytic converters provided by MECA members. The catalysts were thermally aged to roughly 50,000 mile of in-use operation. SwRI then attempted to optimize the emission performance by modifying the existing secondary air and exhaust gas recirculation (EGR) strategies. This was accomplished by using a computer controlled intercept system (Emissions Reduction Intercept and Control system or ERIC). This computer intercept methodology was used to recognize and modify only driving modes associated with high tailpipe emission modes, thereby minimizing the level of modifications to the base vehicle control system. The control tuning approach developed for each vehicle was unique to the individual vehicle. The computer intercept techniques used in this program were capable of modifying secondary air and EGR without setting any on-board diagnostic codes. The modified control strategies also did not have any measurable impact on fuel economy, nor were any detectable changes to vehicle driveability observed during FTP evaluations.

After these modifications, all three vehicles met the Tier 2 NMOG usefull life design targets. The LeSabre and T100 both met the NOx design target. The Crown Victoria, however was a little short of the design target, but did meet the proposed Tier 2 standard with a headroom

of 23 percent. The actual test results are summarized in Table IV-4 below.

Table IV-4. MECA Test Program: Emissions with Catalysts Aged to 100,000 Miles (g/mi).

	NMOG	*NOx*
Tier 2 Design Targets	0.045-0.063	0.035-0.049
Crown Victoria (LDV)	0.049	0.057
Buick LeSabre (LDV)	0.038	0.037
Toyota T100 (LDT2)	0.052	0.014

iv. ARB Test Program

ARB tested five different 1997-98 model year production LEV LDV models. Two of the six models met the proposed Tier 2 design targets for NMOG and NOx. Each vehicle was tested for baseline emissions at approximately 1K miles before any modifications to the vehicle's emission controls were made. Table IV-5 lists the average emissions from these FTP tests.

Table IV-5. ARB Production LEV LDV Passenger Car Emission Data.

Test Vehicle	*NMHC (g/mi)*	*CO (g/mi)*	*NOx (g/mi)*
1997 Mercury Sable	0.035	0.9	0.072
1998 Mercury Grand Marquis	0.048	0.6	0.014
1998 Nissan Altima	0.031	0.7	0.040
1998 Honda Accord EX	0.025	0.3	0.066
1998 Toyota Avalon	0.044	0.4	0.111

After the baseline FTP results were complete, new advanced catalysts supplied by various catalyst suppliers were installed on each test vehicle. In general, the advanced catalysts were placed in the same position as the OEM catalysts. Two of the vehicles had small close-coupled catalysts added to the OEM configuration. FTP tests were then conducted. If the emission results were not below the proposed LEV II standards with a reasonable margin, engine calibration modifications such as spark retard at engine start, O2 sensor biasing (typically rich), or secondary air injection modifications were made to reduce tailpipe emission levels further. In a couple of instances, approximately 4K miles were accumulated on the "green" catalysts before FTP tests were conducted again. All of the vehicles, once modified, had emission levels well below the proposed Tier 2 NMOG and NOx design targets. While these results are not with catalysts aged tofull usefull life, we believe these results are still very promising, since in-use

deterioration rates have been steadily declining. Even if these emissions were to double, they would still be very close to or below the proposed Tier 2 standards. Table IV-6 lists the modified passenger car emission results.

Table IV-6. ARB Modified Passenger Car Emission Data (advanced catalysts with modifications to fuel and/or spark & secondary air)

Manufacturer	*Model*	*Mileage*	*NMOG (g/mi)*	*CO (g/mi)*	*NOx (g/mi)*
Mercury	Sable	0	0.029	1.0	0.036
Mercury	Grand Marquis	4000	0.033	0.5	0.004
Nissan	Altima	0	0.028	0.7	0.033
Honda	Accord EX	0	0.026	0.4	0.035

ARB also tested two identical 1998 Ford Expeditions (LDT4). Both vehicles were tested in the baseline OEM configuration at 2,000 miles with promising results. Table IV-7 lists the baseline emission results for the two Expeditions.

Table IV-7. ARB Ford Expedition Baseline Emission Test Results

Vehicle	*No. of Tests*	*NMHC (g/mi)*	*CO (g/mi)*	*NOx (g/mi)*
#2	8	0.090	1.69	0.030
#3	6	0.077	1.57	0.031

ARB installed advanced Pd/Rh catalyst systems bench aged to 50,000 miles along with 50,000 mile bench aged oxygen sensors on both vehicles and were able to reduce NOx emissions about 50 percent from the NOx certification level of 0.14 g/mi. ARB also added secondary air to the vehicles and made some modifications to the spark timing (retarded) and oxygen sensor bias (rich) and found that they were able to further reduce emissions. Table IV-8 lists the emission results of the Expeditions with advanced catalyst systems.

Table IV-8. ARB Expedition Emission Results with Advanced Catalyst Systems

Vehicle	*No. Of Tests*	*NMHC (g/mi)*	*CO (g/mi)*	*NOx (g/mi)*
#2	4	0.111	3.32	0.048
#3	7	0.112	2.91	0.052

C EPA Test Program

Our test program was aimed at lowering the emissions of a large 1999 LDT3 vehicle. This vehicle has a high horsepower engine, four wheel drive, and a curb weight of 4,500 pounds (GVW of 6,000 lbs). The exhaust system of the pickup was modified to incorporate two close coupled and two underfloor catalytic converters provided by MECA. The catalytic converters used for these tests were nearly identical to the system used on "Vehicle 1" in the work by Webb et al.[s] The only modifications from the specification used by Webb et al. were insulation of the close coupled catalytic converters using a woven ceramic fiber mesh, and the use of a somewhat larger exhaust pipe diameter (same as OEM) to limit exhaust backpressure. All of the catalyst "bricks" were constructed of a 4-mil ceramic monolithic material. The two close coupled catalytic converters each used two "bricks"and were mounted immediately downstream of each exhaust manifold. The first "brick" in each close coupled catalytic converter had a diameter of 7.6 cm, was 7.6 cm long, with a cell density of 600 cpsi, and was coated with 250 g/ft^3 of Pd. The second "brick" in each close coupled catalytic converter had a diameter of 10.2 cm, was 8.5 cm long, with a cell density of 400 cpsi, and was coated with Pd/Rh at a 9:1 ratio to 150 g/ft^3. The two underfloor catalytic converters each contained a single "brick" with a diameter of 10.2 cm, was 11.1 cm long, with a cell density of 400 cpsi, and was coated with Pd/Rh at a 9:1 to 80 g/ft^3.

[s]C.C Webb, B.B. Bykowski, P.A. Weber, D.L. McKinnon; "Using Advanced Emissions Control Systems to Demonstrate LEV II ULEV on Light-Duty Gasoline Vehicles". SAE Technical Paper Series, Paper No. 1999-01-0774, 1999.

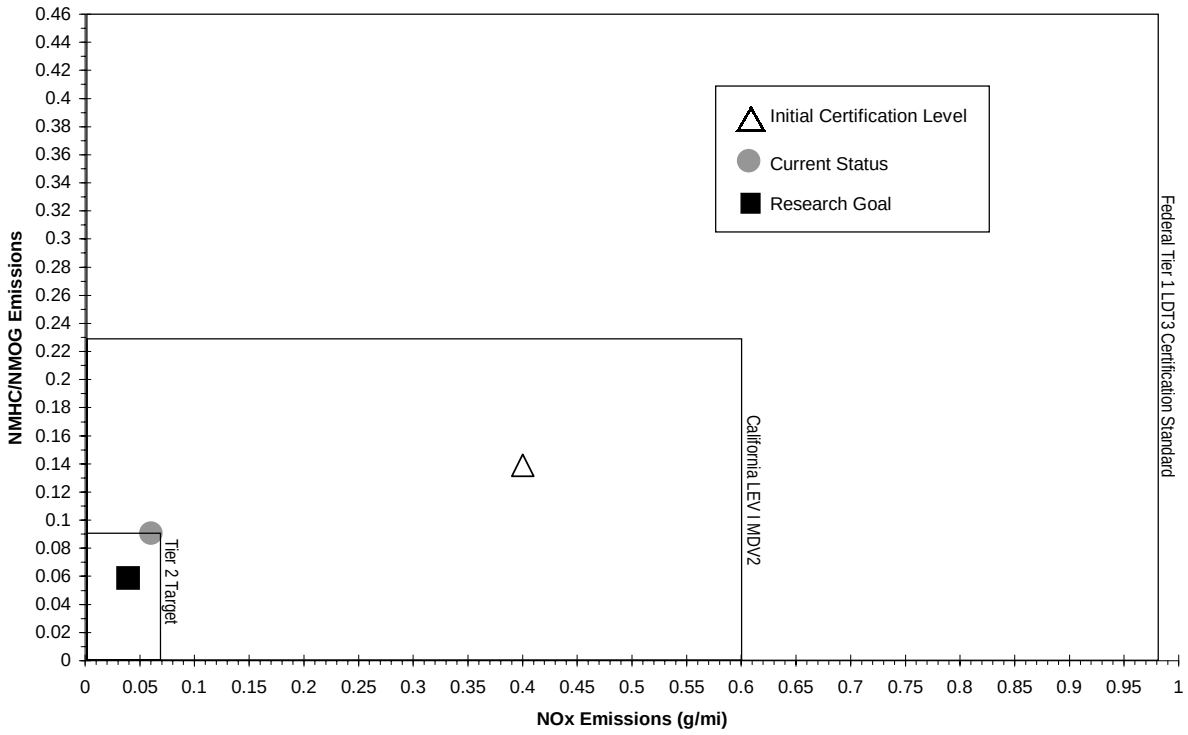

Figure IV-2: Certification Emissions and Initial Research and Development Results for a Large 1999 LDT3 Pickup, as Compared to Federal Tier 1 Emissions Standards, California LEV-I Emissions Standards, and a Tier 2 Corporate Average Target.

Initially, no attempts were made to alter the calibration of the electronic engine controls. Figure IV-2 shows emissions results from testing of the LDT3 vehicle. In this configuration, the pickup achieved emissions levels of 0.060 ± 0.002 g/mi NOx and 0.09 ± 0.01 g/mi NMHC. Based on initial modal emissions results, EPA staff engineers have indicated that the research targets of 0.04 g/mi NOx and 0.06 g/mi NMHC will likely be reached through elimination of fuel cut-offs during decelerations, slight increases in EGR, and a minor degree of air-injection during cold-start.

v. Summary of Technical Feasibility Data

It is very apparent from the data presented above that it is technically feasible for LDVs to meet our proposed Tier 2 emission standards in the proposed time frame. Although the bulk of the data is for LDVs with smaller displacement engines, there are examples of vehicles with larger displacement engines - the 1999 Ford Mustang Convertible and the Ford Crown Vic and Buick LeSabre modified by MECA. Neither of the MECA or ARB test programs modified the basic engine calibrations of the vehicles tested. In general, the engine calibration is designed specifically to match the engine exhaust to the catalytic converter being used on the vehicle.

Since recalibrations optimize engine performance, durability, emissions and safety simultaneously, neither MECA nor ARB modified the original engine calibration. However, it is very likely that such recalibration could better match engine operation and the advanced catalytic converters being tested and reduce emissions beyond the emission levels measured in the test programs. Therefore, we are confident that by 2004, all LDVs should be capable of meeting Tier 2 standards.

Fewer data are available addressing the ability of LDTs to meet the design targets implied by the proposed Tier 2 NMOG and NOx standards. No current LDTs have been certified at such low emission levels. However, this is partially due to the fact that their current emission standards are generally well above those for LDVs. Also, the number of LDTs required to comply with ARB's current LEV and ULEV standards is much lower than the number of LDVs (and LDT1s). Thus, manufacturers have focused their early LEV and ULEV development efforts on LDVs.

The fact that a number of LDTs have been certified at emission levels near the proposed Tier 2 standards indicates that control technology has developed to the point where the differences between LDV and LDT emissions are shrinking.

As highlighted by MECA at the November 1998 annual meeting between EPA and MECA to discuss recent emission control technology developments, there are several areas where technology gaps exist between LDV and LDT technology. Table IV-9 lists these gaps.

Table IV-9. Emission Technology Gaps Between LDVs and LDTs

LEV LDVs	*Tier 1 LDTs*
Tight A/F control	Relatively loose A/F control
Close-coupled + underfloor catalyst combination	Underfloor catalyst with long pipe runs
Ratio of catalyst volume to engine displacement Vcat/Veng = 1-1.5	Vcat/Veng = 0.5 or less
Catalysts with advanced washcoats and higher cell density substrates	Less sophisticated catalysts on standard substrates

These differences have been due to the fact that LDT standards were less stringent than those applicable to LDVs. However, there are no technological reasons why LDTs cannot employ the exact same technology, or even better technology, as LDVs.

The Toyota T100 pick-up (LDT2) modified by MECA and optimized by SwRI had very impressive emission results at 50,000 miles - considerably lower than the Tier 2 design targets. The ARB Ford Expedition had emission reductions of over 50 percent from certification levels,

achieving results just at the LEV II and Tier 2 NOx standard (NMOG was below the design target) with the addition of an advanced catalyst system and the introduction of secondary air at start-up. Finally, our own LDT3 test program had emission results below Tier 2 standards. As stated above, none of the above mentioned test programs modified the basic engine calibrations of the vehicles tested. The modifications they made were minor compared to what vehicle manufacturers are capable of doing. For example, the 1999 certification results for the Ford Expedition show a slight increase in NMOG levels relative to the 1998 model, but a 50 percent reduction in NOx levels at 50,000 miles. The full usefull life NOx certification level in 1998 was 0.14 g/mi but only 0.07 g/mi in 1999. The only difference between the two model years is engine calibration - both model years have the same catalyst system. This highlights the importance of engine calibration on emission control system performance.

Traditionally LDTs have had higher standards because they tend to generate more emissions due to larger displacement engines and the fact that they have typically been operated under high loads. The greatest concern with controlling emissions for LDTs has always been that catalysts couldn't be placed close enough to the engine to reduce cold start emissions because of concerns over thermal damage to the catalyst resulting from the high levels of heat generated by the trucks when under load. But as discussed above, catalysts are now capable of withstanding much higher temperatures, and this is no longer an issue.

Another reason why the emission standards for LDT3s and LDT4s were set so much higher than those for LDVs and lighter LDTs was that the heavier LDTs were tested at adjusted loaded vehicle weight, not loaded vehicle weight. Adjusted loaded vehicle weight is the vehicle's curb weight plus half of its maximum payload capacity. Loaded vehicle weight is the vehicle's curb weight plus 300 pounds. This was done in the past because the LDT3s and LDT4s were believed to be used primarily as cargo carrying vehicles and should be regulated under these conditions. While their weight during emission testing generally increases emissions, the applicable emission standards were numerically increased to compensate for this.

As part of the Tier 2 proposal, LDT3s and LDT4s will be tested like LDVs and the lighter LDTs, at the vehicle's curb weight plus 300 pounds. This change represents the recent trend for these trucks to be used predominantly as passenger carrying vehicles. This change would also reduce the certified emission level of any current LDT3 or LDT4 simply by reducing the amount of fuel the vehicle consumes over the test cycle. Under the proposed test procedure, all current LDT3s and LDT4s would be closer to the design targets for the proposed Tier 2 standards. Likewise, the difference between the current Tier 1 standards for these vehicles and the proposed Tier 2 standards is actually much smaller than a comparison of the numerical standards would indicate.

Overall, several certified and research LDVs have met the design targets for the proposed Tier 2 standards in 1998 with, in many cases, considerable margin to spare. This indicates that significant margin exists with which to accommodate the greater weight and aerodynamic drag of LDT3s and LDT4s when meeting the same design targets. In addition, significant LDT emission reductions were achieved from vehicles emitting well below the applicable LEV design targets by primarily just changing catalysts (in the case of MECA and ARB) or just changing

engine calibration (in the case of Ford). This confirms indicates that the benefits of advanced emission control technology on LDTs has not been exhausted in meeting current LEV emission standards. Overall, these findings indicate that the proposed Tier 2 standards for LDTs should be feasible with the same basic types of emission controls as required by LDVs. The heavier LDTs will likely require somewhat larger catalysts than LDVs and the lighter LDTs and possibly also incorporate a greater number of supporting technologies, such as a low-thermal capacity manifold, in order to meet the same numerical emission standard.

c. Lean-Burn Technology

The above discussion focused on advancements in emission control technology. New gasoline engines designs are also being developed to reduce fuel consumption. In particular, gasoline direct-injection (GDI) engines have been developed (and are being sold in Japan and Europe) which operate on 10-20 percent less fuel than today's gasoline engines.

One of the reasons that these engines use less fuel is that they use much more air than is needed just to burn the fuel. In this respect, they operate similar to a diesel engine. While this is advantageous for fuel efficiency, it makes it more difficult to eliminate NOx emission using aftertreatment technology. Highly efficient 3-way catalysts require that there be little excess oxygen in the exhaust stream in order to convert NOx emissions to nitrogen and oxygen. Unfortunately, if a GDI engine is operated in this way, nearly all of its fuel efficiency benefits are lost.

A number of potential techniques are being developed to control NOx emissions when excess air are present. These techniques are discussed in more detail in Section 5. below. The most promising of these techniques for GDI engines are the lean NOx catalyst and the NOx adsorber. A GDI engine may be able to meet the highest NOx bin of 0.2 g/mi with a lean NOx catalyst and 30 ppm sulfur gasoline. However, this is dependent on achieving engine out emissions below 0.4 g/mi, and this is likely to be a very difficult challenge. NOx adsorbers are potentially more efficient than lean NOx catalysts. Thus, the required engine out NOx emission levels are likely to be well within the capability of GDI engine technology. However, the NOx adsorber is in an earlier stage of development relative to the lean NOx catalyst. Much development work is still necessary in order for this technology to be applied commercially. Also, even 30 ppm sulfur levels degrade long-term performance of NOx adsorbers. Thus, either methods to regenerate the NOx adsorber onboard the vehicle must be developed or even lower sulfur levels will be required.

2. CO Emissions from Gasoline Fueled Vehicles

EPA is only proposing tighter CO emission standards for LDT2s, LDT3s and LDT4s. Basically, CO emissions from these vehicles must be reduced to the levels now required for LDVs and LDT1s under the NLEV program. Also, LDVs and LDTs must comply with the NLEV CO standards over a slightly longer useful life of 120,000 miles instead of the current

useful life of 100,000 miles.

Compliance with the proposed Tier 2 CO emission standards should not be difficult given compliance with the proposed Tier 2 NMOG standards. The control of both pollutants utilizes much of the same technology and the proposed Tier 2 NMOG standards are the more stringent of the two sets of standards. In addition, the above mentioned change in test weight should make it even more easy to meet the proposed Tier 2 CO emission standards. The following table IV-10 summarizes CO emissions from vehicles certified to the LEV standards in California.

Table IV-10. CO Emissions from California LEVs (g/mi)

LDV/LDT	*LDT2*	*LDT3*	*LDT4*
0.8	1.13	2.35	2.95

As can be seen, the CO emissions from all of these vehicles are well below the proposed Tier 2 CO standard of 4.2 g/mi. While CO emissions from LDT3s and LDT4s are more than half the proposed 4.2 g/mi standard, the current LEV standards for these vehicles is more than twice the proposed Tier 2 NMOG standard of 0.09 g/mi. As NMOG emissions are reduced to meet the 0.09 g/mi standard, CO emissions will decrease further, as well. CO emission control is also not a problem for GDI engines. Thus, compliance with the proposed Tier 2 CO standard should not add any additional burden to manufacturers relative to compliance with the proposed NMOG and NOx standards.

3. Formaldehyde Emissions from Gasoline Fueled Vehicles

EPA is only proposing tighter formaldehyde emission standards for LDT2s, LDT3s and LDT4s. Basically, formaldehyde emissions from these vehicles must be reduced to the levels now required for LDVs and LDT1s under the NLEV program. Also, LDVs and LDT1s would have to comply with the NLEV formaldehyde standards over a slightly longer useful life of 120,000 miles versus the current 100,000 mile useful life.

Again, as with CO emissions, compliance with the proposed Tier 2 formaldehyde emission standards should not be difficult given compliance with the proposed Tier 2 NMOG standards. The control of both pollutants utilizes much of the same technology and the proposed Tier 2 NMOG standards are the more stringent of the two sets of standards. Table IV-11, below, summarizes formaldehyde emissions from vehicles certified to the LEV standards in California.

Table IV-11. Formaldehyde Emissions from California LEVs (g/mi)

LDV	*LDV/LDT1*	*LDT2*	*LDT3*	*LDT4*
0.0012	0.0016	0.0013	0.002	0.002

As can be seen, formaldehyde emissions from current California vehicles are roughly a factor of 10 below the proposed Tier 2 formaldehyde standard of 0.018 g/mi. Thus, compliance with the proposed Tier 2 formaldehyde standard should not add any additional burden to manufacturers relative to compliance with the proposed NMOG and NOx standards.

4. Evaporative Emissions

The standards we are proposing today for evaporative emissions are technologically feasible now. Many designs have been certified by a wide variety of manufacturers that already meet these standards. A review of the 1999 model year certification results indicates that the average family is certified at less than 1.0 grams per test on the 3 day diurnal plus hot soak test, i.e. at less than half the current 2.0 g/test standard.

The standards we are proposing will not require the development of new materials or, in many cases, even the new application of existing materials. Low permeability materials and low loss connections and seals are already used to varying degrees on current vehicles. Today's standards will likely ensure their consistent use and discourage manufacturers from switching to cheaper materials or designs to take advantage of the large safety margins they have under current standards ("backsliding").

There are two approaches to reducing evaporative emissions for a given fuel. One is to minimize the potential for permeation and leakage by reducing the number of hoses, fittings and connections. The second is to use less permeable hoses and lower loss fittings and connections. Manufacturers are already employing both approaches.

Most manufacturers are moving to "returnless" fuel injection systems, and at least one major manufacturer utilizes returnless systems on all of their vehicles. Through more precise fuel pumping and metering, these systems eliminate the return line in the fuel injection system which carries unneeded fuel from the fuel injectors, which has been heated from its close proximity to the hot engine, back to the fuel tank. Returned fuel is a significant source of fuel tank heat and vapor generation. The elimination of return lines also reduces the total length of hose on the vehicle and also reduces the number of fittings and connections which can leak.

Low permeability hoses and seals as well as low loss fittings are available and are already in use on many vehicles. Fluoropolymer materials can be added as liners to hose and component materials to yield large reductions in permeability over such conventional materials as monowall nylon. In addition, fluoropolymer materials can greatly reduce the adverse impact

of alcohols in gasoline on permeability of evaporative components, hoses and seals.

5. Diesel Vehicles

Very few LDVs and LDTs are currently sold with diesel engines. Out of annual sales of more than 15 million vehicles, roughly only 30,000 are equipped with diesel engines. This is in part due to the low price of gasoline over the past decade. Recently, a number of vehicle manufacturers have announced aggressive programs to increase the sales of diesel LDVs and LDTs. These programs are scheduled to begin between model year 2000 and 2002 and appear to be aimed at easing manufacturers' compliance with the corporate fuel economy standards, particularly for LDTs.

NOx and PM are the two biggest emission-related challenges for diesel engines. Diesels have inherently low emissions of CO and NMOG and should have no problem meeting the proposed Tier 2 standards for these pollutants. Therefore, the remainder of this discussion will focus on NOx and PM.

Considerable progress has been made over the past 10 years in reducing engine-out emissions from diesel engines. In heavy trucks and buses, PM emission standards which were projected to require the use of exhaust aftertreatment devices were met with only engine modifications. NOx emissions from heavy trucks and buses sold starting in 2002 will also reflect deep reductions from emission levels typical of engines produced in the mid-1980's. However, the benefits of improved diesel engine design appear to be reaching their limits. EPA projects that diesel LDVs and LDTs could only meet NOx emissions standards of roughly 0.5-0.6 g/mi and PM emission standards of roughly 0.05-0.08 g/mi without aftertreatment. These levels are well above the highest allowable certification emission levels included in today's proposal.

In order to comply with the proposed Tier 2 emission standards for NOx and PM, diesels will require the use of effective aftertreatment devices. For NOx emissions, these devices include lean NOx catalysts, selective catalytic reduction (SCR) and NOx adsorbers. Lean NOx catalysts are still under development and appear capable of reducing NOx emissions by 15-30 percent. Therefore, they are unlikely to be sufficiently effective to enable compliance with the proposed Tier 2 standards.

SCR has been demonstrated commercially on stationary diesel engines and can reduce NOx emissions by 80-90 percent. However, SCR requires that the chemical urea be injected into the exhaust before the catalyst. This means that vehicle owners would have to periodically refuel their vehicle with urea, as well as diesel fuel. Ammonia emissions also occasionally occur with use of SCR, which has a very objectionable odor.

Finally, NOx adsorbers can be up to 90 percent efficient at removing NOx from the exhaust. However, these adsorbers are quickly poisoned by sulfur in the fuel and would require reductions in diesel fuel sulfur content. Their use also requires that the engine be run with

excess fuel occasionally, so that the stored NOx can be converted to nitrogen and oxygen. These adsorbers, coupled with techniques for introducing fuel into the exhaust periodically are still at the research stage.

Overall, use of either SCR or a NOx adsorber should be able to enable compliance with the proposed Tier 2 standards. The issue of reducing diesel fuel sulfur levels to enable NOx adsorbers and other technologies is discussed in a separate ANPRM.

Regarding PM, applicable aftertreatment devices tend to fall into two categories: oxidation catalysts and traps. Diesel oxidation catalysts look very similar to the 3-way catalysts used on gasoline vehicles. Diesel catalysts convert the hydrocarbon compounds in the exhaust to water and carbon dioxide. This reduces exhaust NMOG emissions and heavier HC compounds which comprise about 30 percent of total PM mass emissions. The oxidation catalyst can be from 50 percent to 90 percent effective at converting HC. Thus, an oxidation catalyst can reduce total PM emissions by roughly 15-27 percent. By itself, the oxidation catalyst is not likely to be sufficient to enable compliance with the proposed Tier 2 standards without further advancements in engine technology.

Traps can eliminate up to 90 percent of diesel PM emissions. The trap first filters the carbonaceous particles from the exhaust. Then, periodically, this trapped PM must be burned, or the trap will fill up and cause problems in operating the engine. Diesel traps are currently being used on buses in an number of U.S. cities. It appears that these traps can regenerate frequently enough given the operating temperatures of bus engines and over-the-road trucks. However, there is some question whether or not these traps could regenerate frequently enough with the somewhat lower operating temperatures of diesel engines in LDVs and LDTs. Regeneration can be enhanced at lower exhaust temperatures through the use of more active catalysts on the surface of the trap. However, these catalytic materials convert sulfur dioxide in the exhaust to sulfuric acid. Thus, their use requires the removal of most of the sulfur in the fuel. Research indicates that low temperature regeneration may also be enhanced through the use of catalytic fuel additives comprised of cerium or iron. However, particulate containing these chemicals can be emitted from the tailpipe, raising some health concerns. Use of these catalytic fuel additives does not require the removal of sulfur from diesel fuel. An efficient trap should enable compliance with the proposed Tier 2 PM standards.

B. Feasibility of Removing Sulfur from Gasoline

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.[2] The average amount of sulfur in crude oil refined in the U.S. is about one percent.[3] 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 and the embedded sulfur ends up in gasoline. Thus, the refinery units which converts 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 the refinery processing unit most responsible for moving sulfur into gasoline. 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 comes from that unit.[4] Another refinery unit which is responsible for a significant amount of sulfur in gasoline is the coker unit. These units produce coke from the heavy part of the crude oil. In the process of producing coke, some gasoline blendstocks are produced and some of these blendstocks are blended directly into gasoline. While the volume of gasoline blendstock produced by the coker is small (normally less than one percent of the gasoline pool), this stream usually contains more than 3000 ppm sulfur,[5] so the contribution of sulfur to gasoline is significant.

Another gasoline blendstock which contributes sulfur to gasoline is the straight run. Straight run is the portion of the crude oil which falls in the gasoline boiling range which is blended directly into gasoline. Usually only the light straight run is blended into gasoline which has a small amount of sulfur (i.e., on the order of 100 ppm sulfur), although in trying to meet a low sulfur standard, even this amount sulfur of becomes significant. 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. Alkylate is another stream which can have enough sulfur worth mentioning. 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 alkylate, hydrocrackate, and isomerate. Oxygenates which are blended into gasoline usually have no sulfur, however, during shipping through pipelines, they can pick up some sulfur. The implementation of a low gasoline sulfur standard, though, would reduce much of the sulfur which oxygenates could pick up in the pipeline.

Since FCC units and cokers contribute so much sulfur to gasoline, then a reasonable conclusion which could be reached would be that refineries could simply shut down these units to meet a low sulfur standard. This conclusion is not reasonable considering the quality of crude oil which is used today and the products demanded of the oil industry. Much of volume of crude oil is composed of heavy compounds which has no end use, and thus is not usable without processing by these units. Thus, these units make marketable products from what would otherwise be a waste oil stream.

2. Current Levels of Sulfur in Gasoline

It is important to know the average level of sulfur in gasoline because it helps determine the most effective removal methods which should be used. The American Petroleum Institute

(API) and the National Petrochemical Refiners Association (NPRA) surveyed gasoline producers to gather information concerning refining operations during the Summer of 1996.[6] They collected information on the qualities of gasoline for various regions called Petroleum Administrative Districts for Defense (PADDs), as well as for the country as a whole. (These PADDs are illustrated below in Figure IV-2). Their study showed that the gasoline sulfur, outside of California, averaged 340 ppm during the Summer of 1996.

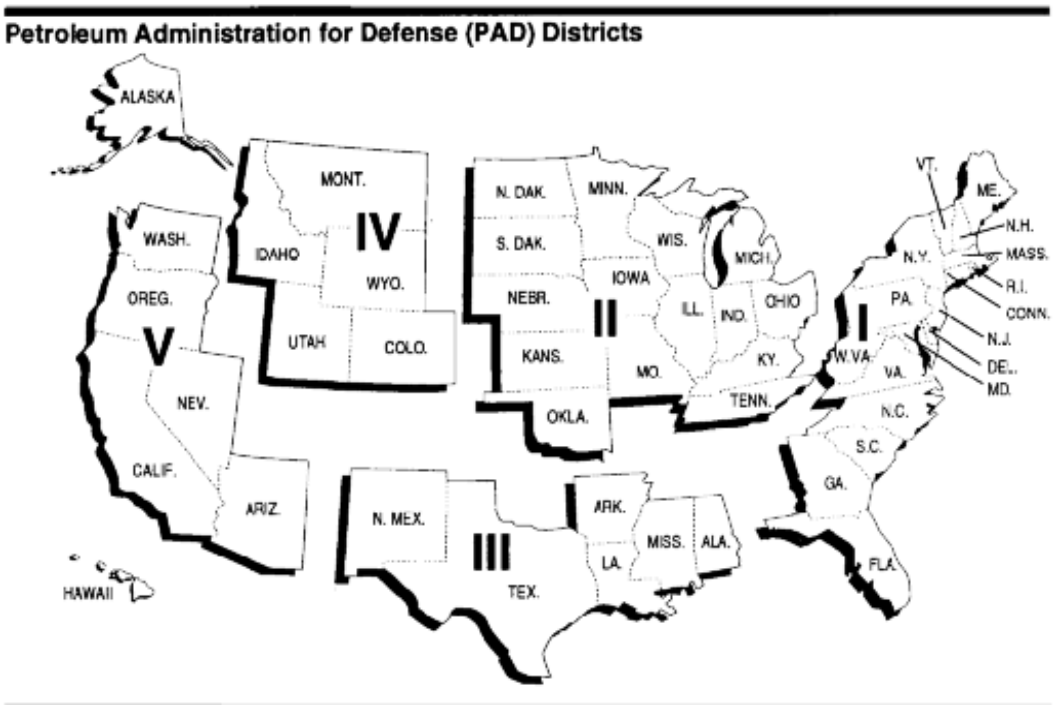

Figure IV-2. Map of U.S. Petroleum Administrative Districts for Defense

When looking closer at the information provided in the report, we discovered that some PADD sulfur levels calculated from the API/NPRA data were not in agreement with some of the average blendstock sulfur levels presented within the same report, nor was it consistent with data reported to EPA for the RFG program in 1995 and 1996. One possible reason for the disagreement between the API/NPRA gasoline pool sulfur level and that reported to the RFG data base is that API and NPRA only surveyed refiners for their summertime gasoline qualities. Other possible reasons for the discrepancy are, that some refiners did not participate with the API/NPRA survey (especially in PADDs 1 and 5), while data handling complications also precluded the inclusion of gasoline sulfur data from some refiners from being reported in the RFG data base. However, because the RFG data base contains year-round data and because it often represents a larger portion of the gasoline sulfur pool, when the sulfur levels were compared between the two data bases, or when the API/NPRA information was compared internally, and there was disagreement, then the RFG data were used over the API/NPRA survey information. The methodology for adjusting the average sulfur levels is described in more detail below in the section on fuel costs.

After adjusting the sulfur values for each PADD, the national average gasoline sulfur level for domestically produced gasoline is 305 ppm. Table IV-12 below summarizes the U.S. sulfur levels by PADD, and for the country as a whole. Because California has it own low sulfur gasoline program, gasoline produced there was excluded from consideration in this analysis.

Table IV-12. Average Sulfur Levels by PADD and for the Nation.

	PADD 1	*PADD 2*	*PADD 3*	*PADD 4*	*PADD 5 OC**	*U.S. Avg.**
Estimated Average Sulfur Levels	215	338	308	265	506	305

* Outside of California

It is important to note that the gasoline sulfur values reported in Table IV-12 are an attempt to estimate the average gasoline sulfur level for estimating the cost of desulfurization. In actuality, each sulfur value represents the volumetric average of a range of sulfur values with each refinery representing a single data point. This range can vary from the tens of ppm to almost 1000 ppm. The 1000 ppm sulfur level is the upper limit of the amount of sulfur permitted to be shipped in pipelines in accordance with the American Society for Testing Materiels (ASTM) consensus standards.[7]

3. Feasibility of Meeting the Proposed Gasoline Sulfur Standards

The feasibility of meeting the proposed standards for low sulfur gasoline 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 the proposed standard. The second way is to determine if refiners are already demonstrating that they can meet a low sulfur gasoline standard similar to this proposed rule. Evidence that refiners are already meeting a stringent gasoline sulfur program is a more compelling example of feasibility since the technology must already be available if low sulfur gasoline is already being produced.

It is indeed the case that there are low sulfur gasoline programs already in place. The State of California requires gasoline sold in the State to meet a 30 ppm gasoline sulfur standard on average and a 80 ppm cap, among a number of other fuel standards.[8] 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 20 ppm sulfur on average.[9] 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 today. Thus, the

experience in California demonstrates that commercial technologies already exist to permit refiners to produce low sulfur gasoline.

In addition to the California experience here in the U.S., a low sulfur requirement in Japan provides additional evidence that reducing gasoline sulfur levels to low levels is feasible. Japanese refineries must meet a 100 ppm per-gallon cap. Based on the gasoline sulfur cap established there, gasoline in Japan averages about 20 ppm sulfur.

4. Meeting a Low Sulfur Gasoline Standard

The methodology that would be used refiners to lower their sulfur level depends on a number of factors specific to their refinery. These factors include:

- The gasoline sulfur level prior to the start of the gasoline sulfur program
- The refinery configuration (A typical complex refinery is illustrated in Figure IV-3, below.)
- The amount of excess refinery desulfurization equipment on hand
- The quality of feedstocks available, especially crude oil
- The quality and types of products produced
- Any plans to change the feedstocks or products of the refinery
- The desulfurization technologies available and their cost
- Other regulatory programs affecting refinery operations in the same time frame

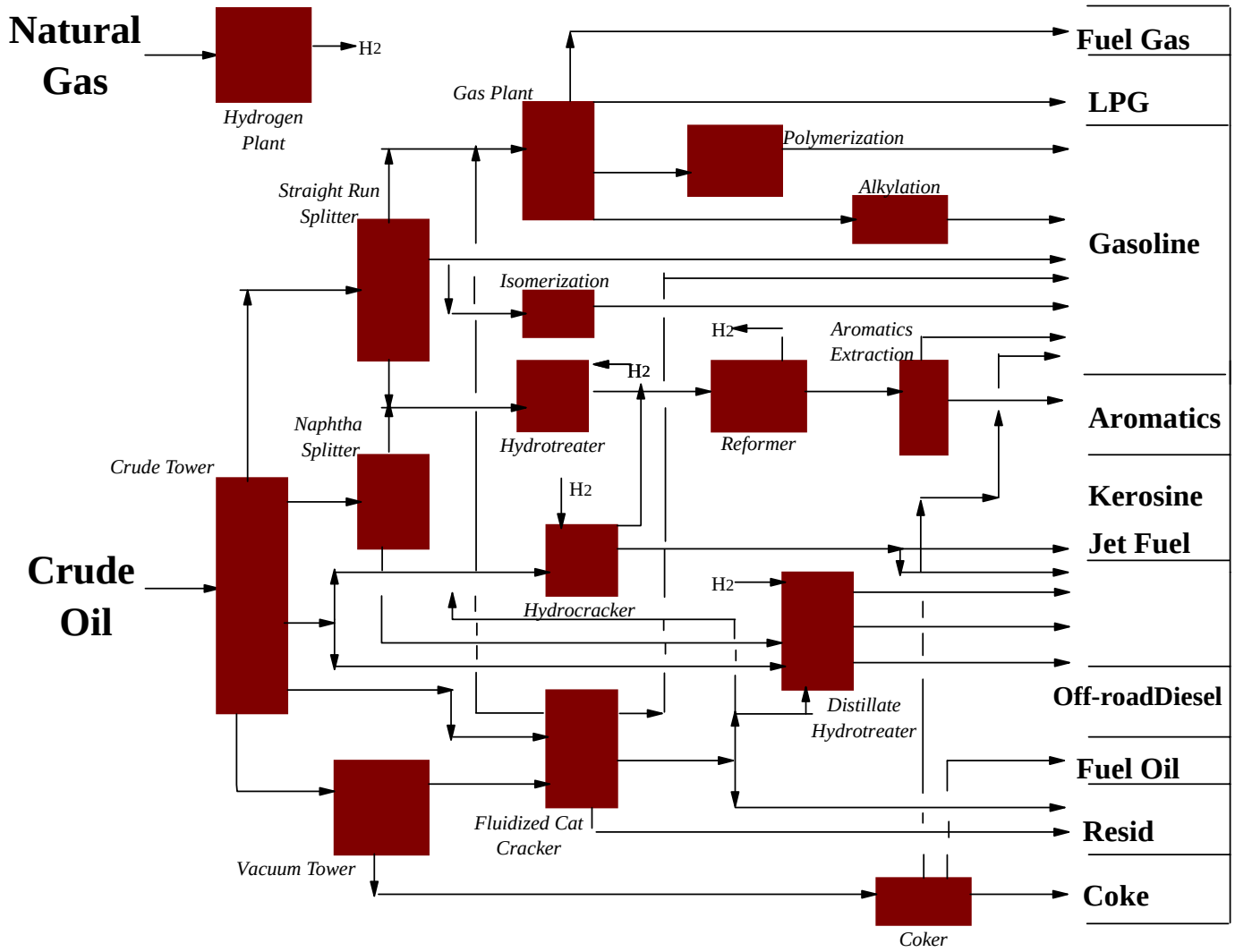

Figure IV-3. Diagram of a Typical Complex Refinery

A refinery's average gasoline sulfur level is the most important factor determining whether a refiner would need to make a substantial capital investment to meet a sulfur standard. After numerous discussions with refiners, we believe that those refiners with low gasoline sulfur levels to begin with (i.e., gasoline sulfur levels lower than, perhaps, 60 ppm) will probably not need to invest in expensive capital. These refineries have such 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 (Figure IV-3 shows these where these units are placed in a refinery). As stated above, these units push more sulfur into gasoline and their absence means less sulfur in gasoline. Alternatively, refiners may use a low sulfur (sweet) crude oil, which results in lower 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 sulfur levels below the proposed sulfur standard would not have to do anything. On the other hand, those refineries with sulfur levels above the proposed standard, but below some level, such as 60 ppm, could probably meet the standard employing operational changes only, which means avoiding capital investments if this is desirable. For example, these refiners may be able to meet the proposed sulfur standard by running existing desulfurization units harder, at capacity if the unit has headroom, or by debottlenecking the unit, perhaps by using more effective catalyst. Alternatively, these refineries may be able to meet the proposed sulfur standard by using a slightly sweeter crude oil. Refiners also have FCC additives available to them which could allow them to reduce their FCC gasoline sulfur level by 15 to 35 percent.[10] Another strategy that these refiners could use to meet the proposed gasoline sulfur standard would be to undercut the FCC gasoline. By cutting out the heaviest 10 volume percent of FCC gasoline and sending that part to on-road diesel before hydrotreating, to off-road diesel or to heating oil, refiners would be able to cut out 40 percent or even more of the sulfur from this high sulfur blendstock. However, the refiners which choose to undercut their FCC gasoline would then produce less volume of gasoline which generally provides the highest profit margin. For this reason undercutting the FCC gasoline would likely be a short term strategy. Finally, these refinery may be able to meet the sulfur standard by blending in low sulfur oxygenates. Refiners may be able to employ several of these desulfurization strategies together in varying degrees. These refiners with very low gasoline sulfur levels to begin with produce only a small portion of the gasoline consumed in this country, on the order of five percent.[11]

The vast majority of gasoline is produced by refineries with higher sulfur levels, and refiners are expected to install capital equipment in these refineries to meet the proposed gasoline sulfur standard. As stated above, the FCC unit is responsible for most of the sulfur in gasoline. Thus, investments for desulfurizing gasoline would likely involve 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.

FCC feed hydrotreating can be accomplished by 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 higher 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, the capital costs may exceed $100 million. Because of the higher temperatures and pressures involved, operating costs are expensive relative to other forms of hydrotreating explained below. Refiners may be better able to justify this approach if they switch to a heavier, more sour crude oil. These crude oils are less expensive per barrel and can offset the increased cost of the FCC desulfurization unit, providing that the combiniation 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. While 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 gasoline, it contributes a larger portion of the total sulfur which ends up in distillate. Thus, FCC hydrotreating would allow a refiner to produce more low sulfur onroad diesel or meet a lower sulfur standard for onroad diesel, which could apply in the future.

A less expensive alternative to hydrotreating the FCC feed for gasoline desulfurization is FCC gasoline hydrotreating. FCC gasoline hydrotreating only treats the gasoline produced by the FCC unit. Understandably, this unit is much smaller because only about 60 percent of the feed to the FCC unit ends up as gasoline produced by the FCC unit. The unit is often smaller than that as refiners typically only treat the heavier, higher sulfur portion of that stream. FCC gasoline hydrotreaters operate at lower temperatures and pressures as well which further reduces the capital and operating costs associated with this type of desulfurization equipment. For a medium to large refinery, the capital costs would be on the order of $50 million for a conventional hydrotreater. One drawback of this process is that octane value and some of the gasoline yield is lost during desulfurization. The loss of this octane must be made up by additional octane production by other units in the refinery or by oxygenate addition, and the volume loss can be made up by additional throughput to gasoline producing units, or also by oxygenate addition.

The loss of octane and gasoline yield caused by FCC gasoline hydrotreating is much lower with gasoline desulfurization technologies which were recently introduced. CDTECH and Mobil Oil each have developed new or improved technologies for desulfurizing gasoline. CDTECH calls its two hydrotreating units for treating FCC full range gasoline CDHydro and CDHDS. Mobil Oil calls its process OCTGAIN 220. These processes preserve much of the octane and gasoline yield because they were designed for treating gasoline blendstocks. One reason why these processes preserve octane and yield is that they operate at lower temperature and pressure compared to conventional hydrotreating processes. The less severe conditions also

lowers the capital and operating costs for this process. The capital cost for these improved processes ranges from $20 to $40 million for a medium to large sized refinery. While the capital costs are somewhat less than conventional hydrotreaters, much more cost savings arise out of the reduced utility and ancillary costs. For example, because these processes are less severe, there is much less saturation of olefins, which means that there is much 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.

While these improved gasoline desulfurization technologies have been in the limelight for over a year now, we have also learned that other desulfurization processes are under development. In conversations with several refiners, they shared with us that they are in the process of developing their own desulfurization technology. We would expect them to use their technologies if their development work is completed in time. Furthermore, other refining process licensing firms shared with us that they are developing their own desulfurization technology. We recently became aware that biodesufurization, which is the removal of sulfur from petroleum using biological means, is on the verge of commercialization for the desulfurization of diesel.[12] The vendor of this technology informed us that the process will be set up and running in about two years in a Petrostar refinery in Alaska. The vendor also shared that gasoline desulfurization is a little further behind, and they believe that they could be ready to market that process for desulfurizing gasoline within the next two years. Two important advantages of this technology are that hydrogen is not needed and that the feed to the unit does not need to be heated to high temperature and compressed to high pressures. The cost savings of these benefits are offset, though, by the need for extensive mixing to maintain an oxygen-rich environment for the bacteria to work effectively. We anticipate that this processes will receive much more attention in the near future as the vendor completes its initial pilot plant work. Our initial assessment is that this process, given time, may be cost competitive with any of the improved gasoline desulfurization technologies. However, at this time, we are only focusing on the improved gasoline desulfurization technologies for which we were given cost information that allowed us to estimate the cost of gasoline desulfurization.

5. Improved Gasoline Desulfurization Technology

We will briefly describe the improved gasoline desulfurization technologies below, but first we'll describe conventional desulfurizing technology to establish a point of reference. Conventional desulfurization occurs in a fixed bed reactor.[13] The reactor is termed fixed bed because a catalyst, which helps to improve the reaction rate and specificity, is contained in a stationary bed within the reactor. The high sulfur gasoline blendstock is heated to a high temperature (on the order of 600 degrees Fahrenheit) and 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, most or all of the olefin compounds which are present in the cracked stream are saturated. Since olefin compounds are much higher in octane than their saturated counterparts, their saturation causes a significant octane loss in any stream with a high olefinic content. Conventional

hydrotreating has generally been used for streams with little or no olefins, such as for virgin gas oil which is treated by the FCC unit, or for feed streams to the reformer and isomerizer. Thus, octane loss upon hydrotreating these streams is not a problem. However, FCC gasoline is very rich in olefins such that hydrotreating this stream normally causes a large reduction in octane (up to 8 octane numbers units can be lost if the entire FCC gasoline stream is treated). The saturation of olefins also substantially increases the need for hydrogen.

The catalyst also tends to cause some of the petroleum compounds to "crack, " converting them from gasoline boiling range compounds to compounds too light for keeping in gasoline, which is termed yield loss. 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, are separated from the liquid compounds. The hydrogen sulfide must be stripped out from the other compounds and then converted to elemental sulfur which is then sold off. If there is enough hydrogen and it can be economically recovered, it is separated from the remaining hydrocarbon stream and recycled. Otherwise it is burned with the light hydrocarbons as fuel gas.

Mobil Octgain will be discussed next since the process is similar to a conventional hydrotreater. This gasoline desulfurization process is the third generation of this process for Mobil, and it is called Octgain 220. Like a conventional hydrotreater, Mobil uses a fixed bed of catalyst for its Octgain process.[14] One primary difference between Octgain and conventional hydrotreating is that Mobil Oil has developed its own catalyst for the reactor. The catalyst not only causes the desulfurization of petroleum, it also causes isomerization reactions to occur (straight chain petroleum compounds are changed to branched chain compounds) which increases the octane of the resultant stream.[15] The octane improvement caused by the catalyst compensates for octane loss resulting from olefin saturation. Mobil designed this generation of Octgain process to operate over a range in severity. If less desulfurization is needed, then the process temperature and pressure are reduced. The less severe operating conditions reduces the saturation of olefins, which in turn reduces less hydrogen consumption and utility use, in addition to causing less octane loss. Under the less severe conditions, much or all of the octane loss can be made up by the isomerization reactions caused by the catalyst. 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. Most of these benefits would be negated if extensive desulfurization, on the order of 99 percent, is necessary. The steps of the process following the reactor are the same for conventional FCC gasoline hydrotreaters. One advantage of the Octgain process is that the reactor vessel for the process is the same as vessels used for conventional hydrotreating. Thus, refiners can save on capital costs by using a spare hydrotreating unit which it may have on hand in the refinery.

The CDTECH process is significantly different from either conventional hydrotreating or Octgain, which makes it a little more complex to describe. The CDTECH process utilizes catalytic distillation.[16][17][18] 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. Based on their experience and success with that process, they applied the same technology to desulfurizing gasoline. As the name implies, distillation and

desulfurization, via a catalyst, take place in the same vessel. This design feature may save the need to add a separate distillation column in some refineries. 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 gasoline, then he may have to add a second distillation column to be able 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 choice is realized by setting up the distillation and associated catalyst to treat only the portion of the pool which needs to be treated.

The most important portion of the CDTech desulfurization process is two distillation columns loaded with desulfurization catalyst in a packed structure. The first vessel, called CDHydro, treats the lighter compounds of FCC gasoline, while the second column, called CDHDS, treats the heavier compounds of FCC gasoline. All of the FCC gasoline is fed to the CDHydro column. The five- and six-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 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 the some of the olefins which increases the octane of this stream by about three octane numbers.

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 Mobil Oil's Octgain process. 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.

6. Expected Desulfurization Technology to be Used by Refiners

If the proposed gasoline sulfur standard is finalized, refiners which produce gasoline would have to meet the standard to be able to continue participating in the U.S. gasoline market. As stated above, most refiners will have to invest in desulfurization technology. Arguably, refiners would try to minimize the cost to their business. As stated above, the improved gasoline desulfurization technology costs of CDTECH and Mobil Oil Octgain provide refiners a lower cost option for meeting a gasoline sulfur standard. However, many refiners have shared with EPA that they may be hesitant to use these improved, but recently developed technologies for gasoline desulfurization. They claim that until the technologies have been installed in one or more refineries and operated for a while, that there will continue to be a significant measure of uncertainty. This uncertainty could tip the balance away from using these improved desulfurization technologies, to applying more expensive conventional desulfurization technology.

While there is a concern now on the part of some refiners about using these improved, but not commercially tested desulfurization technologies, we believe that much of this concern will dissipate shortly. Both processes are expected to be installed and operated in refineries later on this year. Mobil Oil has an Octgain hydrotreater installed at its Joliet, Illinois refinery. Up to now, though, only the second generation Octgain catalyst (Octgain 125) was demonstrated at that site. However, Mobil Oil plans to load its new Octgain 220 catalyst in the hydrotreater at Joliet to determine how it runs in a full scale hydrotreater. This experience should start to occur sometime before midyear of 1999.[19] CDTech has years of accumulated service with its CDHydro unit. In its present service, certain olefins called dienes are reduced and octane is improved. While this service is not intended for desulfurization, these units do in fact combine sulfur compounds together much like how the process will operate in a desulfurization service. Thus, this unit has extensive operational experience already. The CDHDS unit, on the other hand, has not been installed in any refinery. It is to be installed in a Motiva refinery (which was Star) in Port Arthur, Texas, with a start-up date sometime around the third quarter of 1999. Another refinery, which is Transamerican in Louisiana, is also planning to install the CDHDS unit, followed by the CDHydro unit for desulfurization, sometime in the first half of the year 2000.

7. Feasibility for a Low Gasoline Sulfur Standard in 2004

We believe that sufficient evidence exists which supports the conclusion that it is feasible for the U.S. refining industry to meet the 30 ppm average standard in four years or less. We discussed the possibility of meeting a stringent gasoline sulfur program with refiners. The American Petroleum Institute (API) communicated to us that a minimum of four years is needed between when a fuel regulatory requirement is promulgated and when the requirement must be

implemented.[20] In API's comments on this issue, it provided a schematic of a typical refinery project development timeline. This schematic showed that a "best estimate" of installation time would be 4.5 years. However, if contingencies are considered, then 5 years would be required. In more detail and without contingencies, API's project timing schedule without contingencies is summarized here relative to date of the final rule (FR). The table also shows EPA's estimates for the same process steps.

Table IV-13. Leadtime Required Between Promulgation of the Final Rule and Implementation of the Gasoline Sulfur Standard (years)

	EPA		API (without contingencies)	
	Time for Individual Step	Cumulative Time	Time for Individual Step	Cumulative Time
Scoping Studies	0.5-1.0*	0.5	1.5*	1.0
Process Design	0.75-1.5	1.25-2.0	1.5	2.0
Permitting	0.5-1.0	1.75-2.5	1.5	2.5
Detailed Engineering	0.5-1.0	2.0-3.0	1.25	2.75
Field Construction	0.75-1.25	2.25-3.5	1.5	4
Start-up/Shakedown	0.25-0.5	2.5-4.0	0.75	4.5

* Can begin before FRM

Scoping and screeening studies refer to the process whereby refiners investigate various approaches to sulfur control. These studies involve discussions with firms which supply gasoline desulfurization and other refining technology, as well as studies by the refiner to assess the economic impacts of various approaches to meeting the sulfur standard. In the case of gasoline desulfurization, a refiner would likely send samples of their FCC gasoline to the firms marketing gasoline desulfurization technology to determine how well each technology removed the sulfur from that particular type of FCC gasoline (e.g., sulfur removal efficiency, octane and yield loss, hydrogen consumption, etc.).

API projects that these studies can start 6 months prior to the final rule and would continue for a year after the final rule. Based on discussions with both refiners and technology providers, it is clear that many refiners have already been conducting these studies for at least a year. We believe that by the time of the final rule, refiners will already have a very good idea of the performance and economics of the various gasoline desulfurization technologies at the pilot plant level. Some time will be required to process the details of the final rule. More importantly, however, is that many of the new gasoline desulfurization technologies will be demonstrated in actual refinery applications this year. Refiners naturally desire as much demonstrated experience with any new technology as possible prior to investing significant amounts of capital in these technologies. As discussed above, we believe that these new

technologies are sufficiently similar to existing gasoline desulfurization technology that long-term performance will not be an issue if the process operates as designed initially. Thus, we believe that sufficient performance data will be available within 6 months after the final rule to allow refiners to initiate process design. This is the same time period estimated by API, though API estimates that the scoping studies will extend 6 months into the process design period.. As this does not affect the total leadtime needed, the ability to modify the design during the process design period simply gives a refiner more flexibility to optimize its design.

API then estimates that process design, permitting and detailed engineering will require almost two and a half years. While not shown in the table, API estimates that the major appropriation decision will be made two and a half years into the process, or just after receiving the final permit approval and just before detailed engineering is completed.

The time required for process design will depend on the extent of the refinery modifications planned. We expect that the great majority of refiners will hydrotreat their FCC gasoline. If no existing equipment is used, this primarily involves building the hydrotreater and its associated equipment (distillation columns, furnaces, pumps, compressors). The refiner would also require a source of a hydrogen for the desulfurization unit. This could come from hydrogen already being generated in the refinery, or from an outside source. In the extreme, the refiner would have to build its own hydrogen plant. Finally, the refiner will have to ensure that the hydrogen sulfide being generated from the desulfurization equipment can be processed in the refinery's existing sulfur recovery plant. Given the small amount of sulfur being removed from gasoline compared to the amount of sulfur already being processed in the refinery, this is likely to be possible with little change to the sulfur recovery plant. However, some expansion could be required in the extreme.

All of this equipment is already common to refineries. Gasoline desulfurzation units are either very similar to existing distillation columns or gasoline and diesel fuel hydrotreaters already being used in essentially every refinery. Hydrogen plants are widely used throughout the refining and chemical industries and can be purchased from vendors as basically stand alone units. The same is true for sulfur recovery plants. Also, design and construction time has been reduced by up to 40 percent between 1991 and 1996 alone by computerized design and improving construction scheduling using state of the art methods.[21] For example, CDTECH estimates that 10 - 12 weeks are needed for the basic process design of their equipment. While this estimate for basic process design may not represent all the technologies which may be used, even if the process design for these other technologies is 2 or even three times longer, this time would still be significantly less than API's estimate. API does not mention any recent reductions in required project schedules associated with computerization and standardization in design and construction improvements. They do make comparisons to past leadtimes provided for RFG, but only indicate that the leadtime required has increased, not decreased. Thus, it is not clear why API is estimating the need for so much more time for process design and engineering.

It is possible that some refiners might decide to implement more major changes to the refinery, such as adding a FCC feed hydrotreater. This equipment is more unique to each refinery and could require some additional time to design. However, this equipment would

significantly reduce a variety of emissions from the FCC unit. This should ease permitting and compensating for any emission increases elsewhere in the refinery. The upper limits of our estimates shown in Table IV-13 apply to the limited number of these more major modifications which might occur.

API also indicates that the time necessary for permitting has increased even since the mid-1990's when refineries made modifications for RFG production. EPA recognizes that permitting is a necessary step in the process and that it is often outside of the refiner's control. EPA has committed to working with states and local agencies to streamline this process as much as possible. We believe that the permitting can be reduced to as short as six months and to at most a year.

According to a general estimate for construction time for about the 1980 time frame, 18 to 42 months should be allowed for large construction projects over $10 million, which could range up to the installation of an entire refinery or plant.[22] Smaller projects are projected to require substantially less time. The projected capital cost of gasoline desulfurization is near the lower end of the cost range cited, considering inflation. Thus, the 18 month estimate should be considered applicable, which is the same as API's estimate. However, this estimate was well prior to the 35-40% reductions cited above. Also, the construction time for those refiners planning to install demonstration units of the advanced desulfurization technology are well below 18 months. Thus, we estimate the time of construction to be a year, plus or minus three months.

Overall, shortening the permitting and basic process design has a dramatic impact on API's estimated four year time for complying. Based on this analysis, we estimate that refiners should be able to complete the process of designing and installing gasoline desulfurization hardware, and make other refinery changes, in about 2½ to four years. Again, the upper end of this range should only apply to a small number of refiners which will be making major changes to their refinery configuration as a result of gasoline desulfurization.

API estimates that up to an additional year is needed for contingencies. Those refiners which would need that extra time will have added flexibility to meet the proposed program implementation date by participating in the averaging, banking and trading program. Those which can meet the proposed implementation date sooner will be able to generate credits which can be traded to those which need more time to comply. For those refiners which would like to install their own gasoline desulfurization processing units, but are not yet very far along, the trading program would potentially allow them more time to develop their processes.

Several different fuel programs already in place suggest that a stringent gasoline desulfurization program can be phased-in sooner than what API claims. The California sulfur control program which was promulgated in June of 1975, started to phase in only six months after promulgation, and was fully phased in 4½ years later.[23] Similarly, the Phase II California Reformulated Gasoline Program was promulgated in November 1991 and took effect about 4½ years after promulgation.[24] However, in addition to a stringent sulfur control standard, refiners also had to meet stringent controls for aromatics, olefins, Reid vapor pressure, and distillation

index. Thus, if California refiners began to meet the low sulfur program within six months, and the very stringent RFG requirements in 4½ years, then, this argues that if only a stringent gasoline sulfur standard were to be finalized, that most refiners should be able to meet that requirement in less than four years. Also, because the refining industry already has extensive experience with meeting the California low sulfur requirement, it likely could meet a similar standard sooner.

The On-Road diesel sulfur rulemaking provides an example of refiners meeting a much shorter compliance period. Refiners nationwide met the on-highway low sulfur diesel standards in three years time; since the rulemaking was promulgated August 1990 and took effect October 1993.[25] That rulemaking required refiners to reduce diesel sulfur levels from over 2000 ppm down to under 500 ppm. Diesel hydrotreaters are fixed bed hydrotreaters which, as described above, are essentially the same design as Octgain units

For the Reformulated Gasoline Program, EPA proposed to give refiners 4 years to meet the Complex Model requirements of the Reformulated Gasoline program. We felt that 4 years was necessary so that refines could take time to understand how to most cost-effectively use the Complex Model, and to install whatever capital which needed to be installed. However, this rulemaking specifies a single specification and not require the use of a complex emissions model.

Refiners will have a minimum of four years leadtime to comply with the gasoline sulfur standard if the final rule is promulgated by the end of 1999. However, the sulfur averaging banking and trading program provides up to an extra two years for those refiners participating in the program. Thus, the leadtime provided in this proposal should be sufficient, with one exception.

Small refiners may need more time to comply with a sulfur control program. Small refiners generally have a more difficult time obtaining funding for capital projects, and must plan further in advance of when the funds are needed. We contracted a study of the refining industry which included assessing the time required for small refiners to obtain loans for capital investments. The simple survey revealed that small refiners would need two to three months longer than large refiners to obtain funding. If small refiners are forced to or prefer to seek funding through public means, such as through bond sales, then the time to obtain funding could be longer yet, by up to one third longer.[26] In addition, because of the more limited engineering expertise of many small refiners, the design and construction process for these refineries is relatively more difficult and time consuming. We also think that the contractors which design and install refinery processing units will likely focus first on completing the more expensive upgrade projects for large refiners. Thus the design and construction of desulfurization hardware in the refinery would take longer as well. For this and other economic reasons, we are proposing to delay the implementation of the low sulfur program for small refiners.

8. Phase In of Compliance with the Proposed Sulfur Standards

In the previous section, we estimated that it would take 2.5-4 years (30-48 months) to design and construct sulfur desulfurization equipment. The lower end of this range was more relevant to those refiners choosing to desulfurize FCC gasoline, while the upper end of the range would more likely apply to more significant changes, possibly involving the construction of a FCC feed hydrotreater and changes to other units in the refinery to accommodate a change in crude oil which the FCC feed hydrotreater enabled.

The proposed gasoline sulfur requirements begin on October 1, 2003. On October 1, 2003, the per gallon cap of 300 ppm takes effect, followed by similar caps of 180 ppm and 80 ppm which take effect on January 1, 2005 and January 1, 2006, respectively. Also, refiners' actual gasoline production must contain less than 120, 90 and 30 ppm sulfur on average during calendar years 2004, 2005 and 2006 (and beyond). Finally, refiners must also meet a refinery average sulfur standard of 30 ppm starting on January 1, 2004.

Between January 1, 2004 and December 31, 2005, the 30 ppm refinery average standard can be met using credits generated or purchased. Between January 1, 2000 and December 31, 2003, credits can be generated by selling gasoline (conventional or reformulated) that contains no more than 150 ppm sulfur. The credit is the difference between the sulfur content of the fuel produced and the refinery's 1997-1998 sulfur baseline in the case of conventional gasoline or wintertime RFG, multiplied by the volume of gasoline produced. In the case of summertime RFG, the credit is the difference between the sulfur content of the fuel produced and 150 ppm, again multiplied by the volume of gasoline produced. Starting in 2004, credits (and debits) are the product of the difference between the sulfur content of the fuel produced (whether conventional or reformulated) and 30 ppm.

The phase in of both the per gallon sulfur caps and the actual average sulfur standards between 2004 and 2006 and the ability to generate sulfur credits starting in 2000 is intended to allow refiners to stagger their investment in desulfurization technology while protecting Tier 2 vehicles from unreasonable sulfur levels and getting substantial emission reductions from both Tier 2 and existing vehicles. In order to estimate the rate at which individual refineries must install desulfurization equipment, we estimated each refinery's current sulfur level and compared this to the proposed requirements. We based our estimates of refinery's current sulfur levels on these refinery's official 1990 baselines, which were developed in support of the EPA's RFG and antidumping programs. These 1990 baselines were updated using 1997 data which refiners submit, again as part of the RFG and antidumping programs. When the 1997 data were available for an individual refinery, it was used in lieu of the 1990 baseline. However, in some cases, 1997 data were only available for all of a corporation's refineries on an aggregate basis. In this case, each refinery's 1990 sulfur level was multiplied by the ratio of the refiner's 1997 corporate average sulfur level to its 1990 corporate average sulfur level. This procedure assumes that any change in sulfur between 1990 and 1997 occurred proportionately at each refinery. In a few cases, 1997 data were not yet available for a specific refiner, so the 1990 baseline was used unchanged.

We used these sulfur estimates along with estimates of each refinery's gasoline production to develop a profile of the industry. We grouped refineries by current sulfur level

and determined the amount of gasoline produced by non-California refineries in each sulfur grouping. Refiners meeting the definition of a small business were also excluded, as they would have more time to comply with the proposed sulfur requirements than other refiners. The results of this analysis are shown in Table IV-14.

Table IV-14. Distribution of Refineries by Current Gasoline Sulfur Level

	Refinery Groupings			
	1	2	3	4
Range of Gasoline Sulfur (ppm)	0-40	41-180	181-300	>300
Average Baseline Sulfur (ppm)	17	105	246	476
Percentage of total fuel produced	2%	26%	26%	47%
Number of Refineries	10	33	25	39

Starting with this information, we projected the actions which refiners could take in meeting the proposed gasoline sulfur requirements. This analysis revealed that the per gallon caps of 300 and 180 ppm applicable nominally in 2004 and 2005 were the most constraining features of the proposal in these early years of the program. Thus, this discussion will begin with compliance with those caps, followed by a discussion of compliance with the absolute corporate average standards of 120 and 90 ppm in 2004 and 2005 and compliance with the 30 ppm standard, which can be met with credits.

A refiner can take two basic types of actions to meet the 2004 and 2005 sulfur caps. It can make operational changes without adding or substantially modifying its current refining equipment or, it can add new capital equipment. Operational modifications include switching to a low sulfur crude oil, operating existing FCC feed and naptha hydrotreaters more severely, debottle-necking these units to process more volume, and shifting the heaviest portion of FCC gasoline (which contains a disproportionate share of FCC gasoline sulfur) to the distillate pool. As an alternative to the last approach, a refiner could hydrotreat this heavy FCC gasoline in its distillate hydrotreater, desulfurize it, separate it from the hydrotreated distillate and then reblend the desulfurized FCC gasoline back into the gasoline pool. We believe that these techniques would enable refiners to reduce sulfur levels in the near term. However, the degree of this reduction is difficult to estimate. Also, refiners have to meet the Phase 2 requirement of the RFG program in 2000, which is generally expected to require RFG to contain roughly 150 ppm sulfur during the summer months.

Very few refiners have built new gasoline desulfurization equipment in order to meet this requirement. Thus, they appear to be planning to meet the 150 ppm level with operational changes or by reblending. Reblending would involve the production of two distinct gasolines within the refinery, one with lower sulfur levels for the RFG market and another gasoline with higher sulfur levels for the conventional gasoline market. The antidumping requirements which apply to non-RFG gasoline implicitly limit the degree to which this can occur, but it still possible that many refiners will use blending strategies to at least partially meet the Phase 2 RFG requirements. In any event, the Phase 2 RFG requirements are likely to utilize some of refiner's

existing ability to reduce gasoline sulfur without new capital equipment. This, plus the uncertainty in the degree that operational changes can reduce sulfur levels, led us to believe that refiners would not rely on operational changes as the primary means of meeting the 2004 and 2005 per gallon sulfur caps of 300 and 180 ppm. As a result of this, for the purpose of this analysis, we assumed that any major reductions in gasoline sulfur needed to meet the per gallon caps, as well as the eventual 30 ppm standard, would be met through the construction of new desulfurization equipment.

This uncertainty in the way in which refiners will meet the Phase 2 RFG requirements also led us to assume that the pool average sulfur level will not decrease in 2000 due to these requirements. In fact, some reduction is likely. However, this reduction would only serve to delay the timing of investments in desulfurization equipment. In this respect, the projections made below probably overestimate the number of refineries which must invest in the near term to some degree.

In most cases, the overall costs of desulfurization equipment is minimized when its construction is conducted in one step (enabling the production of 30 ppm gasoline), as opposed to a two step process involving some intermediate sulfur level. Thus, we also assumed that if a refinery had to install new equipment to meet a particular sulfur standard, it built equipment sufficient to comply with the 30 ppm standard and 80 ppm cap. There are some situations, particularly those involving higher baseline sulfur levels, where the equipment needed to meet the final 30 ppm standard involves more than one desulfurizing unit. In this case, it may be possible to install the major unit prior to October 1, 2003 and meet the 2004 requirements and delay the other unit(s) until 2005 or 2006. This possibility was not accounted for here.

Sulfur group #4 in Table IV-14 shows that 39 refineries have current sulfur levels above 300 ppm. These refineries must reduce their gasoline sulfur levels to 300 ppm or less by October 1, 2003, due to the per gallon cap taking effect at that time. In accordance with the above premises, the 39 refineries in this group would require fully operational desulfurization equipment by this date. In fact, this is likely an overestimation. Some of the refineries in this group are within 10-15 ppm of the 300 ppm cap. It is likely that these refineries could reduce their sulfur levels by a few ppm without installing new equipment. However, regular grade gasoline tends to contain more sulfur than premium grade. Meeting a per gallon cap with regular grade gasoline may require the refinery average sulfur level to be somewhat below 300 ppm. Also, refineries do not produce identical gasoline each day; there is some variation in the quality of gasoline produced throughout the year. Since the 300 ppm cap applies to each and every batch of gasoline produced, this variation also requires that the average sulfur level be below 300 ppm.

This implies that some of the refineries in Group #3 would also have install desulfurization units to meet the 300 ppm cap. However, this ignores the possibility of sulfur reductions from operational refining modifications and reducing historic variation in gasoline quality given an economic incentive to do so. We project that these more modest modifications, along with improved blending techniques, would be sufficient for those refineries currently near the 300 ppm level to produce regular and premium grades of gasoline under the 300 ppm cap.

Thus, we project that 39 desulfurization units would have to be installed and operating prior to October 1, 2003. We also project that six of these units would be installed by mid-2002, 12 would be installed by January 1, 2003 and the remaining 21 units would be installed by October 1, 2003. The projection of the 6 early units reflects the fact that technology vendors wishing to license their technology to refiners will need to demonstrate this technology early in the process. EPA projects that at least six technologies will be competing in this timeframe. We are already aware of at least three plants which will be in operation during 2000 or early 2001, two CDTech units and one Mobil Octgain unit. Assuming that EPA issues its final Tier 2/Sulfur rule by the end of 1999, mid-2002 is exactly 30 months later, which is generally the minimum time EPA projects for installing such equipment. Of course, given the commercial purposes for constructing and operating this equipment, plans could begin well before the final rule is signed, as indicated by the two projects mentioned above.

The 12/21 split between the 2003 and 2004 units was based on the premise that some refiners would want to generate credits for use in their other refineries in 2004 and 2005 or for sale to other refiners. We also expect that refiners, process design firms, and construction firms would want to spread out the design and construction of this new equipment as much as possible. Installing this new equipment within 36 months of the final rule (i.e., by January 1, 2003) is certainly feasible, given the projections made in the previous section. Thus, EPA believes that there would be an economic incentive to begin construction at some refineries sooner than at others.

Using the same assumptions, those refineries with current sulfur levels between 180 and 300 ppm would have to install equipment for use by January 1, 2005. As shown in Table IV-14, this group includes 25 refineries. Finally, the 30 ppm standard effective in 2006 would require another 33 refineries to install desulfurization equipment. Ten refineries out of the total of 107 refineries located in the U.S. outside of California already have sufficiently low sulfur levels to avoid the need for new equipment.

Table IV-15 shows the effect of the phase-in of this new equipment on average sulfur levels in the non-California U.S. gasoline pool. As can be seen, pool average sulfur levels in 2004 and 2005 are 105 and 49 ppm, respectively, well below the proposed 120 and 90 ppm corporate average standards. Thus, no additional controls should be required to meet these average standards if sufficient credits are available either from within the corporation or on the open market. This conclusion presumes that refineries with current sulfur levels in between the corporate average standard and the per gallon cap (e.g., 120-300 ppm in 2004) are a part of a corporation which has another refinery at 30 ppm, so that its actual corporate average sulfur level is below 120 or 90 ppm, as applicable, since these standards must be met without the use of credits.

Table IV-15. Effect of Phase-In of Sulfur Control to Meet Sulfur Caps in 2004 and 2005

	2000	*2001*	*2002*	*2003*	*2004*	*2005*	*2006*
Pool Average Sulfur Level (ppm)	312	312	296	216	105	49	30
Number of Refineries Building Sulfur Units	0	0	6 *	12	21	28	30
Percentage Controlled to 30 ppm	0	0	7%	22%	47%	73%	100% **
Credits (ppm over the entire U.S. gasoline pool for an entire year)							
Credits Generated from Winter RFG	20	20	20	20	0	0	0
Credits Generated from Sulfur Units	0	0	16	96	0	0	0
Credits Used to Allow Sale of >30 ppm Gasoline	0	0	0	0	-75	-19	0
Cumulative Credit Balance	+20	+40	+76	+192	+117	+98	+98

* Units only operate during second half of 2002.
** Includes 2% of fuel which is currently below 40 ppm sulfur.

This table also shows the sulfur credits generated and used by refineries between 2002 and 2006. As can be seen, 112 ppm of credits were generated by the 18 units operating before January 1, 2004. This amount is greater than the 94 ppm of credits which are needed by the 58 refineries which did not begin operating sulfur units until 2005 or 2006.

Table IV-15 also shows a series of 20 ppm credits under the heading of wintertime RFG. The proposed credit provisions allow winter RFG to generate sulfur credits if its sulfur level is below the individual refinery's baseline sulfur level, which on average is 312 ppm. Summer RFG is expected to contain 150 ppm sulfur or less. EPA projects that the cost of extending this control (or reblending) to the winter months would be minimal and that refiners would likely choose to generate credits in this way. The 20 ppm per year of credits represents the difference between the U.S. pool average sulfur level (312 ppm) and the 150 ppm level (difference of 162 ppm), multiplied by a factor of one-half, since only winter fuel would receive the credit and by a

factor of 0.25, since RFG is roughly 25 percent of the non-California gasoline market.

Given this expectation of significant RFG-related credits, EPA projects that a significant excess of credits would be available. This analysis assumes that all credits which are generated are either used within a corporation or are put up for sale on the open market. This may not occur in all cases. However, this analysis indicates that only about half of the credits expected to be generated are actually needed to allow refineries with current sulfur levels below either 300 ppm or 180 ppm to delay installation of desulfurization units until 2005 or 2006, respectively. It is also possible that many more credits would be available, if many refineries use operational techniques to reduce sulfur to levels below the 150 ppm trigger level before the time that they install desulfurization units. On the other hand, fewer credits would be available if refineries adopt an alternative schedule to phase-in desulfurization capacity (because of capital constraints or site specific factors affecting individual control decisions) than the schedule posited by this analysis. As noted above, for example, some refineries may be close enough to the 300 ppm cap to be able to reduce their sulfur levels to meet the cap without installing new equipment. There may also be cases where refineries have such high baseline sulfur levels that more than one desulfurization unit would be required to produce 30 ppm sulfur gasoline on average. In these cases a decision to phase-in these units rather than installing 30 ppm technology initially would reduce the number of credits generated early. However, even if fewer refineries install desulfurization equipment to generate early credits than our analysis assumed, we believe there will be sufficient credits generated from winter RFG and from early installation of some 30 ppm technology to fully cover the credits needed by the industry.

Chapter IV. References

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Chapter V: Economic Impact

A. Impact of Tier 2 Standards on Vehicle Costs

This section presents a detailed analysis of the vehicle-related costs we estimate would be incurred by manufacturers and consumers as a result of the Tier 2 standards. Section B. of this Chapter presents cost estimates for fuels changes. For manufacturers, the economic impact of the Tier 2 standards would include incremental costs for various vehicle hardware components, as well as up-front costs for research and development (R&D), certification, and facilities upgrades. Impacts on consumers would include increases in vehicle purchase price and changes in vehicle operating costs. Finally, this section provides estimates of the annual nationwide aggregate costs for Tier 2 vehicles.

1. Manufacturer Costs for Tier 2 Vehicles

a. Methodology

This section A.1. discusses EPA's estimates of costs to manufacturers for Tier 2 vehicles, including both hardware and developmental costs. The estimates are based on projections of technology changes we consider most likely to be used by manufacturers to comply with the Tier 2 standards. To estimate costs, we have analyzed two sets of technologies for each vehicle class and engine type, a baseline technology package and a Tier 2 technology package. We used as a baseline, projected NLEV technologies for LDVs, LDT1s, and LDT2s, and Tier 1 technologies for LDT3s and LDT4s. These are the standards that vehicles will be meeting in 2003.[t] We have estimated the baseline technology packages based primarily on California Air Resources Board technology analyses done in support of the California LEV program,[1] with adjustments based on discussions with manufacturers about trends in technology.

The following analysis projects a relatively uniform emission control strategy for various LDV and LDT models. However, this should not suggest that a single combination of technologies would be used by all manufacturers. Selecting technology packages requires extensive engineering judgement and EPA does not know future technology mixes and costs with certainty. New technological developments could significantly change the approach manufacturers would take to meet the standards. In addition, there are several emissions control technologies and several manufacturers of each. The Technological Feasibility portion of this RIA details many of the available technologies. Each manufacturer will choose the mix of technologies best suited for their vehicles. Manufacturers would have as many as eight years for R&D for some vehicles due to the phase-in schedule. We expect a large R&D effort involving extensive systems optimization to find the most cost effective mix of technologies for particular

[t] Even though the NLEV program ends in the Tier 2 time frame, we have not included the NLEV program in our Tier 2 analysis, since we have analyzed and adopted NLEV previously.

vehicle lines.

Nevertheless, we believe that the projections presented here provide a cost estimate representative of the different approaches manufacturers may ultimately take. Clearly, there are key technologies that manufacturers will likely use to meet the standards in most cases. We expect Tier 2 standards would be met through refinements of current emissions control components and systems rather than through the widespread use of new technologies. Current LDV and LDT certification levels also suggest this approach makes sense. We have made a best estimate of the combination of technologies that any manufacturer might use to meet the proposed standards at an acceptable cost and these technologies form the basis of the cost estimates. Since California, in their LEVII program, has adopted essentially the same standards and time-line that EPA is proposing, we used California's technology and cost analyses as a source of information.[2] We also had several conversations with equipment and vehicle manufacturers whose input we also used for these analyses. Most manufacturer input is considered confidential business information and therefore is not described in detail.

We have not specifically analyzed smaller incremental changes in technologies which might occur due to interim standards between the baseline and the Tier 2 standards. For LDVs and LDT1s, the interim standards are a continuation of NLEV and therefore are equivalent to the baseline standards. For LDT2s, given the state of technology on current vehicles, we expect only minor changes in response to the interim standards. Many engine families are already certified at levels meeting the interim standards. In addition, broad averaging would be available which manufacturers could use in the early years of the phase-in when significant numbers of LDVs and LDT1s are also in the averaging program for the interim standards.

In 2006, when LDT2s may make up the large majority of vehicles remaining in the interim program manufacturers could use credits from model years 2004/2005 to comply with the interim standards. If this is not an option, we expect manufacturers could make a few minor modifications which would result in needed reductions. Most likely, the standards could be met through calibration changes which entail changes to software. These changes would not involve hardware or tooling changes. The R&D costs associated with these changes are already included in the relatively large R&D costs included for the program as a whole. In addition there are likely to be incremental improvements in the standard catalyst system for these vehicles due to progress made by catalyst manufacturers. These incremental improvements in washcoat technology are part of the normal progression of technology and would not likely result in an increase in the catalyst cost due to the competitiveness of the catalyst industry.

For LDT3s and LDT4s, there is a phase in to an interim fleet average NOx standard of 0.20 g/mile with an accompanying NMHC average of 0.156 g/mile. Vehicles have their emissions capped at 0.60 g/mile NOx and 0.23 g/mile NMHC. Most engine families currently meet the caps. EPA expects that manufacturers could apply calibration changes and incremental catalyst improvements, as noted above for LDT2s, where necessary to ensure compliance with the caps. In addition, much of the R&D will have already taken place due to the California program which includes the same standards (MDV2 standards) for pre-2004 model year LDT3s. We do not expect these changes to result in increases to the cost of the program.

For the interim fleet average NOx standard, (average standard of 0.2 g/mile NOx with a NMHC standard of 0.156 g/mile), the approaches noted above may not be adequate in some cases. For vehicles well above the standard, manufacturers could redesign the vehicles to meet the interim standards. However, we believe it is more likely that manufacturers would phase these vehicles into the interim standards later in the phase-in period and use the program averaging flexibility to meet the interim standard. Therefore, rather than project a cost for vehicles to meet the interim standards, we have projected sales of Tier 2 vehicles prior to 2008 to average with and off-set those exceeding the interim standards. We believe this approach is reasonable considering manufacturers are likely to avoid significant R&D efforts to meet a standard that is in effect for only a few model years. Essentially, a few such vehicle models would have to be immediately redesigned to meet Tier 2 levels. Due to timing considerations, manufacturers are more likely to focus their resources on meeting the Tier 2 standards.

Vehicle phase-in estimates are needed to project annual aggregate costs during the phase-in period. For both phase-in periods (for LDVs, LDT1s, LDT2s, and for LDT3s, LDT4s), EPA has modeled that manufacturers will start the phase-in of Tier 2 standards with lighter vehicles and work their way to heavier vehicles until all vehicles up through LDT4s meet the Tier 2 standard in 2009. The phase-in projections described in further detail in section A.3., below.

Costs to the manufacturer are broken into variable costs (for hardware and assembly time) and fixed costs (for R&D, retooling, and certification). EPA projected costs separately for LDVs, the different LDT classes, and for different engine sizes (4, 6, 8-cylinder) within each class. Cost estimates based on the projected technology packages represent expected incremental variable and fixed costs for vehicles in the near-term, or during the first years of implementation.. For the long term, we have identified factors that would cause cost impacts to decrease over time. The analysis incorporates the expectation that manufacturers and suppliers will apply ongoing research and manufacturing innovation to making emission controls more effective and less costly over time. Also, we project that fixed costs would be recovered over the first five years of production, after which these costs would be recovered. These factors are discussed in further detail below.

b. Hardware Costs for Exhaust Emissions Control

The following section briefly describes each of the technologies EPA has included in the cost analysis and their costs incremental to the baseline use of the technology. Tables V-1 through V-5 at the end of this section provide the complete detailed projection of hardware changes and costs for each vehicle and engine type. A breakdown of the hardware costs for the evaporative system follow in section A.1.c. The Technological Feasibility portion of this RIA provides further detail on the technologies included in the cost analysis, as well as others that are less likely to be used to meet Tier 2 standards. The costs presented in this section are near-term costs, during the first few years of production. Long-term hardware costs are discussed in a following section.

Manufacturers are likely to use a systems approach to meeting the Tier 2 standards and

much of the effort will be in optimizing how the various components and subsystems (engine, catalyst, fuel system, etc.) interact to achieve peak emissions performance. Some of these items are included as part of the technology discussions below. However, there are no hardware costs associated with these changes. The costs of optimization and calibration are part of a significant R&D effort EPA anticipates will be necessary to meet the Tier 2 standards.

i. Catalytic Converter System

The catalytic converter system is central to meeting current standards and improvements to the systems will be critical in meeting Tier 2 emissions standards. EPA projects that all Tier 2 LDVs and LDTs will be equipped with advanced catalysts. Catalyst manufacturers are currently working with engine manufacturers on new catalyst systems. To determine the cost increases due to improved catalyst systems, we first analyzed current Tier 1 and NLEV systems for the baseline and then projected what changes may be necessary to meet Tier 2 standards.

EPA first determined an average catalyst system for the baseline vehicles. Catalyst systems vary in size and configuration due to factors such as engine size and emissions levels, vehicle packaging constraints, cost, and manufacturer preference. Catalyst systems typically consist of single or dual units (main or underfloor catalysts) and may also include one or two smaller catalysts placed close to the engine (close coupled). For the baseline, we examined the total volume, precious metal loading, and architecture of the main, or underfloor catalysts to derive an average baseline catalyst for the various vehicle types and engine sizes. We also noted whether or not vehicles were also equipped with additional close coupled catalysts.

After establishing baseline catalyst systems, we then projected changes to the catalyst system for the Tier 2 analysis. In general, manufacturers could meet the standards by using very large catalysts with relatively high precious metal loading. Many of the test programs that have been conducted to demonstrate the feasibility of very low standards have featured vehicles with such catalyst systems. However, based on uniform input from catalyst manufacturers, this is not the approach we expect manufacturers to take in meeting the Tier 2 standards. Catalyst manufacturers anticipate that improvements to the catalyst systems design, structure, and formulation will also play a critical role in reducing emissions. These improvements are aimed at decreasing emissions while minimizing the increase in catalyst volume and precious metal loading. Manufacturers are working on these catalyst systems today.

We do expect some increase in average catalyst size (volume) and precious metal loading. We believe that it is reasonable to expect catalyst systems to be sized such that the underfloor catalyst volume will be equal to engine displacement and that loading will increase by about 10 percent. Perhaps of equal importance will be the R&D efforts on the vehicle manufacturers part to optimize engine performance and control systems so that the catalyst can function at peak efficiency. Additional information on catalyst test programs and catalyst changes is available in the Technical Feasibility Section of this RIA.

For the main or underfloor catalysts, EPA projects that improvements to the catalyst

architecture and formulation will increase catalyst costs by $2.44 to $6.59, depending on the vehicle and engine type. These improvements include double layer washcoats and increasing the cell density of the catalyst substrate to 600 cells per inch (cpi). We estimate that increases in the catalyst volume and precious metal loading will account for the largest portion of the catalyst cost increase due to the high cost of precious metals. We anticipate the change in catalyst volume to cost between $10.00 and $55.00 per vehicle. We derived the increased volume cost by taking the baseline cost of the catalyst per liter ($50/liter) and multiplying by the increase in catalyst volume. Larger catalyst volume increases are projected for 6-cylinder engines in LDT applications than for 8-cylinder engines due to relatively low baseline catalyst volumes for 6-cylinder engines. We projected an increase in precious metal loading, in addition to the increased volume, at a total cost of between $1.84 and $11.26 per vehicle. The details of the underfloor catalyst cost estimates are provided in Table V-1.

Table V-1. Main or Underfloor Catalyst Cost Breakdown

Vehicle Type	Engine Type	Sales wtd. Engine Displacement (liter)	Projected Baseline Cat. Volume (liter)	Projected Tier 2 Cat. Volume (liter)	Increased Volume Cost (a) (dollars)	Increased Platinum (Pt) (grams)	Increased Palladium (Pd) (grams)	Increased Rhodium (b) (Rh) (grams)	Added Pt cost (dollars)	Added Pd cost (dollars)	Added Rh cost (b) (dollars)
LDV	4-cylinder	2.0	1.8	2.0	10.00	0.000	0.000	0.085	0	0	1.84
	6-cylinder	3.2	2.8	3.2	20.00	0.000	0.000	0.138	0	0	2.95
	8-cylinder	4.5	4.0	4.5	25.00	0.000	0.000	0.194	0	0	4.14
LDT	4-cylinder	2.3	2.3	2.3	0.00	0.000	0.000	0.097	0	0	2.10
	6-cylinder	3.7	2.6	3.7	55.00	0.035	0.540	0.157	0.43	5.17	3.41
	8-cylinder	5.4	4.7	5.4	35.00	0.082	0.550	0.229	1.01	5.28	4.97

Precious Metal Costs

	$/troy ounce	$/gram
Pt	384	12.35
Pd	300	9.64
Rh	675	21.70

(a) Catalyst cost is $50/liter. Increased catalyst volume costs are the increase in catalyst volume multiplied by $50/liter.
(b) Increase in Rh of 1.2 g/cu ft

Close coupled catalysts are typically small relative to the main catalysts, under one-half liter in volume. Their small size is due to packaging constraints associated with their location close to the engine and their purpose, to warm-up quickly and reduce cold-start emissions. They also typically have relatively high precious metal loading. Due to these factors, EPA is not projecting changes to the close coupled catalysts, only changes in their usage. For NLEV vehicles (LDV, LDT1 and LDT2), the percentage of baseline vehicles equipped with close coupled catalysts is high, between 60 and 100 percent, depending on the vehicle and engine type. We believe that the use of close coupled catalysts has likely peaked in these classes and we have not projected increases in usage for Tier 2. For LDT3s and LDT4s, the use of close coupled catalysts is currently low relative to the other classes. For Tier 2 LDT3s and LDT4s, we have projected the use of close coupled catalysts to increase to be equivalent to the other vehicle categories. The cost of dual close coupled catalysts are projected to be between $90 and $110, for six and eight liter engines, respectively.

ii. Improved Fuel Control and Delivery

Precise fuel metering is critical to keeping the catalyst at peak operating efficiency. Much of the effort for improved fuel control is in calibration and system optimization. For some vehicles, EPA has included costs for hardware changes including improved exhaust gas oxygen sensors and air-assisted fuel injection. There are two types of improved oxygen sensors that EPA believes will be used increasingly for Tier 2 vehicles, universal exhaust gas oxygen sensors (UEGO) and fast light-off or planar sensors. UEGO sensors are the most expensive type of sensor and offer the most precise fuel control. However, only some manufacturers believe the additional control is worth their higher incremental cost of 10 dollars. We believe more manufacturers will opt for planar sensors, which offer a key advantage of quick warm-up, allowing for precise fuel control sooner during cold starts. Many baseline vehicles also will likely be equipped with planar sensors. The incremental cost of planar sensors is estimated to be four dollars per sensor. We expect that the improved sensors would be used only before the catalyst in the exhaust system for fuel control, with conventional heated exhaust gas oxygen sensors used post catalyst for catalyst monitoring and additional fuel control.

Air assisted fuel injection is used to provide a better air fuel mixture to the engine, which can be especially critical during engine warm-up. The technology can offer other advantages in terms of engine performance which also makes it an attractive technology. For air assisted fuel injection, the injectors must be redesigned to include a new adapter. We have projected that 50 percent of Tier 2 vehicles will be equipped with air assisted fuel injection at a cost of two dollars for each improved injector.

As indicated above, much of the improvements in fuel control are likely to be accomplished through system calibration. As such, they include software upgrade costs, rather than hardware costs. EPA has included such costs in the R&D cost. These improvements may include individual cylinder fuel control and adaptive learning.

iii. Secondary Air Injection

Manufacturers sometimes use a rich air/fuel mix during cold start to improve engine performance and driveability. Secondary injection of air into exhaust ports after cold start when the engine is operating rich can be used to promote combustion of unburned HC and CO which results from the rich air/fuel mix. Air injection can also be used in conjunction with spark retard to provide additional heat to the catalyst for quicker catalyst warm-up. EPA projects increased use of electric air injection strategies for Tier 2 vehicles equipped with 6- and 8- cylinder engines. The air injection systems consist of an electric air pump with integrated filter and relay, wiring, an air shut-off valve with integrated solenoid, a check valve, tubing, and brackets. We estimate the system cost to be 50 and 65 dollars for six- and eight- cylinder engines, respectively.

iv. Exhaust System Improvements

Manufacturers can insulate the exhaust system so the exhaust heat does not escape, but is instead maintained within the system to promote catalyst warm-up. Improved materials include laminated thin-walled exhaust pipes and double walled low thermal capacity manifolds (the two walls have a small air gap between them that acts as an insulator). EPA estimates that improved exhaust pipe costs one dollar per foot, with total system costs of between one and six dollars, depending on engine size. Low thermal capacity manifolds are estimated to cost 20 to 40 dollars depending on engine size. Due to the relatively high cost of these improvements, we have projected manufacturers would use them only on LDTs, where it may be more difficult to meet the Tier 2 standards. In some cases, manufacturers may be able to use exhaust system improvements in lieu of adding close-coupled catalysts.

In addition, exhaust systems can be made leak-free which improves fuel control and catalyst efficiency. As noted in the previous section, precise fuel control is critical to catalyst performance and the oxygen sensor is a key element of fuel control. Air leaking into the exhaust system can influence the oxygen sensor causing an improper fuel adjustment. Also, additional air in the exhaust stream can lead to an oxidizing environment in the catalyst, diminishing the catalyst's ability to reduce NOx. Leak-free systems include corrosion-free flexible couplings, corrosion-free steel, and improved welding of catalyst assemblies. We estimate that many baseline vehicles and all Tier 2 vehicles will be equipped with leak-free exhaust systems at an incremental cost of 10 to 20 dollars depending on engine size.

v. Engine Combustion Chamber Improvements

Manufacturers may make a number of improvements to their engines as they are redesigned, including adding a second spark plug to each cylinder, adding a swirl control valve to improve mixing of air and fuel, or other changes needed to improve cold start combustion. Engine changes are not likely to be uniform throughout the industry. EPA believes that significant engine improvements for LDVs, LDT1s and LDT2s are likely to have been made as part of the effort to meet NLEV standards. The Tier 2 standards are not likely to drive a second

set of major changes to these engines. Therefore, EPA has not included an engine modification cost for these vehicles. For LDT3s and LDT4s, which would be changing from Tier 1 to Tier 2 technology, we have included a hardware cost for engine modifications of $10 and $15 for six and eight cylinder engines, respectively.

vi. Exhaust Gas Recirculation (EGR)

One of the most effective means of reducing engine-out NOx emissions is exhaust gas recirculation. By recirculating spent exhaust gases into the combustion chamber, the overall air-fuel mixture is diluted, lowering peak combustion temperatures and reducing NOx. Many EGR systems in today's vehicles utilize a control valve that requires vacuum from the intake manifold to regulate EGR flow. Some vehicles are being equipped with electronic EGR in place of mechanical back-pressure designs. By using electronic solenoids to open and close the EGR valve, the flow of EGR can be more precisely controlled. EPA projects that the use of full electronic EGR systems will increase due to Tier 2 standards. We estimate that about 50 percent of Tier 2 LDVs and LDTs will be equipped with electronic EGR at an incremental cost of ten dollars per vehicle.

vii. Total Hardware Costs for Exhaust Emissions Control

Table V-3 provides a summary of the total hardware costs for each vehicle and engine type. Tables V-3 through V-7 present detailed estimated manufacturer costs itemized for each vehicle and engine type. The tables indicate EPA's estimate of the percentage of use of the technologies for both the baseline and the Tier 2 vehicles. Some of the technologies listed, such as individual cylinder fuel control and retarded spark timing, involve calibration changes only and have no hardware costs associated with them.

Table V-2. Total Estimated Per Vehicle Manufacturer Incremental Hardware Costs for the Tier 2 Standards

	LDV ($)	*LDT1 ($)*	*LDT2 ($)*	*LDT3 ($)*	*LDT4 ($)*
4-cylinder	23.78	15.15	15.15	N/A	N/A
6-cylinder	62.85	85.45	94.97	235.32	N/A
8-cylinder	71.63	N/A	80.98	194.45	194.45
sales weighted	42.85	39.13	89.78	198.58	194.45

Table V-3. Estimated Incremental Manufacturer Hardware Cost for Tier 2 LDV Compared to NLEV LDV

	4-Cylinder (53%)				6-Cylinder (39%)				8-Cylinder (8%)			
Emission Control Technology	Tech. cost est. (in dollars)	% of NLEV vehs. that use tech.	% Tier 2 that will req. tech.	Inc. cost over Tier 1 (in dollars)	Tech. cost est. (in dollars)	% of NLEV vehs. that use tech.	% Tier 2 that will req. tech.	Inc. cost over Tier 1 (in dollars)	Tech. cost est. (in dollars)	% of NLEV vehs. that use tech.	% Tier 2 that will req. tech.	Inc. cost over Tier 1 (in dollars)
Universal Exhaust Gas Oxygen Sensor (UEGO)	10.00	0	15	1.50	20.00	0	15	3.00	20.00	0	15	3.00
Air-assisted fuel injection (a)	8.00	50	50	0.00	12.00	50	50	0.00	16.00	50	50	0.00
Individual cylinder fuel control (b)	0.00	0	10	0.00	0.00	10	10	0.00	0.00	10	10	0.00
Retarded spark timing at start-up (b)	0.00	100	100	0.00	0.00	100	100	0.00	0.00	100	100	0.00
Improved precision fuel control (c)	0.00	100	100	0.00	0.00	100	100	0.00	0.00	100	100	0.00
Faster microprocessor	3.00	0	100	3.00	3.00	0	100	3.00	3.00	0	100	3.00
Fast light-off exhaust gas oxygen sensor (planar)	4.00	100	100	0.00	8.00	100	100	0.00	8.00	100	100	0.00
Heat optimized exhaust pipe (d)		0	0	0.00		0	0	0.00		0	0	0.00
Leak-free exhaust system (e)	10.00	100	100	0.00	20.00	100	100	0.00	20.00	100	100	0.00
Engine modifications (f)	0.00	0	0	0.00	10.00	100	100	0.00	15.00	100	100	0.00
Full electronic EGR	10.00	0	50	5.00	10.00	0	50	5.00	10.00	0	50	5.00
Close-coupled catalyst	55.00	60	60	0.00	55.00	0	0	0.00	55.00	0	0	0.00
Underbody or main catalyst	80.00	70	70	0.00	80.00	100	100	0.00	80.00	60	60	0.00
Dual close-coupled catalyst		0	0	0.00	90.00	100	100	0.00	110.00	80	80	0.00
Dual underbody or main catalyst		0	0	0.00	160.00	0	0	0.00	160.00	40	40	0.00
Increased catalyst volume	10.00	0	100	10.00	20.00	0	100	20.00	25.00	0	100	25.00
Increased catalyst loading (Rh)	1.84	0	100	1.84	2.95	0	100	2.95	4.14	0	100	4.14
Improved double layer washcoat + 600 cpsi cell density	2.44	0	100	2.44	3.90	0	100	3.90	5.49	0	100	5.49
Secondary air injection (g)	50.00	0	0	0.00	50.00	0	50	25.00	65.00	10	50	26.00
Total Incremental Cost				23.78				62.85				71.63

(a) Air assisted fuel injection requires minor redesign of the idle air control valve at no additional cost and addition of an adapter to each injector at a cost of $2 each.

(b) Improved precision fuel control envisioned here and retarded spark-timing at start-up constitute software changes only, at no additional hardware cost.

(c) Improved precision fuel control constitute software changes only, at no additional hardware cost.

(d) Length of heat optimized exhaust pipe required is estimated to be one foot for 4-cylinder engines, four feet for 6-cylinder engines, and six feet for eight-cylinder engines, at a cost of $1 per foot incremental.

(e) Leak-free exhaust system includes corrosion free flexible coupling, plus improved welding of catalyst assemblies.

(f) Types of engine modifications may be less uniform throughout the industry and may include items such as an additional spark plug per cylinder, addition of a swirl control valve or other hardware needed to achieve cold combustion stability, improved fuel economy

(g) Cost of air injection includes an electric air pump with integrated filter and relay, wiring, air-shut-off valve with integral solenoid, check valve, tubing and brackets.

Table V-4. Estimated Incremental Manufacturer Hardware Cost for Tier 2 LDT1 Compared to NLEV LDT1

	4-Cylinder (65.9%)				6-Cylinder (34.1%)			
Emission Control Technology	Tech. cost est. (in dollars)	% of NLEV vehs. that use tech.	% Tier 2 that will req. tech.	Inc. cost over Tier 1 (in dollars)	Tech. cost est. (in dollars)	% of NLEV vehs. that use tech.	% Tier 2 that will req. tech.	Inc. cost over Tier 1 (in dollars)
Universal Exhaust Gas Oxygen Sensor (UEGO)	10.00	0	15	1.50	20.00	0	15	3.00
Air-assisted fuel injection (a)	8.00	50	50	0.00	12.00	50	50	0.00
Individual cylinder fuel control (b)	0.00	10	10	0.00	0.00	10	10	0.00
Retarded spark timing at start-up (b)	0.00	100	100	0.00	0.00	100	100	0.00
Improved precision fuel control (c)	0.00	100	100	0.00	0.00	100	100	0.00
Faster microprocessor	3.00	0	100	3.00	3.00	0	100	3.00
Fast light-off exhaust gas oxygen sensor (planar)	4.00	100	100	0.00	8.00	100	100	0.00
Heat optimized exhaust pipe (d)	1.00	0	100	1.00	4.00	0	100	4.00
Leak-free exhaust system (e)	10.00	100	100	0.00	20.00	100	100	0.00
Engine modifications (f)	0.00	0	0	0.00	10.00	100	100	0.00
Full electronic EGR	10.00	0	50	5.00	10.00	0	50	5.00
Close-coupled catalyst	55.00	60	60	0.00	55.00	0	0	0.00
Underbody or main catalyst	80.00	70	70	0.00	80.00	100	100	0.00
Dual close-coupled catalyst	0.00	0	0	0.00	90.00	100	100	0.00
Dual underbody or main catalyst	0.00	0	0	0.00	160.00	0	0	0.00
Increased catalyst volume	0.00	100	100	0.00	55.00	0	100	55.00
Increased catalyst loading	1.84	0	100	1.84	2.95	0	100	2.95
Improved double layer washcoat + 600 cpsi cell density	2.81	0	100	2.81	4.52	0	0	0.00
Secondary air injection (g)	50.00	50	50	0.00	50.00	50	75	12.50
Total Incremental Cost				15.15				85.45

(a) Air assisted fuel injection requires minor redesign of the idle air control valve at no additional cost and addition of an adapter to each injector at a cost of $2 each.

(b) Improved precision fuel control envisioned here and retarded spark-timing at start-up constitute software changes only, at no additional hardware cost.

(c) Improved precision fuel control constitute software changes only, at no additional hardware cost.

(d) Length of heat optimized exhaust pipe required is estimated to be one foot for 4-cylinder engines, four feet for 6-cylinder engines, and six feet for eight-cylinder engines, at a cost of $1 per foot incremental.

(e) Leak-free exhaust system includes corrosion free flexible coupling, plus improved welding of catalyst assemblies.

(f) Types of engine modifications may be less uniform throughout the industry and may include items such as an additional spark plug per cylinder, addition of a swirl control valve or other hardware needed to achieve cold combustion stability, improved fuel economy

(g) Cost of air injection includes an electric air pump with integrated filter and relay, wiring, air-shut-off valve with integral solenoid, check valve, tubing and brackets.

Table V-5. Estimated Incremental Manufacturer Hardware Cost for Tier 2 LDT2 Compared to NLEV LDT2

	4-Cylinder (2.3%)				6-Cylinder (73.7%)				8-Cylinder (24%)			
Emission Control Technology	Tech. cost est. (in dollars)	% of NLEV vehs. that use tech.	% Tier 2 that will req. tech.	Inc. cost over Tier 1 (in dollars)	Tech. cost est. (in dollars)	% of NLEV vehs. that use tech.	% Tier 2 that will req. tech.	Inc. cost over Tier 1 (in dollars)	Tech. cost est. (in dollars)	% of NLEV vehs. that use tech.	% Tier 2 that will req. tech.	Inc. cost over Tier 1 (in dollars)
Universal Exhaust Gas Oxygen Sensor (UEGO)	10.00	0	15	1.50	20.00	0	15	3.00	20.00	0	15	3.00
Air-assisted fuel injection (a)	8.00	50	50	0.00	12.00	50	50	0.00	16.00	50	50	0.00
Individual cylinder fuel control (b)	0.00	10	10	0.00	0.00	10	10	0.00	0.00	10	10	0.00
Retarded spark timing at start-up (b)	0.00	100	100	0.00	0.00	100	100	0.00	0.00	100	100	0.00
Improved precision fuel control (c)	0.00	100	100	0.00	0.00	100	100	0.00	0.00	100	100	0.00
Faster microprocessor	3.00	0	100	3.00	3.00	0	100	3.00	3.00	100	100	0.00
Fast light-off exhaust gas oxygen sensor (planar)	4.00	100	100	0.00	8.00	100	100	0.00	8.00	100	100	0.00
Heat optimized exhaust pipe (d)	1.00	0	100	1.00	4.00	0	100	4.00	6.00	0	100	6.00
Low thermal capacity manifold	20.00	25	50	5.00	40.00	25	50	10.00	40.00	25	50	10.00
Leak-free exhaust system (e)	10.00	100	100	0.00	20.00	100	100	0.00	20.00	100	100	0.00
Engine modifications (f)	0.00	0	0	0.00	10.00	100	100	0.00	15.00	100	100	0.00
Full electronic EGR	10.00	50	50	0.00	10.00	50	50	0.00	10.00	50	50	0.00
Close-coupled catalyst	55.00	60	60	0.00	55.00	0	0	0.00	55.00	0	0	0.00
Underbody or main catalyst	80.00	70	70	0.00	80.00	100	100	0.00	80.00	60	60	0.00
Dual close-coupled catalyst		0	0	0.00	90.00	100	100	0.00	110.00	80	80	0.00
Dual underbody or main catalyst		0	0	0.00	160.00	0	0	0.00	160.00	40	40	0.00
Increased catalyst volume	0.00	0	0	0.00	55.00	0	100	55.00	35.00	0	100	35.00
Increased catalyst loading (Pt)	0.00	0	0	0.00	4.32	0	0	0.00	10.13	0	0	0.00
Increased catalyst loading (Pd)	0.00	0	0	0.00	51.67	0	0	0.00	52.83	0	0	0.00
Increased catalyst loading (Rh)	1.84	0	100	1.84	2.95	0	100	2.95	4.14	0	100	4.14
Improved double layer washcoat + 600 cpsi cell density	2.81	0	100	2.81	4.52	0	100	4.52	6.59	0	100	6.59
Secondary air injection (g)	50.00	0	0	0.00	50.00	50	75	12.50	65.00	50	75	16.25
Total Incremental Cost				15.15				94.97				80.98

(a) Air assisted fuel injection requires minor redesign of the idle air control valve at no additional cost and addition of an adapter to each injector at a cost of $2 each.

(b) Improved precision fuel control envisioned here and retarded spark-timing at start-up constitute software changes only, at no additional hardware cost.

(c) Improved precision fuel control constitute software changes only, at no additional hardware cost.

(d) Length of heat optimized exhaust pipe required is estimated to be one foot for 4-cylinder engines, four feet for 6-cylinder engines, and six feet for eight-cylinder engines, at a cost of $1 per foot incremental.

(e) Leak-free exhaust system includes corrosion free flexible coupling, plus improved welding of catalyst assemblies.

(f) Types of engine modifications may be less uniform throughout the industry and may include items such as an additional spark plug per cylinder, addition of a swirl control valve or other hardware needed to achieve cold combustion stability, improve fuel economy

(g) Cost of air injection includes an electric air pump with integrated filter and relay, wiring, air-shut-off valve with integral solenoid, check valve, tubing and brackets.

Table V-6. Estimated Incremental Manufacturer Hardware Cost for Tier 2 LDT3 Compared to Tier 1 LDT3

	6-Cylinder (10.1%)				8-Cylinder (89.9%)			
Emission Control Technology	Tech. cost est. (in dollars)	% of Tier 1 vehs. that use tech.	% Tier 2 that will req. tech.	Inc. cost over Tier 1 (in dollars)	Tech. cost est. (in dollars)	% of Tier 1 vehs. that use tech.	% Tier 2 that will req. tech.	Inc. cost over Tier 1 (in dollars)
Universal Exhaust Gas Oxygen Sensor (UEGO)	20.00	0	15	3.00	20.00	0	15	3.00
Air-assisted fuel injection (a)	12.00	0	50	6.00	16.00	0	50	8.00
Individual cylinder fuel control (b)	0.00	0	10	0.00	0.00	0	10	0.00
Retarded spark timing at start-up (b)	0.00	25	100	0.00	0.00	25	100	0.00
Improved precision fuel control (c)	0.00	50	100	0.00	0.00	50	100	0.00
Faster microprocessor	3.00	0	100	3.00	3.00	0	100	3.00
Fast light-off exhaust gas oxygen sensor (planar)	8.00	80	100	1.60	8.00	80	100	1.60
Heat optimized exhaust pipe (d)	4.00	0	100	4.00	6.00	0	100	6.00
Leak-free exhaust system (e)	20.00	50	100	10.00	20.00	50	100	10.00
Low thermal capacity manifold	40.00	25	75	20.00	40.00	25	100	30.00
Engine modifications (f)	10.00	0	100	10.00	15.00	0	100	15.00
Full electronic EGR	10.00	0	50	5.00	10.00	0	50	5.00
Close-coupled catalyst	55.00	0	0	0.00	55.00	0	0	0.00
Underbody or main catalyst	80.00	100	100	0.00	80.00	60	60	0.00
Dual close-coupled catalyst	90.00	12	100	79.20	110.00	55	80	27.50
Dual underbody or main catalyst	160.00	0	0	0.00	160.00	40	40	0.00
Increased catalyst volume	55.00	0	100	55.00	35.00	0	100	35.00
Increased catalyst loading (Pt)	0.43	0	100	0.43	1.01	0	100	1.01
Increased catalyst loading (Pd)	5.17	0	100	5.17	5.28	0	100	5.28
Increased catalyst loading (Rh)	3.40	0	100	3.40	4.97	0	100	4.97
Improved double layer washcoat + 600 cpsi cell density	4.52	0	100	4.52	6.59	0	100	6.59
Secondary air injection (g)	50.00	0	50	25.00	65.00	0	50	32.50
Total Incremental Cost				235.32				194.45

(a) Air assisted fuel injection requires minor redesign of the idle air control valve at no additional cost and addition of an adapter to each injector at a cost of $2 each.

(b) Improved precision fuel control envisioned here and retarded spark-timing at start-up constitute software changes only, at no additional hardware cost.

(c) Improved precision fuel control constitute software changes only, at no additional hardware cost.

(d) Length of heat optimized exhaust pipe required is estimated to be one foot for 4-cylinder engines, four feet for 6-cylinder engines, and six feet for eight-cylinder engines, at a cost of $1 per foot incremental.

(e) Leak-free exhaust system includes corrosion free flexible coupling, plus improved welding of catalyst assemblies.

(f) Types of engine modifications may be less uniform throughout the industry and may include items such as an additional spark plug per cylinder, addition of a swirl control valve or other hardware needed to achieve cold combustion stability, improved fuel economy

(g) Cost of air injection includes an electric air pump with integrated filter and relay, wiring, air-shut-off valve with integral solenoid, check valve, tubing and brackets.

Table V-7. Estimated Incremental Manufacturer Hardware Cost for Tier 2 LDT4 Compared to Tier 1 LDT4

	8-Cylinder (100%)			
Emission Control Technology	Tech. cost est. (in dollars)	% of Tier 1 vehs. that use tech.	% Tier 2 that will req. tech.	Inc. cost over Tier 1 (in dollars)
Universal Exhaust Gas Oxygen Sensor (UEGO)	20.00	0	15	3.00
Air-assisted fuel injection (a)	16.00	0	50	8.00
Individual cylinder fuel control (b)	0.00	0	10	0.00
Retarded spark timing at start-up (b)	0.00	25	100	0.00
Improved precision fuel control (c)	0.00	50	100	0.00
Faster microprocessor	3.00	0	100	3.00
Fast light-off exhaust gas oxygen sensor (planar)	8.00	80	100	1.60
Heat optimized exhaust pipe (d)	6.00	0	100	6.00
Leak-free exhaust system (e)	20.00	50	100	10.00
Low thermal capacity manifold	40.00	25	100	30.00
Engine modifications (f)	15.00	0	100	15.00
Full electronic EGR	10.00	0	50	5.00
Close-coupled catalyst	55.00	0	0	0.00
Underbody or main catalyst	80.00	60	60	0.00
Dual close-coupled catalyst	110.00	55	80	27.50
Dual underbody or main catalyst	160.00	40	40	0.00
Increased catalyst volume	35.00	0	100	35.00
Increased catalyst loading (Pt)	1.01	0	100	1.01
Increased catalyst loading (Pd)	5.28	0	100	5.28
Increased catalyst loading (Rh)	4.97	0	100	4.97
Improved double layer washcoat + 600 cpsi cell density	6.59	0	100	6.59
Secondary air injection (g)	65.00	0	50	32.50
Total Incremental Cost				194.45

(a) Air assisted fuel injection requires minor redesign of the idle air control valve at no additional cost and addition of an adapter to each injector at a cost of $2 each.

(b) Improved precision fuel control envisioned here and retarded spark-timing at start-up constitute software changes only, at no additional hardware cost.

(c) Improved precision fuel control constitute software changes only, at no additional hardware cost.

(d) Length of heat optimized exhaust pipe required is estimated to be one foot for 4-cylinder engines, four feet for 6-cylinder engines, and six feet for eight-cylinder engines, at a cost of $1 per foot incremental.

(e) Leak-free exhaust system includes corrosion free flexible coupling, plus improved welding of catalyst assemblies.

(f) Types of engine modifications may be less uniform throughout the industry and may include items such as an additional spark plug per cylinder, addition of a swirl control valve or other hardware needed to achieve cold combustion stability, improved fuel economy

(g) Cost of air injection includes an electric air pump with integrated filter and relay, wiring, air-shut-off valve with integral solenoid, check valve, tubing and brackets.

c. Hardware Costs for Evaporative Emissions Control

The standards proposed for evaporative emissions are technologically feasible now. Many designs have been certified by a wide variety of manufacturers that already meet these standards. A review of the 1999 model year certification results indicates that the average family is certified at slightly less than 1.0 grams per test (gpt) on the three day diurnal plus hot soak test, i.e. at less than half the current 2.0 gpt standard. Many families are certified at levels considerably below 1.0 gpt, including a few families that are certified below 0.5 gpt.

The proposed standards will not require the development of new materials or even the new application of existing materials. Low permeability materials and low loss connections and seals are already used to varying degrees on current vehicles. The standards will likely ensure their consistent use and discourage switching to cheaper materials or designs to take advantage of the large safety margins manufacturers have under current standards ("backsliding").

Complex (and perhaps somewhat more expensive) approaches have been proposed which involve pressurized fuel systems or fuel bladders. Such systems have not been implemented in production, nor do we believe they are necessary for the standards we are proposing. We believe manufacturers will follow more traditional paths in reducing their evaporative emissions.

There are two traditional approaches to reducing evaporative emissions. The first is to minimize the potential for permeation and leakage by reducing the number of hoses, fittings and connections. However, some joints and connections are necessary for vehicle assembly and service and no known joint has zero emissions.

The second traditional approach is to use less permeable hoses and lower loss fittings and connections. Low permeability hoses and seals as well as low loss fittings are currently available. Fluoropolymer materials can be added as liners to hose and component materials to yield large reductions in permeability over such conventional materials as monowall nylon. In addition, fluoropolymer materials can greatly reduce the impact of alcohols on hydrocarbon permeability of evaporative components, hoses and seals. Alcohols, present in about 10% of gasoline sold in the U.S., cause swelling of conventional materials which leads to increases in permeability and can also lead to tearing and leakage in situations where the materials are constrained in place, such as with gaskets and O-rings. Due to the common presence of alcohols such as ethanol in the gasoline pool and its adverse affect on materials and emissions durability, we believe material upgrades such as those discussed above are necessary to ensure that the benefits are captured in-use.

Steel fuel tanks and steel fuel lines have essentially zero losses due to permeation, but are vulnerable to leakage at joints and interfaces. Manufacturers are moving toward plastic fuel tanks for their lighter weight and greater ability to be molded to odd shapes. However, plastic tanks are permeable and are also susceptible to seepage and higher permeability at areas where connections and welds are made. Materials and manufacturing techniques exist to reduce these losses.

To estimate the per vehicle cost of an improved evaporative system, we looked at the incremental cost for an average current model year vehicle with a steel fuel tank (certified at - 1.0 g) to go from a certification level of 1.0 grams per test to a level of about 0.5 grams per test on the three day test cycle. The emission levels of 1.0 and 0.5 gpt were chosen because 1.0 represents the current average certification level and 0.5 gpt represents a certification target that leaves a compliance margin of about 100 percent between the certification level and the applicable standard (0.95 gpt for our proposed LDV/LLDT standard). The reductions and costs of the individual items are shown in Table V-8 below, and reflect the incremental cost of moving to low permeability materials, improved designs or low loss connectors. The items in the chart are ranked in order of decreasing cost effectiveness. Since the evaporative test procedure measures evaporative emissions each day over a three day period and then uses the highest day, gram per day numbers in the table are a reasonable proxy for grams per test data.

Table V-8. Potential Evaporative Improvements and Their Costs to Manufacturers [3] (grams per day)

Emission Source	*Baseline Vehicle (a)*	*Improved Vehicle (b)*	*Change (a-b)*	*Cost ($) (d)*	*Cost Effectiveness Ranking (d)/(a-b)*
Fuel cap seal	0.10	0.01	0.09	0.20	1
Fuel pump assembly seal	0.10	0.01	0.09	0.40	2
Fuel and vapor line	0.23	0.01	0.22	1.25	3
Fuel rail/manifold connectors	0.06	0.02	0.04	0.40	4
Canister improvements	0.12	0.04	0.08	1.00	5
Fill tube clamps	0.06	0.02	0.04	0.60	6
Fuel and vapor line connectors	0.18	0.06	0.12	2.20	7
Fill tube/fill neck connector	0.20	0.10	0.10	5.00	8
Allowance for non-fuel emissions	0.20	0.20	0	------	-------

Table V-8 shows that a manufacturer can choose from a range of improvements, and attain significant reductions in evaporative emissions. By selecting the first five items from the table, the manufacturer can achieve a reduction in evaporative emissions of about 0.5 g/day for a total cost of about three dollars per vehicle. The cost-effectiveness of these five items taken together is approximately $2400 per ton of VOCs removed. While these figures were based on a passenger car, we believe it is reasonable to assume the same costs here for light duty trucks since the same basic components are used on trucks and cars. Non fuel emissions may be higher

for larger vehicles, but our proposed evaporative standard for HLDTs (1.2 gpt) is higher to include a larger allowance for non-fuel losses.

Lastly, we note that most manufacturers are moving to "returnless" injection systems, and at least one major manufacturer's current products are 100 percent returnless. Through more precise fuel pumping and metering, these systems eliminate the return line in the fuel injection system which carries unneeded fuel from the fuel injectors back to the fuel tank. Returned fuel is a significant source of fuel tank heat and vapor generation, and therefore of evaporative emissions. The elimination of return lines reduces the total length of hose on the vehicle and also reduces the number of fittings and connections which can leak. We believe that most vehicles will move to returnless injection systems either before or in conjunction with the phase-in of the Tier 2 standards.

Our analysis is conservative in that it did not include the impact of these returnless systems. We believe that changing to a returnless injection system may provide a 0.15 g/day evaporative emissions benefit. If the example vehicle described above were equipped with a returnless injection system, then, we would expect evaporative emissions of about 0.85 gpt. Such a vehicle would require a smaller emission reduction (0.35 gpt) to hit the certification target of 0.5 gpt.

Returnless vehicles have about one third less vapor and fuel line footage and proportionately fewer connections and joints, accounting for most of the reduction attributable to returnless systems. We would expect an emission improvement and cost about one third less than those shown in the table above for fuel and vapor lines and fuel and vapor line connectors. Because the emission improvement and cost change by the same fraction, we would not expect a change in the cost effectiveness or ranking of these items. While the 0.15 gpt is also due to small reductions in losses from all but the last item in the table above, we believe that, in the end, the cost effectiveness of the proposed standards will not be significantly different for vehicles with return or returnless systems.

d. Assembly Costs

Another variable cost manufacturers may incur are increases in vehicle assembly costs. EPA has not estimated increased assembly costs for Tier 2 vehicles because the vast majority of changes to the vehicles are likely to be improvements to existing emissions control systems. Therefore, we believe that assembly cost increases are likely to be negligible. Assembly costs for components would be incurred by the component supplier and included in the component price estimates shown above.

e. Development and Capital Costs

In addition to the hardware costs described in the previous section, vehicle manufacturers would also incur developmental and capital costs due to the Tier 2 standards. These fixed costs

include costs for reasearch and development (R&D), tooling, and certification, which manufacturers incur prior to the production of the vehicles.

The Tier 2 standards would be phased-in over four model years beginning in 2004 for LDVs, LDT1s, and LDT2s and a two year period beginning in 2008 for LDT3s and LDT4s. This approach would provide lead-time for R&D for the various vehicle lines to proceed systematically. EPA estimates R&D costs of about $5 million per vehicle line (100,000 vehicles). R&D primarily includes engineering staff time and development vehicles. A large part of the research effort will be evaluating and selecting the appropriate mix of emission control components and optimizing those components into a system capable of meeting the Tier 2 standards. It also includes engine modifications where necessary and air/fuel ratio calibration. Manufacturers will take differing approaches in their research programs. We estimate that $5 million would cover about 25 engineering staff person years and about 20 development vehicles.[u] We have estimated this large R&D effort because calibration and system optimization is likely to be a critical part of the effort to meet Tier 2 standards. However, we believe that the R&D costs are likely overstated because the projection ignores the carryover of knowledge from the first vehicle lines designed to meet the standard to others phased-in later.

Tooling costs include facilities modifications necessary to produce and assemble components and vehicles meeting the new standards. EPA has included tooling costs due to the Tier 2 standards of approximately $2 million per vehicle line (100,000 vehicles). We believe that this is a reasonable estimate based on engineering judgement, after reviewing previous estimates of tooling costs for emissions control components.[4]

EPA recently conducted a detailed cost analysis of its vehicle certification program as part of the CAP 2000 rulemaking, which revised the certification program and is expected to significantly reduced manufacturer certification costs.[5] For CAP 2000, EPA estimated a total annual certification cost to the industry of between $40 and $65 million. Manufacturers incur a large portion of these costs annually as part of certification and compliance and would incur those costs without any change to the standards. However, EPA does allow manufacturers to carry-over some data generated for certification when vehicles are not significantly changed from one model year to the next. This test data is generated to demonstrate vehicle emissions levels and emissions durability. Due to the new standards, such data would have to be generated for the new Tier 2 vehicles, rather than carried over from previous model years. Therefore, we believe it is appropriate to include the cost of generating new emissions test and durability data as part of the cost analysis for Tier 2. Based on the CAP 2000 rule, EPA estimates the cost of this testing to be about $15 million industry-wide.

EPA estimated that the R&D costs would be incurred on average three years prior to production and the tooling and certification costs would be incurred one year prior to production. These fixed costs were then increased by seven percent for each year prior to the start of

[u] This estimate is based on staff cost of $60 per hour and development vehicle cost of $100,000 per vehicle.

production to reflect the time value of money. We estimated total R&D and tooling costs per vehicle class by multiplying the costs per vehicle line (100,000 vehicles) by sales estimates for each vehicle class divided by 100,000 vehicles. Finally, for the cost analysis, the fixed costs were recovered over the first five years of production at a rate of seven percent.

EPA estimates the average per vehicle fixed costs to be between $19 and $22, as shown in Table V-9. We derived the per vehicle fixed cost by dividing the total fixed cost per vehicle class over the five year recovery period by the estimated total sales per vehicle class over the same period. Differences in fixed costs among vehicle classes occur because we have projected a phase-in of Tier 2 LDVs and LDTs and changes in sales volumes over time for the vehicle classes. The aggregate fixed costs, vehicle phase-ins, and sales projections are described in section 3., below.

Table V-9. Per Vehicle Fixed Costs

	LDV ($)	*LDT1 ($)*	*LDT2 ($)*	*LDT3 ($)*	*LDT4 ($)*
R&D	16.10	14.23	14.08	14.34	15.48
Tooling	5.63	4.97	4.92	5.01	5.41
Certification	0.30	0.27	0.26	0.26	0.29
Total	22.03	19.47	19.26	19.61	21.18

f. Total Near-term and Long-term Manufacturer Costs

The previous section presented estimates of per vehicle variable and fixed costs to the manufacturer for the first few model years of production. These near-term per vehicle costs are shown in Table V-10. The costs in Table V-10 include the costs for the evaporative system.

Table V-10. Total Per Vehicle Manufacturer Costs - Near Term

	LDV ($)	*LDT1 ($)*	*LDT2 ($)*	*LDT3 ($)*	*LDT4 ($)*
Variable	46.10	42.38	93.03	201.83	197.70
Fixed	22.03	19.47	19.26	19.61	21.18
Total	68.13	61.85	112.29	221.44	218.88

For the long-term, there are factors that EPA believes are likely to reduce the costs to manufacturers. As noted above, we project fixed costs to be recovered by manufacturers during

the first five years of production, after which they would expire. For variable costs, research in the costs of manufacturing has consistently shown that as manufacturers gain experience in production, they are able to apply innovations to simplify machining and assembly operations, use lower cost materials, and reduce the number or complexity of component parts. These effects are often described as the manufacturing learning curve.[6]

The learning curve is a well documented and accepted phenomenon dating back to the 1930s. The general concept is that unit costs decrease as cumulative production increases. Learning curves are often characterized in terms of a progress ratio, where each doubling in cumulative production leads to a reduction in unit cost to a percentage "p" of its former value (referred to as a "p cycle"). The organizational learning which brings about a reduction in total cost is caused by improvements in several areas. Areas involving direct labor and material are usually the source of the greatest savings. These include, but are not limited to, a reduction in the number or complexity of component parts, improved component production, improved assembly speed and processes, reduced error rates, and improved manufacturing process. These all result in higher overall production, less scrappage of materials and products, and better overall quality.

Companies and industry sectors learn differently. In a 1984 publication, Dutton and Thomas reviewed the progress ratios for 108 manufactured items from 22 separate field studies representing a variety of products and services.[7] As shown in Figure V-1, of the 108 progress ratios observed, eight were less than 70 percent, 39 were in the range of 71 to 80 percent, 54 were in the range of 81 to 90 percent, and seven were above 90 percent. The average progress ratio for the whole data set falls between 81 and 82 percent. The lowest progress ratio of 55 percent shows the biggest improvement, representing a remarkable 45 percent reduction in costs with every doubling of production volume. At the other extreme, except for one company that saw *increasing* costs as production continued, every study showed cost savings of at least five percent for every doubling of production volume. This data supports the commonly used p value of 80 percent, i.e., each doubling of cumulative production reduces the former cost level by 20 percent. As each successive p cycle takes longer to complete, production proficiency generally reaches a relatively stable plateau, beyond which increased production does not necessarily lead to markedly decreased costs.

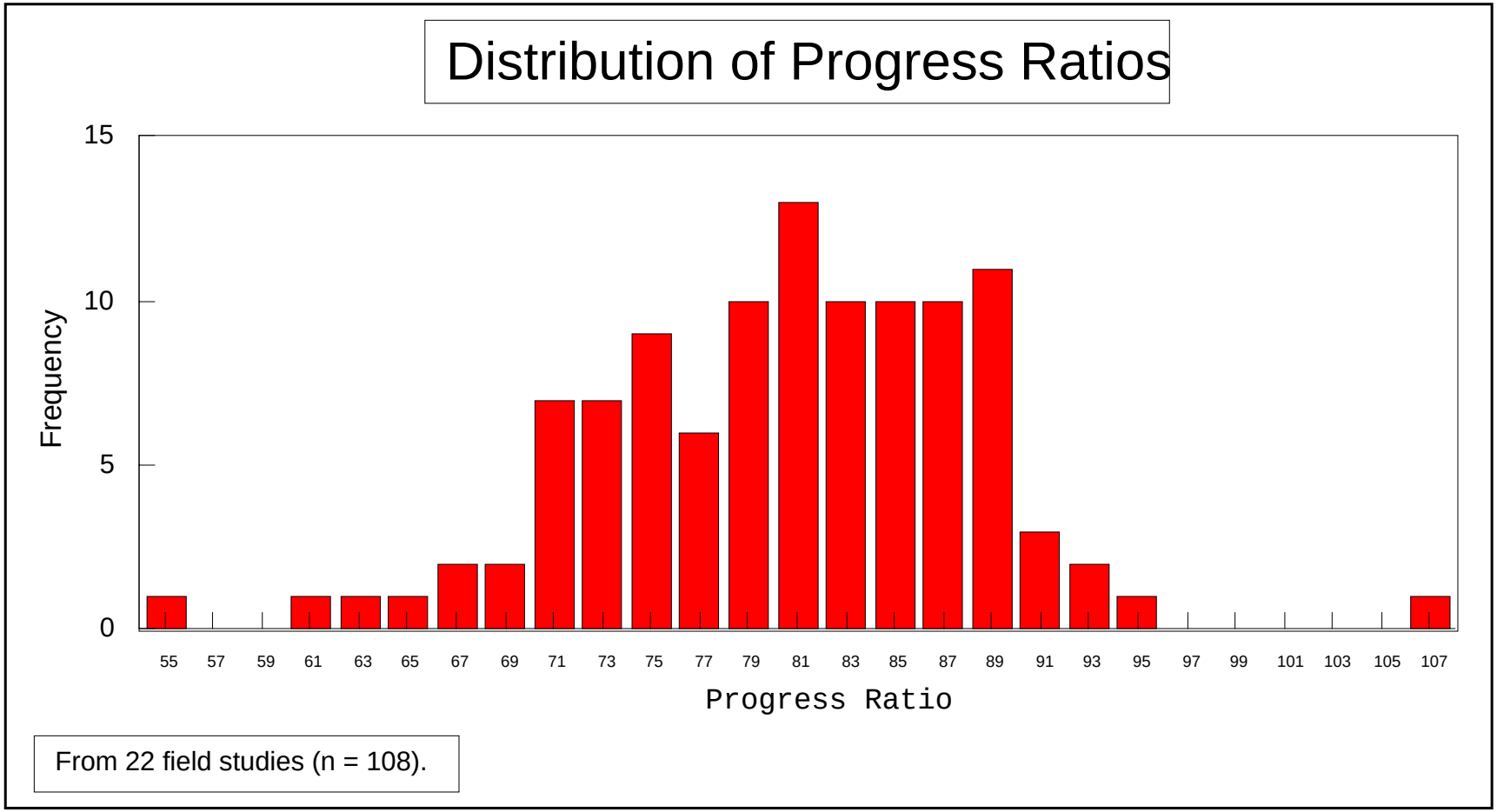

Figure V-1. Distribution of Progress Ratios

EPA applied a p value of 20 percent beginning in the third year of production in this analysis. That is, the variable costs were reduced by 20 percent for each doubling of cumulative production. To avoid overly optimistic projections, we included several additional constraints. Using one year as the base unit of production, the first doubling would occur at the start of the third model year of production. To be conservative, we did not incorporate further cost reductions due to the learning curve. We applied the learning curve reduction only once because we anticipate that for the most part the Tier 2 standards would be met through improvements to existing technologies rather than through the use of new technologies. With existing technologies, there would be less opportunity for lowering production costs.

In addition, we did not apply the learning curve to the catalyst precious metal costs due to the uncertainty of future precious metal prices. Although manufacturers may be able to reduce the use of precious metals due to the learning curve, the future price of precious metals is highly uncertain. Any savings due to a reduction in the amount of precious metals used for a catalyst system could be overcome by increased precious metal unit costs. Finally, we did not apply the learning curve to the evaporative system costs. Evaporative systems have been well developed and the anticipated system improvements are available today and are likely to be employed by manufacturers prior to 2004 on a large number of vehicles.

Table V-11 presents EPA's estimates of long-term per vehicle manufacturer costs. As noted above, we have projected cost reductions due to the learning curve to occur in the third year of production and the fixed costs to expire for the sixth year of production. Due to the phase-in of standards, these cost reductions are not tied to particular model years. As shown in Table V-11, we project manufacturer costs to decrease by 21 to 40 percent for the long-term. The percentage decrease in costs varies largely due to the variation in projected costs for precious metals, which are not subject to the learning curve cost reduction factor. We have projected a larger increase in the use of precious metals for LDT3s and LDT4s than for LDVs.

Table V-11. Long-term Total Incremental Per Vehicle Manufacturer Costs

Production Year	*LDV ($)*	*LDT1 ($)*	*LDT2 ($)*	*LDT3 ($)*	*LDT4 ($)*
1st and 2nd year	68.13	61.85	112.29	221.44	218.88
3rd year: learning curve applied	61.95	56.82	101.17	192.97	190.36
6th year: fixed costs expire	39.92	37.36	81.91	173.36	169.18

2. Tier 2 Vehicle Consumer Costs

Costs to consumers consists of increases in vehicle purchase price and increases in vehicle operating costs. EPA has not estimated an increase in vehicle operating costs due to the Tier 2 standards. Manufacturers will most likely meet the standards through improvements to

existing technologies. We do not anticipate that the improvements to technologies will affect fuel economy or in-use maintenance. The costs of fuel quality improvements are provided in section B, below.

For the up-front cost or purchase price increase, EPA anticipates that manufacturers would pass along their incremental costs for Tier 2 vehicles, including a markup for overhead and profit, to vehicle purchasers. Thus, we expect consumers would experience purchase price increases based on the manufacturer costs discussed in section A.1. To account for manufacturer overhead and profit, manufacturer incremental variable costs are multiplied be a Retail Price Equivalent (RPE) factor. The RPE factor we used in this analysis, 1.26, is the same one EPA has used in previous analyses for LDVs and LDTs. This methodology and the RPE mark-up factor are based on contractor studies regarding hardware costs and RPEs.[8,9] Table V-12 presents the increases in vehicle costs to consumers EPA has estimated for Tier 2 vehicles. The costs shown in Table V-12 include the costs of the evaporative system improvements, as well as the improved exhaust emissions control system.[v] We expect decreases in manufacturing costs over time, described in section 1.f., above, to be passed along to consumers in the form of purchase price decreases.

Table V-12. Incremental Per Vehicle Costs to Consumers for Tier 2 Vehicles

Production Year	*LDV ($)*	*LDT1 ($)*	*LDT2 ($)*	*LDT3 ($)*	*LDT4 ($)*
1st and 2nd year	80.12	72.88	136.48	273.92	270.28
3rd year: learning curve applied	72.34	66.55	122.47	238.05	234.35
6th year: fixed costs expired	50.31	47.08	103.21	218.44	213.17

3. Annual Total Nationwide Costs for Tier 2 Vehicles

a. Overview of Nationwide Vehicle Costs

The above analyses developed incremental per vehicle manufacturer and consumer cost estimates for each class of Tier 2 LDVs and LDTs. With data for the current size and characteristics of the vehicle fleet and projections for the future, we have translated these per vehicle costs into estimated total annual costs to the nation for the Tier 2 standards. Table V-13 presents the results of this analysis. As shown in Table V-13, EPA projected total cost starting at $256 million in 2004 and peaking at $1,587 million in 2009 when the phase-in of the standards is complete. Per-vehicle costs savings over time reduce projected costs to a value of $1,346 million in 2014, after which the growth in vehicle population leads to increasing costs that reach

[v] EPA estimated costs to the manufacturer for evaporative system improvements to be $3.25. The RPE for the evaporative system would therefore be $4.10.

$1,386 million in 2020. The calculated total costs represent a combined estimate of fixed costs, as they are allocated over fleet sales during the first five years of sale, and variable costs assessed at the point of sale. The aggregate costs include exhaust and improved evaporative control systems. These estimates do not include costs due to improved fuel quality, which are presented in section 2., below. The remainder of this section discusses the methodology we used to derive the total annual cost estimates and provides total annual vehicle costs for calender years 2004 through 2020.

Table V-13. Estimated Annual Nationwide Costs (thousands of dollars)

Category	*2004*	*2009*	*2014*	*2020*
LDV	246,026	342,543	285,556	294,231
LDT1	0	96,101	70,113	72,243
LDT2	0	592,396	512,604	528,175
LDT3	10,507	373,188	329,438	339,445
LDT4	0	182,341	147,904	152,397
Total	256,533	1,586,569	1,345,614	1,386,491

b. Methodology

To prepare these estimates, we projected sales for each vehicle class, the change in sales over time, and the phase-in of Tier 2 vehicles for each class over the phase-in schedule. We estimated current vehicle sales based on sales data submitted by vehicle manufacturers as part of certification. These sales estimates correlated reasonably well with other available sales information. We reduced the national sales numbers by 10 percent for LDVs and nine percent for LDTs to account for sales in California.[10] California sales were excluded from this analysis because California emissions standards apply to those vehicles.

To account for the current trend in sales of fewer LDVs and more LDTs, we reduced the LDV fraction of total sales and increased the LDT fraction of total sales by 1.6 percent per year from 1998 through 2008. After 2008, sales were stabilized at a mix of 40 percent LDVs and 60 percent LDTs. We also applied this shift in sales in its analysis of emissions reductions. These projections are based on the current trend toward increased sales of LDTs. We are aware of an industry study that projects the sales split leveling off much sooner at half LDVs and half LDTs.[11] Using a higher percentage of LDT sales results in higher overall cost projections because the per vehicle costs are higher for LDTs. In this way, EPA's cost analysis is more conservative than if we assumed sales leveled off at one-half LDVs and one-half LDTs. Finally, we have modeled overall vehicle sales to grow at 0.5 percent per annum on average over the

period of the analysis.[12] Table V-14 provides EPA's estimates for vehicle sales for 1998 and projections for select future years.

Table V-14. Estimated Annual 49-State Vehicle Sales (thousands of vehicles)

Category	*1998*	*2004*	*2008*	*2012*	*2020*
LDV	7,352	6,266	5,502	5,620	5,849
LDT1	1,012	1,268	1,447	1,475	1,535
LDT2	3,374	4,228	4,824	4,917	5,117
LDT3	1,025	1,284	1,465	1,493	1,554
LDT4	471	591	674	687	715
Total	13,234	13,636	13,911	14,192	14,769

In addition to vehicle sales, EPA also projected a phase-in of Tier 2 vehicles (including improved evaporative controls systems) for each vehicle class. Projecting the phase-in of Tier 2 vehicles is necessary to estimate aggregate costs of the standards during the phase-in period. Rather than assume a phase-in of 25/50/75/100 percent for each vehicle class, LDV, LDT1, and LDT2, we projected a phase-in based on cost and difficulty considerations. We projected that manufacturers would begin the phase-in with LDVs and end with LDT2s. We believe manufacturers will be able to meet Tier 2 standards more easily and at a lower cost for lighter vehicles compared to heavier vehicles.

We have projected some sales of Tier 2 LDT3s and LDT4s prior to 2008, for reasons described in section V.A.1.a. above. These early sales would off-set vehicles in higher bins in the averaging program for the interim standards. To make these projections, we assessed the current certification levels of LDT3s and LDT4s to determine how averaging could be used by manufacturers to avoid redesigning vehicles to meet interim standards. We found that, currently, about 25 percent of vehicles overall would fall into the highest bin (0.60 g/mile NOx), 30 percent in the next highest bin (0.3 g/mile NOx) and the remaining 45 percent would meet the interim standard (0.2 g/mile NOx). We conducted this analysis for each manufacturer and determined how many vehicles meeting the Tier 2 standards would be needed to off-set vehicles in the higher bins. In this analysis, the vehicles in the highest bin were phased-in last. This analysis may overestimate the number of Tier 2 vehicles necessary because it does not account for the manufacturers' ability to make minor adjustments to vehicles close to the interim standard (i.e., those in the 0.3 g/mile NOx bin) which may allow those vehicles to meet the interim standard.

Essentially, these analyses have resulted in projections of Tier 2 vehicle phase-ins which start with the lighter vehicles within each of the two categories and progress through the heavier vehicles until all vehicles meet the Tier 2 standards in 2009. Table V-15 presents EPA's

projected phase-in of Tier 2 vehicles we modeled for the aggregate cost analysis over the phase-in period of 2004 through 2008. Manufacturers would select the appropriate phase-in for their vehicle fleets. These modeling projections simply allow EPA to perform the aggregate cost analysis, reasonably accounting for the standards phase-in and the manufacturer's ability to average within the various programs.

Table V-15. Projected Overall Industry Phase-in of Tier 2 Vehicles and Improved Evaporative Emissions Controls For Purposes of the Aggregate Cost Analysis

Model Year	*LDV (%)*	*LDT1 (%)*	*LDT2 (%)*	*LDT3* (%)*	*LDT4* (%)*
2004	50	0	0	2	0
2005	100	0	0	7	0
2006	100	100	30	22	0
2007	100	100	100	55	0
2008	100	100	100	100	35
2009	100	100	100	100	100

*Improved evaporative systems have been projected to phase-in 50 percent in 2008 and 100 percent in 2009 for LDT3s and LDT4s, starting with LDT3s in 2008.

This is the phase-in schedule for Tier 2 vehicles EPA used in this analysis based on the assumption that manufacturers would perceive a fleet-wide integrated strategy as the most efficient and least-cost approach. Others are possible, but overall costs during the phase-in years would not be significantly different.

c. Estimates of Total Nationwide Vehicle Costs by Vehicle Class

EPA used the above sales and phase-in projections along with per vehicle variable and fixed costs to estimate total annual vehicle costs by vehicle class. We have summed the fixed costs for the vehicle categories and have amortized them over the first five years of production at a seven percent discount rate. We multiplied sales by per vehicle variable costs (with the RPE mark-up applied) to calculate total annual variable costs. As discussed above, variable costs are reduced after the second year of production due to the learning curve factor. Tables V-16 through V-20 present total annual nationwide costs by vehicle class for years 2004 through 2020. Table V-21 presents these cost figures summed for all LDVs and LDTs.

Table V-16. Annual Nationwide Costs For Tier 2 LDVs

Calendar Year	*Fixed Cost ($)*	*Variable Cost ($)*	*Total Cost ($)*
2004	64,020,172	182,006,058	246,026,230
2005	128,040,345	353,094,621	481,134,966
2006	128,040,345	319,146,974	447,187,318
2007	128,040,345	286,574,509	414,614,854
2008	128,040,345	276,809,911	404,850,256
2009	64,020,172	278,523,090	342,543,263
2010	0	279,915,706	279,915,706
2011	0	281,315,284	281,315,284
2012	0	282,721,861	282,721,861
2013	0	284,135,470	284,135,470
2014	0	285,556,147	285,556,147
2015	0	286,983,928	286,983,928
2016	0	288,418,848	288,418,848
2017	0	289,860,942	289,860,942
2018	0	291,310,247	291,310,247
2019	0	292,766,798	292,766,798
2020	0	294,230,632	294,230,632

Table V-17. Annual Nationwide Costs For Tier 2 LDT1s

Calendar Year	*Fixed Cost ($)*	*Variable Cost ($)*	*Total Cost ($)*
2004	0	0	0
2005	0	0	0
2006	27,715,184	72,431,363	100,146,547
2007	27,715,184	74,828,038	102,543,222
2008	27,715,184	68,098,756	95,813,941
2009	27,715,184	68,386,267	96,101,452
2010	27,715,184	68,728,199	96,443,383
2011	0	69,071,840	69,071,840
2012	0	69,417,199	69,417,199
2013	0	69,764,285	69,764,285
2014	0	70,113,106	70,113,106
2015	0	70,463,672	70,463,672
2016	0	70,815,990	70,815,990
2017	0	71,170,070	71,170,070
2018	0	71,525,920	71,525,920
2019	0	71,883,550	71,883,550
2020	0	72,242,968	72,242,968

Table V-18. Annual Nationwide Costs For Tier 2 LDT2s

Calendar Year	*Fixed Cost ($)*	*Variable Cost ($)*	*Total Cost ($)*
2004	0	0	0
2005	0	0	0
2006	27,725,154	159,053,529	186,778,683
2007	92,417,180	547,721,457	640,138,637
2008	92,417,180	545,161,597	637,578,777
2009	92,417,180	499,978,476	592,395,655
2010	92,417,180	502,478,368	594,895,548
2011	64,692,026	504,990,760	569,682,786
2012	0	507,515,714	507,515,714
2013	0	510,053,292	510,053,292
2014	0	512,603,559	512,603,559
2015	0	515,166,576	515,166,576
2016	0	517,742,409	517,742,409
2017	0	520,331,121	520,331,121
2018	0	522,932,777	522,932,777
2019	0	525,547,441	525,547,441
2020	0	528,175,178	528,175,178

Table V-19. Annual Nationwide Costs For Tier 2 LDT3s

Calendar Year	*Fixed Cost ($)*	*Variable Cost ($)*	*Total Cost ($)*
2004	869,782	9,636,772	10,506,553
2005	2,029,491	23,267,227	25,296,718
2006	6,378,400	74,126,448	80,504,848
2007	15,946,000	191,702,483	207,648,483
2008	28,992,728	359,149,330	388,142,058
2009	28,122,946	345,064,896	373,187,842
2010	26,963,237	322,930,549	349,893,785
2011	22,614,328	324,545,202	347,159,529
2012	13,046,727	326,167,928	339,214,655
2013	0	327,798,767	327,798,767
2014	0	329,437,761	329,437,761
2015	0	331,084,950	331,084,950
2016	0	332,740,375	332,740,375
2017	0	334,404,076	334,404,076
2018	0	336,076,097	336,076,097
2019	0	337,756,477	337,756,477
2020	0	339,445,260	339,445,260

Table V-20. Annual Nationwide Costs For Tier 2 LDT4s

Calendar Year	*Fixed Cost ($)*	*Variable Cost ($)*	*Total Cost ($)*
2004	0	0	0
2005	0	0	0
2006	0	0	0
2007	0	0	0
2008	4,819,090	57,785,178	62,604,267
2009	13,768,828	168,572,016	182,340,843
2010	13,768,828	160,863,474	174,632,302
2011	13,768,828	145,707,212	159,476,040
2012	13,768,828	146,435,748	160,204,576
2013	8,949,738	147,167,927	156,117,665
2014	0	147,903,766	147,903,766
2015	0	148,643,285	148,643,285
2016	0	149,386,502	149,386,502
2017	0	150,133,434	150,133,434
2018	0	150,884,101	150,884,101
2019	0	151,638,522	151,638,522
2020	0	152,396,714	152,396,714

Table V-21. Annual Nationwide Costs For Tier 2 LDVs and LDTs

Calendar Year	*Fixed Cost ($)*	*Variable Cost ($)*	*Total Cost ($)*
2004	64,889,954	191,642,830	256,532,784
2005	130,069,836	376,361,848	506,431,684
2006	189,859,083	624,758,314	814,617,397
2007	264,118,709	1,100,826,487	1,364,945,196
2008	281,984,526	1,307,004,772	1,588,989,298
2009	226,044,310	1,360,524,745	1,586,569,055
2010	160,864,429	1,334,916,295	1,495,780,724
2011	101,075,181	1,325,630,297	1,426,705,478
2012	26,815,555	1,332,258,449	1,359,074,004
2013	8,949,738	1,338,919,741	1,347,869,479
2014	0	1,345,614,340	1,345,614,340
2015	0	1,352,342,411	1,352,342,411
2016	0	1,359,104,123	1,359,104,123
2017	0	1,365,899,644	1,365,899,644
2018	0	1,372,729,142	1,372,729,142
2019	0	1,379,592,788	1,379,592,788
2020	0	1,386,490,752	1,386,490,752

B. Gasoline Desulfurization Costs

In this section, we will first lay out the methodology for our analysis of gasoline desulfurization costs. Then we will present the estimated cost of desulfurizing gasoline. Finally, we will discuss other relevant issues concerning the desulfurization of gasoline.

1. Methodology

The approach to estimating gasoline desulfurization costs is different from how we estimated costs in the Gasoline Sulfur Staff Paper. The costs presented in that report were developed using a refinery model run by the Oak Ridge National Laboratory (ORNL). Due to some improvement work which was being done with that refinery model, we were not able to develop costs for this analysis using that model. For this reason, we developed our own gasoline desulfurization model. For the Final Rule, we expect that the ORNL refinery model will be used to develop gasoline desulfurization costs and we will consider those costs as well as other costs from any other refinery modeling studies which may be performed by other studies.

The analysis was performed on a regional basis. The regions used are Petroleum Administrative Districts for Defense (PADDs). The analysis was conducted this way to take advantage of the PADD-level refinery information which is available for each PADD. This will help improve the understanding of how the cost for desulfurization will differ between these regions. Figure IV-2 above depicts the various PADDs of the country. As shown in the Figure, PADD 1 comprises the Northeast states, PADD 2 comprises the Midwest states, PADD 3 comprises the Gulf Coast states, PADD 4 comprises the Rocky Mountain states, and PADD 5 comprises the West Coast states. One issue to note is that PADD 5 normally includes California. However, since California already requires low sulfur gasoline as part of its California Phase II Reformulated Gasoline program, it would be inappropriate to include California in any part of this analysis. Thus, this analysis estimates the cost of desulfurizing gasoline in PADD 5 outside of California, which will be indicated as PADD 5OC from this point on.

The cost analysis for each PADD is performed for a single refinery which represents the average refinery characteristics for that PADD. Each PADD-average refinery is created by taking all the refining capacity and throughput in that PADD and averaging it over the number of refineries in that PADD.[w] The costs for the entire PADD can be calculated by simply multiplying the individual refinery cost by the number of refineries in that PADD. This analysis presumes that each refinery must install a desulfurization unit which slightly overestimates the capital cost, as some refineries already produce gasoline with less than or close to 30 ppm sulfur and they would meet the proposed sulfur standard without adding any gasoline desulfurization units.

[w] This methodology of modeling an average refinery, or a representation of the PADD-average, is the only practical method (since modeling every refinery would require proprietary information and substantial complexity) and the industry-accepted method for estimating fuel costs. This method, however, comes with the trade-off of only approximating the cost which would be developed if we were able to average and aggregate the results of modeling each and every refinery.

Throughout most of this analysis, we presumed that the average refinery modeled will make their capital investments to meet a 30 ppm sulfur standard starting January 1, 2004. This investment scenario was assumed to simplify the analysis, however, it does not capture possible investment scenarios which could arise in response to refiners taking advantage of the proposed Averaging, Trading and Banking (ABT) program. Participating in the ABT program, refiners would choose a timeframe which best fits their company's financial situation, credit generation and banking capacity, and credit purchasing options, within the constraints of the per-gallon and corporate average sulfur standards. The net effect is that capital investments would likely be incurred over a six year period instead of all at once in 2003, which, if considered throughout this analysis, would have a small, decreasing effect on the costs estimated in the analysis. At the end of the analysis, we project the distribution of the capital costs over the years of the ABT program.

Each PADD was calibrated so that the volumes and sulfur levels for the various streams which contributed to the sulfur in the whole pool balanced with the sulfur level in the gasoline pool. The streams which contribute any significant amount of sulfur in the gasoline pool include the FCC gasoline, straight run (nonrefined crude oil in the gasoline boiling range), alkylate, and coker gasoline, if any was blended directly into gasoline (it may have been sent to other units such as the reformer, the alkylate plant, and the isomerate unit, which all desulfurize their feeds prior to processing). While alkylate sulfur levels can typically be equal to or less than five ppm, refineries which make alkylate from coker naphtha can have high levels of sulfur in alkylate (higher than 50 ppm). When these higher sulfur alkylate streams are averaged with the lower sulfur streams, the level of the average alkylate sulfur level will probably be high enough that we felt that it should be accounted for. The actual sulfur balance is described in detail further below.

This analysis does not directly estimate gasoline desulfurization costs for a portion of the industry affected. California refiners currently produce some non-California, low sulfur non-reformulated gasoline which is shipped outside of the state, yet this analysis did not attempt to estimate the cost to those refiners of desulfurizing that gasoline. Similarly, nondomestic refiners import some gasoline to the U.S., and these costs are not estimated as well. However, after estimating the average gasoline desulfurization cost for domestic refiners outside of California, the aggregate desulfurization cost is calculated by multiplying the domestic cost outside of California by a factor which accounts for the total number of gallons of gasoline sold in the U.S. outside of California. Thus, this analysis uses the estimated cost increase of gasoline produced by non-California U.S. refiners to represent the cost desulfurizing all gallons of gasoline consumed in the U.S.

The first step in desulfurization was presumed to be complete use of at least some of the existing desulfurization capacity available in the refinery. There are FCC feed hydrotreaters already present in many refineries which apparently are not being operated at capacity. The API/NPRA survey of 1997, which summarizes the operating characteristics and gasoline qualities of most of the U.S. refining industry, summarized the capacity and utilization of that capacity for FCC feed hydrotreaters for each PADD. Using that data, it was presumed that these units could be run at 100 percent of stream day capacity minus five percent which would allow

for increased use which is expected to occur between now and when the gasoline sulfur program is proposed to begin. Thus, before calculating the size and costs associated with a FCC gasoline hydrotreater, the initial sulfur level in each PADD was adjusted to reflect the use of this capacity. The operating cost for running FCC feed hydrotreaters at capacity was based on data from operating costs data for a FCC hydrofiner. In some PADDs there was additional hydrocracker capacity as well. However, running these units at capacity was found to cost more per unit sulfur removed than putting in a Mobil Oil Octgain or a CDTECH unit. Thus, these units were presumed to not be operated at capacity. It should be noted that there are other hydrotreaters in refineries which perhaps could provide additional hydrotreating, either before additional hydrotreating capacity is installed, or to meet a low sulfur gasoline target. Feeds to the reformer, isomerate and alkylate units are almost always hydrotreated, and running these units at capacity could provide additional desulfurization with some operating cost, and perhaps some additional capital cost for debottlenecking. However, trying to estimate the cost and incremental desulfurization available from these units was not possible with the information we had available to us.

In most cases, cost estimation for desulfurization down to 30 ppm is made based on CDTECH and Mobil Oil's desulfurization technologies, which are improved FCC gasoline desulfurization technologies. For this analysis, we presume that half of the FCC gasoline hydrotreaters which would be installed are CDTECH units and the other half would be Mobil Oil Octgain units. Since past gasoline sulfur cost analyses were made based on Mobil Oil's Octgain 125 process (2nd generation Octgain), the cost of desulfurization of PADD 3 gasoline was also estimated with this process as well. This will allow us to compare the estimated desulfurization cost of newer desulfurization technologies with the technology previously relied upon in these other studies. Coker gasoline (that part of the coker stream in the gasoline boiling range which is blended directly into gasoline), if there was any, is assumed to be treated along with the FCC gasoline. Because maximum hydrotreating with the improved FCC gasoline desulfurization technologies did not reduce the gasoline sulfur levels in PADDs 4 and 5 down to 30 ppm, some straight run was presumed to be desulfurized as well. The process presumed to be used for that desulfurization is Merox. We obtained generic capital and operating cost data for adding a Merox unit.

The CDTECH costs for achieving the target sulfur level are based on the combined units of CDHydro and CDHDS. The minimum severity of these CDTECH units that would result in treating the entire FCC gasoline stream down to 30 ppm was presumed to be used, in lieu of more severely hydrotreating the heaviest fraction of the FCC gasoline stream. To allow us to estimate desulfurization at different severities, CDTECH provided us cost and unit operations data for a range in hydrotreating severities, from 50 percent to almost 98 percent, for their process.

Mobil Oil provided OCTGAIN 3 desulfurization cost data at one desulfurization severity. To estimate the desulfurization cost to reach 30 ppm, the fraction of FCC and coker gasoline to be desulfurized at that severity was determined. The Octgain unit was then sized to process that fraction. The sizing of the Octgain unit is consistent with how refiners are expected to use this technology, which is treat only the heavy FCC gasoline if this achieves the sulfur target. If not,

then the heavy and medium FCC gasoline would be hydrotreated. Finally, only if this did not achieve the desired sulfur target, the entire FCC gasoline stream would be treated. In all cases, only one unit is used, but the unit is sized to treat the appropriate portion of the FCC gasoline pool until the target sulfur level is met. To facilitate this selective desulfurization strategy, a splitter (distillation column) may be needed between the FCC main fractionation tower and the OCTGAIN unit (however, if the entire FCC pool is being treated then a splitter may not be needed). We presume that half the refineries already have a splitter and are using it while the other half will have to install this splitter. Thus each PADD-average refinery has half the capital and operating cost of a full sized splitter. In cases of meeting a less stringent gasoline sulfur target where less than all the heavy FCC naphtha is being treated, the splitter is sized according to the volume of the FCC heavy naphtha being treated (if 60 percent of the FCC heavy naphtha must be treated to reach a particular sulfur reduction target, then only 60 percent of the FCC naphtha is routed to the splitter).

As stated above, cost estimation is based on vendor supplied operating and capital costs for CDTECH, OCTGAIN, FCC feed hydrotreating, and Merox units; while the ORNL refinery model is referenced for splitter operating and capital costs. Shell Oil (now Equilon) engineers analyzed the cost of installing a CDTECH unit into a generic refinery and compared their costs to those of CDTECH. This comparison is summarized below.

The cost of sulfur reduction was estimated for sulfur reductions down to PADD-average levels of 150, 100, 80, 40 and 30 ppm. The national cost of desulfurization is calculated by volume weighting the individual PADD costs. The costs are estimated for meeting the averaging standard, which is the cost estimation methodology recommended to us by the oil industry. Some additional cost may be incurred for meeting the cap standard, however, estimating these costs is more uncertain, so only the issues associated with meeting the cap standard are discussed. Therefore, no explicit costs of a cost over and above an averaging standard are developed.

a. Cost Inputs

Vendors for various desulfurization technologies were contacted to obtain detailed information on the raw material and utility needs and desulfurization capabilities for their technologies. This information is summarized below in Table V-22:

Table V-22. Raw Material and Utility Needs and Desulfurization Capabilities for Several Desulfurization Technologies

	FCC Feed Hydrotreating	*CDTECH** *(96% desul)*	*Mobil Octgain 220†* *(95% desul)*	*Mobil Octgain 125* *(98% desul)*	*Merox* *(60% desul)*
Feed (Bbls/Day)	-	40,000	25,000	8000	10,000
Capital Cost ($MM) ISBL	-	22.5	25	14.5	3.5
Six Tenths Rule Exponent	-	0.65	0.65	0.65	0.6
H2 Consumption (SCF/Bbl)	290	82	125	420	-
Electricity (KwH/Bbl)	1.5	0.5	1.1	2.3	-
HP Steam (Lbs/Bbl)	14	-	40	-	-
Fuel Gas (MBtu/Bbl)	56	55	12	51	-
Catalyst Cost ($/Bbl)	0.04	0.19	0.25	0.43	-
Cooling Water (Gals/Bbl)			220	45	
Octane Loss (R+M)/2	-	1.2	0.8	1.6	-
Yield Loss (vol.% gasoline) (vol.% LPG) (vol.% diesel) (vol.% resid)	(6.5) (3.4) 2.2 3.1	-	0.7	14	-
Operating Cost ($/Bbl)					0.06

* CDTECH provided data for desulfurization from 50 percent to 98 percent; only the data for 96 percent gasoline desulfurization is summarized here.

† Data was presented separately for light cat naphtha, medium cat naphtha, and heavy cat naphtha; however, in this table the data was volume-averaged together into one column for treating all three together.

I. Capital Cost

Capital costs are the one-time costs incurred by purchasing and installing new hardware in refineries. A number of factors are accounted for when estimating capital costs. The cost is calculated by first starting with the capital costs summarized in Table V-22 above. However, those capital costs are for the throughputs indicated, and must be adjusted to reflect throughputs different from that listed. The throughput normally listed for a new facility is the day to day throughput used to calculate operating cost, which is normally expressed as barrels of feed per calendar day. This throughput must be adjusted to estimate the capital cost based on stream days.[x] A calendar day to stream day factor is used to account for the difference between the throughput in calendar days versus the throughput in stream days. The ORNL refinery model provides calendar day to stream day inflation factors and the factor for the FCC unit, which is seven percent, is used here (the calendar day throughput is multiplied by 1.07 to estimate a stream day throughput). The factor for the FCC unit is used because these improved technologies are designed to operate with and be shutdown for maintenance on the same schedule as the FCC unit.

Also, a 15 percent design safety factor was applied to the capital cost. This means that facilities are sized 15 percent larger than what planned throughput would otherwise require.[13] This design factor, also sometimes called a contingency factor, is normally applied to cost estimates to account for uncertainties in the design. An additional five percent is added to the safety design factor, for a total of 20 percent, to account for the newness of these technologies.[14]

Once the stream day throughput is estimated, and the design factor is applied, if the recalculated throughput is different from the throughputs listed in the above table, the capital cost is estimated at this other throughput using an exponential equation termed the "six-tenths rule."[15] The equation is as follows: $(Sb/Sa)^e x Ca = Cb$, where Sa is the size of unit quoted by the vendor, Sb is the size of the unit for which the cost is desired, e is the exponent, Ca is the cost of the unit quoted by the vendor, and Cb is the desired cost for the different sized unit. The exponential value "e" used in this equation is 0.9 for a splitter, 0.65 for OCTGAIN and CDTECH units, and 0.6 for a merox unit.

The capital costs are adjusted further to capture other cost factors which affect the ultimate cost of installing capital, and these factors vary by PADD. One of these factors adjusts

[x] The throughput in calendar days is simply the total throughput of a unit in a year divided by the number days in a year. The throughput in stream days is the total throughput of a unit in a year divided by the number of days which the unit is operating. The stream day daily throughput determines the necessary capacity of the unit since a unit must be able to handle that throughput on the days which the unit is operating.

the onsite costs upward to account for offsite costs.[y] According to Gary and Handwerk, the proportion of offsite cost to onsite cost varies depending on the crude oil throughput of the refinery. These varying factors are summarized in Table V-23.[16]

Table V-23. Offsite Factors for Different Sized Refineries

Refinery Size in Crude Oil Feed (BPSD)	*Offsite Costs, Percent of Inside Battery Limit Costs*
Less than 30,000	50
30,000 - 100,000	30
More than 100,000	20

Based on these offsite factors, because PADD 3 refineries average about 150,000 barrels per day, the representative refinery used in this analysis for that PADD was assigned an offsite factor of 1.2 (or a 20 percent increase). PADD 1, PADD 2, and PADD 5OC, refineries all average about 100,000 barrels of crude oil per day, so the representative refinery used in this analysis was assigned an offsite factor of 1.25. Finally, PADD 4 refineries average less than 30,000 barrels of crude oil per day, so the representative refinery for that PADD was assigned an offsite cost factor of 1.5. These factors are summarized in Table V-25 below.

Another factor which varies from PADD-to-PADD is the labor cost for installing the capital. Gary and Handwerk provide estimates for labor costs for a number of different cities, and these estimates are summarized in Table V-24, below.[17]

[y] When vendors normally report a capital cost, that cost includes what are called onsite costs for complete installation of the hardware, but excludes other costs integral for the functioning of the unit, and these other costs are called offsite costs. Onsite costs normally include the capital cost for the process unit, storage facilities, cooling water facilities, and steam facilities. Offsite costs normally include electric power distribution, any fuel gas facilities, water supply and treatment, plant air, fire protection, flare hookup, drain system, waste containment, plant communication, roads and walks, railroads, roads and walkways, fences and buildings. Thus offsite costs are other capital costs which will allow the facility to run as an integral unit within the refinery.

Table V-24. Labor Costs in Selected Cities

Location	*Relative Cost*
U.S. Gulf Coast	1.0
Los Angeles	1.4
Portland, Seattle	1.2
Chicago	1.3
St. Louis	1.4
Detroit	1.3
New York	1.7
Philadelphia	1.5
Alaska, North Slope	3.0
Alaska, Anchorage	2.0

Based on this information, each PADD was assigned a cost factor to account for the labor cost for installing capital. PADD 1 was assigned a value of 1.5 which corresponds with the factor for Philadelphia, where a number of PADD 1 refineries are located. PADD 2 was assigned a value of 1.3 which corresponded with Chicago and Detroit. PADD 3 was assigned a value of 1.0, which is accepted as the reference refinery-related labor cost for the country. PADD 4 was assigned a value of 1.4, which corresponds to the value of St. Louis, the closest city to PADD 4, and PADD 5 outside of California was assigned a value of 1.2, which corresponds with Portland and Seattle. These location factors are summarized below in Table V-25.

Table V-25. Capital Cost Factors Which Vary by PADD

	PADD 1	*PADD 2*	*PADD 3*	*PADD 4*	*PADD 5 Outside CA*
Offsite Factor	1.25	1.25	1.2	1.5	1.25
Location Factor	1.5	1.3	1.0	1.4	1.2

The capital costs which would be incurred by refiners in order to comply with the proposed sulfur standards must be amortized in order to combine this cost with recurring

operating costs to produce a total per gallon cost in future years. In past analyses, EPA used a cost amortization factor of 0.173, which was based on a 10 percent return on investment (ROI), a 34 percent income tax rate, a 13 year economic and project life, and a 13 year depreciation life.

Regarding the 10 percent ROI, in 1997 we received comments from the automobile industry that the ROI for capital employed in the refining industry was less than 10 percent. They recommended use of an eight percent ROI, which we accepted and used to develop sulfur control costs in EPA's Staff Paper on Gasoline Sulfur Issues. The 1993 National Petroleum Study presented the actual ROI for the refining industry during the 1980's and early 1990's. ROI averaged close to eight percent during that timeframe. Since 1992, the refining industry has experienced a much lower ROI, averaging roughly three percent. However, these levels are clearly depressed and we do not believe that these low levels should be projected into the future. Thus, eight percent appears to be a reasonable level of ROI for assessing the impact of these regulations on the refining industry. However, in assessing the impact of these regulations on society, OMB Circular A-94 suggests that EPA use a seven percent discount factor in determining the net present value of both costs and benefits. Thus, a seven percent ROI will be used in determining the cost of reducing gasoline sulfur content for use in the cost effectiveness and cost benefit analyses. In assessing the impact of these regulations on the refining industry, the eight percent ROI will be used. Since the ROI of individual refiners can vary, we will also evaluate the impact of some variation around the average of eight percent ROI and use a range of six to 10 percent.

The 1993 National Petroleum Study also used slightly different estimates for the economic and depreciation life of capital and for the income tax rate than those cited above. In particular, the 1993 National Petroleum Study used an economic life of 15 years, a depreciation life of 10 years and an income tax rate of 39 percent.[18] Since the NPC study received a substantial amount of peer review, we decided to use these financial factors from that study, coupled with the above-mentioned estimates of ROI. The one exception is the elimination of the income tax from the assessment of societal costs. Since income taxes are simply transfer payments between various sectors of society, they are not included in societal costs. These factors and the resulting capital amortization factors are summarized in Table V-26 below.

Table V-26. Economic Cost Factors Used and the Resulting Capital Amortization Factor

Amortization Scheme	*Depreciation Life*	*Economic and Project Life*	*Federal and State Tax Rate*	*Return on Investment (ROI)*	*Resulting Capital Amortization Factor*
Societal Cost	10 Years	15 Years	0 %	7%	0.11
Capital Payback	10 Years	15 Years	39 %	6% 8% 10%	0.12 0.14 0.16

ii. Fixed Operating Costs

Operating costs which are based on the cost of capital are called fixed operating costs. These are fixed because the cost is normally incurred even when the unit is temporarily shutdown. These costs are incurred each and every year after the unit is installed and operating.

Maintenance must be performed on all operating hardware to keep it in an operable condition, and when it is running, to keep the unit operating efficiently. Maintenance cost is estimated to be four percent of capital cost after adjusting to include the outside battery limit cost, and after adjusting the capital cost for the higher labor cost due to the location. This factor is based on the maintenance factor used in the ORNL refinery model.

Other operating costs are accounted for as well in terms of generic cost factors which were taken from the ORNL refinery model. These factors are three percent of capital costs for buildings, 0.2 percent for land, one percent for supplies which must be inventoried such as catalyst, and two percent for insurance. These factors sum to 6.2 percent which is applied to the total capital cost (which includes offsites, and the adjustment for location) to generate a perennial fixed operating cost.

Annual labor costs are estimated using the cost equation in the ORNL refinery model. Labor cost is very small; on the order of one ten thousandth of a cent per gallon.

iii. Variable Operating Cost

Variable operating costs are those costs incurred to run the unit on a day to day basis, and are based completely on the unit throughput. Thus, when the unit is not operating, variable operating costs are not being incurred. These costs are summarized in Table # V-27 below.

Table V-27. Summary of Costs Taken From EIA and NPC Data Tables *

	PADD 1	*PADD 2*	*PADD 3*	*PADD 4*	*PADD 5OC*
Electricity (c/KwH)	5.9	3.9	4.2	3.4	5.4
LPG (c/Gal)	19.7	18.4	16.5	17.8	19.7
Gasoline (c/Gal)	27.0	25.9	24.9	28.9	30
Diesel (c/Gal)	25.2	25.7	24.7	29.6	28.6
Residual Oil (c/Gal)	17.9	15.2	15.4	10.8	16.1
Octane Cost (cents)	4.3	2.8	3.5	11.4	9.0
Octane Spread (R+M)/2	5.7	5.2	5.4	5.2	4.6
Fuel Gas ($/MMbtu)	3.75	3.75	3	4.5	3.75
Hydrogen Cost ($/MSCF)	2.5	2.5	2.0	3.0	2.5

* c/KwH is cents per kilowatt-hour, c/Gal is cents per gallon, (R+M)/2 is octane number as determined by Research and Motor octanes divided by two, c/Gal is cents per gallon, $/MMbtu is dollars per million British Thermal Units (Btu), $/MSCF is dollars per thousand standard cubic feet.

Electricity is consumed in running pumps, air coolers, and other refinery equipment electrically powered. Electricity costs were taken from the EIA publication "Monthly Electric Utility Sales and Revenue Report with State Distributions." The 1997 industrial electricity costs for individual states which comprise a PADD are averaged together to form a single individual PADD-wide cost.

Fuel gas is consumed in running furnaces for heating up streams including the reboilers used in distillation. Fuel gas cost is based on an estimation factor which is three dollars per million British thermal units (BTU) for PADD 3,[19] one quarter higher than that for PADDs 1, 2 and 5OC, and half higher for PADD 4. Steam demand is converted to BTU demand on the basis

that it is 300 pound per square inch (psi) steam, and that demand is presumed to be met with fuel gas. Producing steam is presumed to demand 809 BTU per pound of steam required.

Cooling water is used for cooling streams, especially the vapor which comes off the top of a distillation column and must be condensed for recycling it back into the top of the distillation column. Cooling water is estimated to cost seven cents per 1000 gallons for PADD 3, seven and a half cents per gallon for PADDs 1, 2, and 5OC, and eight cents per gallon for PADD 4.[20]

Octane loss is caused by saturation of unsaturated compounds including olefins and aromatics which normally present in FCC gasoline. For each PADD, the cost of this loss is estimated by using the price differentials between premium and regular grades. The price differentials were based on the cost of gasoline grades sales to resale from the Petroleum Marketing Annual for 1997. Octane ((R+M)/2) spread, which is the octane difference between premium and regular grades, is from 1993 refining study by NPC.[21] According to DOE, octane spread has been increasing in recent years, so the cost for making up lost octane may be overestimated to some degree.

Yield loss is the loss of gasoline to lower boiling point petroleum compounds. It sometime occurs as gasoline is processed and tends to occur with hydrotreating. The conversion of gasoline to lower boiling point compounds incurs a cost because gasoline brings a higher profit than the other compounds. For this analysis, yield loss is presumed to occur by gasoline being converted to liquid petroleum gas (LPG).[22] Thus, yield loss is the resale price of gasoline minus the resale price of LPG. The costs of gasoline and LPG are from the Petroleum Supply Annual for 1997.

Finally, hydrogen costs also vary by PADD. The cost of hydrogen supply was estimated for PADD 3, and then increased for other PADDs that typically have higher costs. Hydrogen cost for PADD 3 is based on an average of refiners putting in their own hydrogen plants, which could cost as much as three dollars per thousand standard cubic foot (MSCF), and purchasing hydrogen as a commodity from a large hydrogen plant at a little more than one dollar per MSCF.[23] Based on this range of possible cost, PADD 3 would be expected to have access to hydrogen supplied at a cost of about two dollars per MSCF. PADD 4 is assumed to have to pay the more conservative cost of three dollars per MSCF, and the other PADDs are assumed to incur a cost between PADDs 3 and 4, which would be $2.5 per MSCF. This analysis does not consider numerous other possibilities of providing hydrogen at a reduced cost by using hydrogen recovery technology (which would recover hydrogen from plant gas), or by increasing hydrogen production from the reformer by converting high pressure reformers to low or ultra low pressure reformers.

b. Determination of Blendstock Sulfur Levels

A sulfur balance is performed for each PADD average refinery to establish the volumes and sulfur levels of blendstocks which contribute significantly to the pool sulfur level (FCC

naphtha, alkylate, straight run, and coker). The sulfur levels for these streams were volume-weighted and compared to the pool gasoline sulfur level. If the calculated pool sulfur level did not agree with the pool sulfur level, then the FCC gasoline sulfur level or volume was adjusted, under the presumption that the noncalculated value is more likely to be correct. This exact process is explained in detail below in the discussion on how the calibration was carried out for each PADD.

The volumes and sulfur levels of the various blendstocks are established based on information from different sources. FCC gasoline volumes and sulfur levels were taken from the 1996 API/NPRA survey, or the RFG baseline data base. The RFG data base was used when the API/NPRA data for a PADD was incomplete or internally inconsistent, as described further below. The RFG data base was not used first because of the difficulty in gathering the data, and because not all refiners reported their blendstock sulfur levels. Coker gasoline volumes and sulfur levels were taken from the 1996 API/NPRA survey. Straight run sulfur levels and volumes are from the 1989 NPRA survey.

Alkylate sulfur levels are set at 10 ppm. This value was arrived at through an analysis of alkylate sulfur levels from the baselines submitted for the RFG program, and a review of alkylate sulfur levels in various refining consultant refinery models. From the 1990 RFG baseline database, alkylate sulfur levels from nine refineries were averaged together. Then, the averaged value, which was determined to be 22 ppm, was compared to the alkylate sulfur levels used in several refinery models. The refinery models alkylate sulfur levels averaged about 10 ppm (the values ranged from 0 to 25 ppm). The difference between the average sulfur level seen in the RFG data base and the average alkylate sulfur levels from the various refinery models was reconciled by presuming that if the average alkylate sulfur level is indeed about 20 ppm, then refiners could decrease alkylate sulfur levels by increasing the severity or better managing existing desulfurization of the alkylate blendstock. Other blendstocks, such as isomerate, reformate, raffinate, dimate, poly gasoline, hydrocrackate, aromatics, butane and any oxygenates which may be blended into gasoline, are all assumed to make a negligible sulfur contribution to the gasoline sulfur pool.

The gasoline pool sulfur levels (not calculated from blendstocks) were taken from either the API/NPRA survey or the RFG data base and were compared to the values calculated from the sulfur-containing blendstocks. For simplicity reasons, the API/NPRA data base was consulted first, however, for reasons explained below, sometimes the RFG database was preferred.

PADD 1 - The 1996 API/NPRA survey only collected data from refiners which comprise half of the gasoline production in PADD 1 (nine reported gasoline quality, and only five reported FCC sulfur level); thus, it did not seem viable to use that survey data. Instead, the RFG baseline data was used exclusively (based on data from 11 refineries). The average gasoline pool sulfur values for each refinery were obtained from the 1995/1996 data reported by refiners to EPA. When all the refineries' average gasoline sulfur values were averaged together, the average ended up being 215 ppm. The FCC gasoline sulfur values for each refiner were used to estimate the average sulfur level of FCC gasoline for the PADD, which was estimated to be about 460 ppm (although,

this value seems low compared to the straight run sulfur level from the 1989 NPRA survey, which was reported to be 330 ppm). The FCC sulfur level of any refinery was adjusted if the 1995/1996 gasoline sulfur level was significantly different from the level reported in the 1990 baseline submission. Based on the RFG baseline submissions, the FCC volume was calculated to comprise 46 percent of the gasoline pool. The blendstock calculated pool sulfur level was higher than the calculated gasoline sulfur level, so the FCC volume was adjusted downward from 46 percent to 42 percent to result in a pool sulfur level of 215 ppm.

These figures may need to be adjusted to account for the implementation of Phase II RFG in 2000. Phase II RFG plays an important role for PADD 1 refiners since those refiners produce more than 60 percent of its gasoline as RFG. The average gasoline sulfur level was calculated for RFG in 1995 and 1996 found to be about 150 ppm. Since we expect RFG to be about 150 ppm, no changes in sulfur level are expected to occur to produce Phase II RFG. The PADD 1 blendstock sulfur levels and relative volumes are summarized in Table V-28.

Table V-28. PADD 1 Blendstock Sulfur Levels and Gasoline Pool Fraction

	FCC	*Alkylate*	*Straight Run*	*Coker*
Sulfur (ppm)	442	10	343	3289
Percentage of gasoline pool	42	10	4	0.44
Contribution to pool (ppm)	185	1	14	14

PADD 2 - The API/NPRA survey data for the gasoline pool sulfur level and the FCC sulfur and volume was used. According to the survey data, PADD 2 FCC gasoline has a sulfur level of 924 ppm and it comprises about 27 percent of the gasoline pool. However, based on that FCC sulfur level and volume and other blendstock sulfur levels and volumes, the gasoline pool would have a sulfur level of 260 ppm which is lower than the pool average of 338 ppm based on the API/NPRA survey. To account for this discrepancy, the FCC contribution to the gasoline pool was increased to 35 percent. Since PADD 2's RFG production is only 11 percent, Phase 2 RFG is presumed to have no affect on the average sulfur level of PADD 2. The PADD 2 blendstock sulfur levels and relative volumes are summarized in Table V-29.

Table V-29. PADD 2 Blendstock Sulfur Levels and Gasoline Pool Fraction

	FCC	*Alkylate*	*Straight Run*	*Coker*
Sulfur (ppm)	924	10	397	0
Percentage of gasoline pool	35	13	3.4	0
Contribution to pool (ppm)	323	1	14	0

PADD 3 - According to the 1996 API/NPRA survey FCC gasoline comprises 35 percent of the gasoline pool and the sulfur level of that blendstock is 722 ppm. When considering all the blendstocks together, they result in a pool sulfur level of 271 ppm. However, the 1996 API/NPRA survey has PADD 3 pool sulfur levels at 305 ppm. To make the blendstock agree with the pool sulfur level, the PADD 3 FCC gasoline volume was increased from 35 percent of the pool to 40 percent. The PADD 3 blendstock sulfur levels and relative volumes are summarized in Table V-30.

Table V-30. PADD 3 Blendstock Sulfur Levels and Gasoline Pool Fraction

	FCC	*Alkylate*	*Straight Run*	*Coker*
Sulfur (ppm)	722	10	139	3255
Percentage of gasoline pool	40	14	2.8	0.42
Contribution to pool (ppm)	288	1	4	14

PADD 4 - According to the 1996 API/NPRA survey, 31 percent of the gasoline pool comes from FCC gasoline blendstock, and the sulfur level of that blendstock is 1100 ppm. When considering the sulfur contribution from the other blendstocks, the pool average sulfur level is calculated to be about 350 ppm. However, according to the 1996 API/NPRA survey the pool sulfur level was about 260 ppm, and this pool sulfur level is corroborated by 1995/1996 gasoline sulfur data reported by refiners to EPA. The PADD 4 FCC gasoline sulfur level from refiner baseline submissions, after adjusting for changes in gasoline sulfur levels from when the baseline were submitted in 1995/1996 (based on simple ratioing), averaged 760 ppm. This FCC sulfur level was used and, combined with other blendstocks, resulted in a pool sulfur level of 263 ppm. The PADD 4 blendstock sulfur levels and relative volumes are summarized in Table V-31.

Table V-31. PADD 4 Blendstock Sulfur Levels and Gasoline Pool Fraction

	FCC	*Alkylate*	*Straight Run*	*Coker*
Sulfur (ppm)	762	10	122	0
Percentage of gasoline pool	31	12	21	0
Contribution to pool (ppm)	236	1	26	0

PADD 5 OC - Based on the 1996 API/NPRA survey data, the FCC gasoline sulfur level was 666 ppm (based on only four refineries), and the volume was 38 percent of the entire gasoline pool. However, when all the blendstock sulfur levels and volumes were combined together, the calculated gasoline pool sulfur level would only average 256 ppm which is much lower than the pool sulfur levels from the API/NPRA gasoline parameter data, which averaged 480 ppm. Based on the RFG data base, the pool sulfur level for PADD 5 was 510 ppm, and the FCC gasoline sulfur level for the 6 refineries was about 1200 ppm. The RFG baseline FCC sulfur level was much more consistent with the average gasoline sulfur level and thus was used for cost estimation. To match the blendstock sulfur levels with the RFG data base average pool sulfur level (510 ppm), the fraction of FCC gasoline to the rest of the gasoline pool was increased from 38 percent to 42 percent. The PADD 5 outside of California blendstock sulfur levels and relative volumes are summarized in Table V-32.

Table V-32. PADD 5 Outside of California Blendstock Sulfur Levels and Gasoline Pool Fraction

	FCC	*Alkylate*	*Straight Run*	*Coker*
Sulfur (ppm)	1197	10	41	0
Percentage of gasoline pool	42	10	5.9	0
Contribution to pool (ppm)	503	1	2	0

Gasoline Volume - To estimate the aggregate capital and operating cost of desulfurizing gasoline by PADD, and for volume weighting the separate PADDs to calculate the national average cost, the gasoline production volumes for each PADD and the production and consumption values for the Nation as a whole are used. These values are summarized below in Table V-33.

Table V-33. Projected Volume of Gasoline Produced by an Average Refinery in each PADD, by Each PADD of Refineries and for the U.S.* in 2004

	PADD 1	*PADD 2*	*PADD 3*	*PADD 4*	*PADD 5OC*	*U.S. OC*
Gasoline Produced by Avg. Refinery (MBbl/day)	77	66	76	19	27	-
Total Gasoline Produced (MMBbl/yr)	404	764	1430	107	166	2872
Gasoline Consumed (MMBbl/yr)						3192

* California gasoline not included.

2. The Cost of Desulfurizing Gasoline

a. The Cost of the Averaging Standard

The refinery blendstocks sulfur levels, the vendor desulfurization technology information, the various cost inputs, and various desulfurization assumptions were combined together in a spreadsheet to estimate the cost of desulfurizing gasoline from the base sulfur level, down to various gasoline sulfur levels. A parametric analysis was undertaken to understand how the cost varies in each PADD as the sulfur standard is made more stringent. Costs are estimated for average sulfur standards of 150 ppm, 100 ppm, 80 ppm, 40 ppm and 30 ppm. The costs for desulfurizing gasoline to each of these levels is summarized below in Table V-34.

Table V-34. Per-Gallon Cost of Desulfurizing Gasoline

	PADD 1	*PADD 2*	*PADD 3*	*PADD 4*	*PADD 5OC*	*U.S. Avg.*
Average Sulfur Level (ppm)	Societal Cost (7 percent ROI and no Income Taxes)					
150	0.8	0.7	0.7	1.2	1.6	0.8
100	1.3	0.9	0.9	1.7	1.9	1.1
80	1.5	1.0	1.0	2.0	2.0	1.2
40	2.1	1.2	1.3	2.8	2.3	1.5
30	2.3	1.4	1.4	3.2	2.8	1.7
ROI	Cost to Refiners of a 30 ppm Average Sulfur Standard					
6%	2.4	1.5	1.4	3.3	2.8	1.7
8%	2.5	1.5	1.5	3.5	2.9	1.8
10%	2.6	1.6	1.5	3.6	3.1	1.9

As seen in the above table, our analysis shows that the per-gallon cost of desulfurizing gasoline to 30 ppm varies from PADD to PADD. PADDs 2 and 3 would experience lower costs than the other PADDs. Because of the smaller size of the refineries which increases the cost of installing capital, and because of the higher expense of refining, PADD 4 is expected to be the most expensive, and would be about twice as much to desulfurize gasoline as PADDs 2 and 3. A national average cost is calculated by volume-weighting the various PADDs. The result is an average national societal cost of about 1.8 cents per gallon to desulfurize gasoline down to 30 ppm. The societal cost represents capital amortized based on a seven percent rate of return on investment (ROI), and no income taxes; and this cost was used to calculate cost-effectiveness. We also show that the cost would be 1.8 cents per gallon based on a typical capital recovery scenario for the refining industry, which is based on an eight percent ROI and taxes included. As a sensitivity, we also show the cents per-gallon cost for six percent and 10 percent ROI. Both the societal cost and typical refinery cost are intended to represent the average cost across an entire PADD. Individual refiners within a PADD are expected to experience costs which are either higher or lower than these costs. The societal costs are shown in graph form in Figures V-2 - V-7 at the end of this Section.

To help the reader better understand the cost of the program for a typical refinery, the per-refinery costs for 150 ppm and 30 ppm are summarized in Table V-35, below.

Table V-35. Estimated Average Per-Refinery Capital and Operating Cost of Desulfurizing Gasoline to 150 ppm and 30 ppm

	PADD 1	*PADD 2*	*PADD 3*	*PADD 4*	*PADD 5OC*	*U.S. Avg.*
150 ppm						
Capital Cost ($MM)	30	23	21	10	17	22
Operating Cost ($MM/yr)	8	6	7	3	12	7
30 ppm						
Capital Cost ($MM)	73	40	40	23	25	43
Operating Cost ($MM/yr)	25	13	15	9	21	15

Table V-34 shows that, on average, refiners would have to pay out $43 million in capital costs for each refinery to lower gasoline sulfur to 30 ppm. In addition, each refinery would incur about 15 million dollars per year in operating costs. While the smaller refiners in PADD 4 are expected to pay out less than other refiners, their costs are higher on a per-gallon basis. To meet a 150 ppm standard, the capital and operating costs are about half as much as having to meet a 30 ppm standard. Once again, since these figures are averages, larger refineries with high gasoline sulfur levels will experience higher costs, while smaller refineries with lower sulfur levels will experience lower costs.

The estimated yearly aggregate cost to the country, and to importers, of meeting 30 and 150 ppm sulfur standards is summarized in Table V-36, below.

Table V-36. Aggregate Cost of Desulfurizing Gasoline to 150 ppm and 30 ppm

	PADD 1	*PADD 2*	*PADD 3*	*PADD 4*	*PADD 5OC*	*U.S. Total*	*U.S. Total w Foreign Cost*
150 ppm							
Capital Cost ($MM)	380	640	810	140	260	2230	2450
Operating Cost ($MM/yr)	90	160	310	40	80	680	750
30 ppm							
Capital Cost ($MM)	930	1100	1850	340	390	4650	5100
Operating Cost ($MM/yr)	290	340	630	110	150	1520	1670
Year which Capital Dollars are Expended						*Amount ($MM)*	
2001						145	
2002						727	
2003						1018	
2004						1358	
2005						1455	

Table V-35 shows that the aggregate capital cost to the U.S. refining industry for meeting the proposed 30 ppm sulfur standard is expected to total about 4.7 billion dollars. With the implementation of an averaging, trading and banking program, these capital investments are expected to be spread out over several years. The bottom of Table V-35 summarizes our forecast of the capital dollars expended during each year which the refining industry is expected to make investments. This level of capital expenditure is less than previous capital expenditures made by

the refining industry for environmental programs. In 1996, the Energy Information Administration studied and reported on the capital investment made by the major energy producing companies in the U.S. during the early nineties.[24] During this time, these companies invested from one to two billion dollars per year in capital for environmental controls for their refining operations; this cost represented about one third of the total capital expenditures made by refiners for their refineries. Considering that these expenses were incurred by less than three quarters of the refining industry, we believe that a program requiring the entire industry to spend up to one and one half billion dollars of capital costs per year over several years is not unreasonable. The aggregate operating cost to the U.S. refining industry is expected to be about 1500 million dollars per year. When considering the cost to foreign refiners, the capital and operating costs of this program would increase to 5.1 billion dollars and 1670 million dollars per year, respectively.

b. Verification of the Desulfurization Cost Based on the Improved Technologies

Shell Oil engineers (who now work for Equilon) provided EPA their estimate of the cost of a 40,000 barrel per day CDTECH unit. The Shell cost estimate showed substantially higher costs in certain areas compared to the CDTECH estimates (based on a May 1998 CDTECH cost estimation booklet)[25]. Later (September and December 1998), CDTECH provided updates on their costs, and the most updated cost table was integrated into our cost analysis spreadsheet. We compared the new CDTECH costs to the Shell Oil costs and the previous CDTECH costs, and summarized the comparison here. The sulfur reduction case which we costed out is consistent with the past cost comparison between the early CDTECH costs and the Shell engineers' calculated costs, which is 90 percent FCC gasoline desulfurization. We presumed that the comparison was done for a Gulf Coast refinery, which would be in PADD 3, thus the cost inputs we developed for PADD 3 above were used here. The cost comparison is summarized in Table V-37 below.

Table V-37. Summary of the Cost of Desulfurization by the CDTECH Process Based on 90 percent Desulfurization Severity

	Previous CDTECH costs	*Shell*	*Adjusted Shell costs*[z]	*EPA (costs revised by CDTECH Dec. '98)*
Capital Onsite $/BBL	375	600	660	690
H2 Reqd. SCF/BBL	60	200	80	68
Octane Value CPG	0.6	1.0	1.0	0.7
Hydrogen Cost ($/MSCF)	3	3	3	2
$/BBL FCC Gasoline				
Maint(5%&4%Cap) ($/BBL)	0.10 (5%)	0.16 (5%)	0.16 (5%)	0.09 (4%)
Catalyst ($/BBL)	0.10	0.10	0.10	0.15
Utilities ($/BBL)	0.07	0.10	0.10	0.19
H2 ($/BBL)	0.18	0.60	0.24	0.13
Octane ($/BBL)	0.25	0.42	0.42	0.27
Net Misc Downgrades ($/BBL)	0	0.10	0.10	0
Total ($/BBL)	0.70	1.48	1.12	0.83
c/gal Gasoline Pool (FCC fract is 0.34)	0.57	1.20	0.91	0.67

As depicted in the above table, CDTECH's revised capital costs are substantially higher than the initial costs, and, after adjusting the Shell costs to include the cost for a hydrogen compressor, the revised CDTECH and the Shell capital costs are essentially the same. The

[z] Costs are adjusted to add a recycle compressor which, according to the Shell engineers, would reduce hydrogen loss by over fifty percent, add to the capital cost by approximately 10 percent (about two million dollars), and would, according to Shell, add a small cost to downgrades (not specified).

operating costs are closer now as well. Improved agreement in the operating costs occurs because CDTECH's revised costs are somewhat higher in operating cost, and the adjustment in Shell's hydrogen consumption to account for the addition of a hydrogen compressor dramatically reduced the hydrogen cost. There are still cost differences between the Shell costs and the costs we develop in our analysis. Most of the differences occur because of three cost factors.

The first cost factor which differs is the cost of hydrogen supply. Shell used three dollars per MSCF compared to two dollars per MSCF in our analysis. In a conversation with one of the Shell engineers, he stated that their hydrogen cost which they used was conservative. This suggests the possibility that their cost estimating procedure may be conservative to provide a safety factor for their cost analysis. Another cost factor which differs is the cost of maintenance. Shell used a five percent cost rate while we used a four percent rate. Similarly, Shell later informed us that the five percent maintenance cost factor could be conservative and that a four percent factor is also a reasonable factor to use. For the octane cost factor, Shell used a one cent per gallon factor while we used a 0.7 cents/gallon cost factor. We believe our estimate is reasonable because it is based on the actual cost of making octane in PADD 3. In our analysis, the cost of making octane is higher in other PADDs and considering those other costs would increase our cost somewhat making our cost closer to the cost used by Shell. Finally, Shell added a 0.1 dollar per barrel cost for downgrades, which provides for potential yield loss from the CDTECH unit. Shell said that they add the factor to account for all losses from the unit. We called CDTECH to ask them whether there are any losses from their desulfurization unit, they stated that there is none. We are presuming that there is none. If the Shell costs were calculated using these same cost factors which we used, their operating cost would decrease to 0.78 dollars per barrel for the FCC gasoline and 0.63 cents per gallon for the entire gasoline pool, which is essentially identical to our costs.

In summary, the revised CDTECH costs for their desulfurization unit brings their costs much closer to the Shell costs. Since the Shell analysis of the CDTECH may have some conservative cost factors involved, adjusting their analysis for these factors closes the remaining gap between the two analyses. Shell engineers' review of the cost of using CDTECH CDHydro and CDHDS corroborates the revised costs provided CDTECH, which corroborates that portion of our analysis.

We have no third party verification of Mobil Oil's cost factors for their third generation Octgain process. However, Mobil has monitored its own track record for estimating the performance of a full scale unit based on pilot plant data. They went through this process two times since they created two different generations of the Octgain process before this third generation was created. Based on this experience, Mobil Oil feels confident that their process will operate in a refinery as claimed.

c. Future Cost of Desulfurization

Like any refinery processing unit which was newly installed, the per-barrel cost will normally decrease over time. We discussed how this change in cost would occur with several

different refining industry consultants who cited the following reasons.

Two of the consultants stated that the per-gallon costs could be expected to decrease further through engineering improvements in the process. Normally, the vendor which licensed the technology will discover engineering changes to the unit that would reduce its operating cost, although the refinery engineering and operations staffs can also make such discoveries. Engineering changes would be expected to occur in the catalyst technology which would lower operating cost such as reduced hydrogen utilization, and reduced octane and yield loss.

Two of the consultants mentioned that a another type of cost reduction can occur incrementally over time due to debottlenecking of the process throughput. The debottlenecking of this unit would occur in step with the debottlenecking of other gasoline producing units, such as the FCC unit, to help increase gasoline production to meet increased gasoline demand. Such increases in throughput would result in decreased per-barrel fixed operating cost, such as operating labor and maintenance costs, and insurance and other similar costs.

One consultant stated that refinery operations personnel will learn to operate the process more efficiently. These improvements would most likely help to reduce operating cost, such as improved energy utilization, reduced electricity demand and decreased operating labor and maintenance costs. However, the other two consultants seemed to think that these sort of improvements are less likely, as refiners have learned to already squeeze the most efficiency from their refinery units.

Processing unit improvements can also reduce the capital cost of the improved technologies. Capital improvements can primarily be taken advantage of when the unit is first installed. However, units installed for 2004 will already be sunk investments if improvements to the design of these technologies are discovered later. Thus, capital improvements would probably not be taken advantage of until new investments are made in these desulfurization processes.

For this analysis, we presumed that there would be reductions in costs in the ways stated by at least two of the refinery consultants. First, there is a presumed reduction in operating cost due to an improvement in catalyst technology. Similar to the estimate of future motor vehicle costs, operating costs are presumed to decrease by 20 percent after two years. This improvement is expected to occur in the catalyst cost, hydrogen cost, and decreased octane and yield losses. This improvement in operating cost is presumed to only happen once, although the reduction applies to additional throughput created through debottlenecking.

A second reduction in cost occurs in fixed operating cost because the unit is debottlenecked to keep up with increased gasoline demand. Since there are no new refineries being built, the increase in gasoline demand is presumed to occur by the existing refiners which currently produce gasoline for the U.S. Gasoline consumption is presumed to increase at the same rate as VMT is presumed to increase, and this growth rate is 2.05 percent per year. Since capital is sized larger than necessary by a 15 percent margin, the first eight years of debottlenecking are presumed to occur with no new capital expenditures. Then, as capital must

be invested to increase throughput, the newly invested capital is presumed to cost one-third of the originally invested capital on a per-barrel basis. The ratio of one-third presumes that debottlenecking would cost about half of the inside battery limit capital cost. These debottlenecking capital costs are also amortized at a seven percent rate of return over a 15 year period. The variable operating costs for the increased barrels desulfurized are presumed to be the same on a per-barrel basis as the original throughput. However, the fixed operating costs of the original equipment are presumed to stay the same, thus the same fixed costs are spread over a larger volume of gasoline produced.

A third type of cost reduction occurs for future capital investments in desulfurization units. This new investment is assumed to be made after 15 years, which is the assumed economic life and project life of these units and the point at which they would have to be replaced. At that point, the capital cost is presumed to be 20 percent lower than the cost in 2004. Presuming that refiners would reinvest in capital after 15 years is probably conservative since most refineries today are still using originally installed equipment which was erected 20, 30 and sometimes even 50 years ago.

As expected, the implementation of these cost assumptions results in a decreasing cent-per-gallon cost over time. The estimated future national cost of desulfurizing gasoline are summarized below in Table V-38.

Table V-38. Projected Future Average Per-Gallon National Cost of Desulfurizing Gasoline to 30 ppm

Year	*Cost (cents per gallon)*
2004	1.68
2005	1.67
2006	1.54
2007	1.52
2008	1.51
2009	1.49
2010	1.47
2011	1.45
2012	1.44
2013	1.42
2015	1.40
2020	1.38
2025	1.30
2030	1.23

d. Comparison with Previous Cost Estimates

Over the last several years, EPA and other organizations have estimated the cost of sulfur control. In our recent technical report entitled "EPA Staff Paper on Gasoline Sulfur Issues," we provided a cost estimate for reducing sulfur in gasoline. That cost is summarized here in Table V-39 along with our current costs.

Table V-39. Cost of Desulfurizing Gasoline by Refiners in PADDs 1 & 3 Reported in the "EPA Staff Paper on Gasoline Sulfur Issues," and our Current Costs.

	Base to 150 ppm	*Base to 100 ppm*	*Base to 40 ppm*
Previous Cost (c/gal)*	1.1 - 1.8	1.9 - 3.0	5.1 - 8.0
Current Cost (c/gal)**	0.7	1.1	1.6

* Based on Octgain 125 (second generation) technology, and calculated with the ORNL refinery model with excessively high reformate sulfur levels, among other problems which tended to overestimate costs.

** Based on improved gasoline desulfurization technologies assuming a typical refinery capital cost recovery.

Most of the difference in cost between these two cost estimates can be explained by a couple factors. The most important factor is the type of desulfurization hardware which we presumed would be used by the refining industry. For our previous cost study, we worked with the Department of Energy to develop costs using refinery model run by the Oak Ridge National Laboratory (ORNL). That refinery model chose Mobil Oil's Octgain 125, which is the second generation of the Octgain process. Octgain 125 must be operated under very severe conditions (higher temperature and pressure) to realize the octane recovery which the process is designed to deliver. However, the more severe conditions also results in higher capital and operating costs than that incurred by these improved gasoline desulfurization technologies. To quantify the cost reduction of the improved technologies relative to what we were modeling with previously, we put the inputs of the older Octgain process into our spreadsheet and developed a cost curve at the different sulfur levels modeled. Since we only are trying to get a sense of the cost reduction for the older Octgain process relative to the improved technologies, we only developed the cost curve for Octgain 125 for PADD 3. A comparison of the cost of desulfurizing gasoline is summarized below in Table V-40.

Table V-40. A Comparison of the Per-Gallon Gasoline Desulfurization Cost of Improved Desulfurization Technologies to that of the Earlier Mobil Octgain Process for PADD 3

	150 ppm	*100 ppm*	*80 ppm*	*40 ppm*	*30 ppm*
Mobil Octgain 125	1.1	1.7	2.0	2.6	2.9
Improved Desulfurization Technologies	0.7	1.0	1.1	1.3	1.5

This comparison shows that the difference between our current costs and our previous costs for 150 and 100 ppm can mostly be explained by the difference in the technologies we used in our modeling. To reach a low gasoline sulfur standard of 40 or 30 ppm, the improved desulfurization technologies are nearly 50 percent less costly than the older technology. This difference explains a part of the cost difference between these two studies, but not all the cost difference. Probably the next most important factor is a problem which was discovered with the refinery model which we were modeling with at the time. That model assigned reformate a sulfur level of 35 ppm, which is normally 1 ppm or less. Achieving low sulfur levels with the previous Octgain process caused a significant loss in octane and yield. Increasing either the volume or octane of reformate would have been a likely source of the needed octane. However, the refinery model did not select either of these options, due to the fact that the reformate sulfur level was so high and could not be reduced. Thus, the refinery model had to find other more costly ways to make up the octane losses caused by desulfurization, which likely increased cost. The same refinery model was later run with reformate sulfur levels reset to low levels. This run showed that this problem with the reformate sulfur level may have increased the cost of desulfurization by as much as 1.5 cents per gallon. Thus, an unreasonably high reformate sulfur level explains another large portion of the difference between the two studies.

Another possible reason for this difference in cost between the two studies is that we are estimating costs using a simpler refinery model which focuses primarily on the sulfur content of gasoline, instead of a more sophisticated refinery model, which attempts to optimize production volumes and quality all at the same time. The advantage of the simpler model is that the source of all costs is clear and can be easily evaluated. The disadvantage is that some aspects of refinery operation, such as making up lost octane or gasoline yield, is handled in a fairly simple fashion (e.g., by adding the current market cost of increasing octane or of producing gasoline). The disadvantage of the more complex linear programming refinery models is that it is very difficult for anyone except the operator of the model to understand why the model is making certain decisions or the cause of many of the projected costs. The example of the over-estimated reformate sulfur level is a case in point, as this problem and its impact on costs was not at all obvious. On the other hand, the more complex models attempt to more realistically simulate the actions which would be required for refiners to make up lost octane or gasoline volume. This presumes that the model reflects all of the flexibilities and constraints facing refiners in accomplishing these goals. Again, this is difficult to determine given the complexity of both refining and these refinery models.

For example, some uncertainty exists concerning the cost of supplying hydrogen. Since refinery cost data is not available for estimating hydrogen cost, we are using cost factors which we believe are reasonable, but may slightly over or underestimate costs. A more complex refinery model would include one or more hydrogen producing processes. However, the fundamental operating and capital costs of these processes are usually not published and cannot therefore be evaluated.

Differences in capital recovery used to develop the two different sets of costs shown in Table V-39. provide a negligible impact on the cost difference.

An important point deserves to be made concerning the improvement which Mobil Oil has made with its Octgain technology over the last several years. As seen in Table V-39, the desulfurization cost to achieve a low sulfur gasoline with their later technology is about half as much as with their earlier technology. This improvement over a several year period of timeframe corroborates our assumptions above that desulfurization cost will decrease in future years.

3. Other Effects of This Program

a. Effect of the Cap Standard

In addition to the 30 ppm averaging standard, we are proposing a 80 ppm per-gallon standard. The per-gallon standard or cap on sulfur level provides an additional challenge to refiners by preventing them from producing moderate and high sulfur batches of gasoline. While the averaging standard would force refiners producing higher sulfur gasoline to produce lower sulfur gasoline on average, which would be comprised mostly of batches of low sulfur gasoline along with occasional batches at a moderate sulfur level, a sulfur cap would preclude refiners from producing a single batch of gasoline with moderate sulfur levels that would exceed the cap.

High sulfur batches of gasoline would likely be produced when the refinery is experiencing problems with the added desulfurization unit, or problems with other units within the refinery responsible for, or associated with, desulfurizing gasoline blendstocks. However, changes in other refinery operations or other factors can also result in varying amounts of sulfur in gasoline. These include changes in feedstock qualities, changes in products produced, changes in throughput, process fluctuations, and changes in hardware processing efficiency caused by breakdown in equipment or catalyst inactivation.

During conversations some time ago with the economics committee of API, we discussed how we could estimate the cost of a cap standard. The committee's response was that the cost of the cap standard could be estimated by estimating the average sulfur level which would result from the cap standard. Later on, API sent us a letter which stated that the relationship between a cap standard and the resulting average sulfur level could be estimated from the variation in current gasoline sulfur levels presuming that the cap would represent the 90th percentile of that variation. The cost of meeting the cap standard could be estimated by estimating the cost of reducing gasoline sulfur to meet the average sulfur level determined by this relationship. Based on this advice, we analyzed this relationship using gasoline batch sulfur levels provided to EPA for the Reformulated Gasoline Program. We also compared the proposed API methodology for estimating the relationship between the cap and averaging standards to current capped sulfur levels. We put the results of that study in the EPA Staff Paper on Gasoline Sulfur Issues.

The analysis showed that if a 80 ppm cap standard were established, the resulting averaging standard would be in the range of 30 ppm to nearly 50 ppm. Because the averaging standard is at the lower end of this range, this suggests that the cap standard would not control the average gasoline sulfur level. Instead, the 30 ppm average standard would be the primary

controlling standard, and if the cap standard did not exist, then while meeting the 30 ppm averaging standard, refiners would occasionally produce gasoline which exceeded the 80 ppm sulfur level (our analysis shows probably about five percent of the time). The addition of the 80 ppm cap would require refiners to modify their refinery operations further to not produce batches of gasoline with sulfur levels that would exceed the cap standard.

Since refiners are likely producing these high sulfur batches because they are not trying to control gasoline sulfur now, stopping the production of these batches may not be a difficult task. However, in our analysis of the relationship of the cap and averaging standards, the refiners which have lower sulfur levels now are probably at that level because they are using sweet crude oils, or don't have a FCC unit which elevates the sulfur level in gasoline. Sour crude refiners, in the day-to-day variances in their refining operations, may have a more difficult time preventing the occurrences of high sulfur gasoline batches. Their gasoline sulfur levels is expected to be very high if their desulfurization units were to fall into disrepair, or would vary more widely when any of the situations summarized above which cause variance in gasoline sulfur levels were to occur. To manage this situation in those refineries, the refinery managers would likely have to do a better job managing the entire refinery, not just the gasoline desulfurization unit, to deliver low sulfur gasoline. This improved operations management would likely involve changes in the computer systems which control the refinery operations. There would likely have to be better management of the maintenance performed refining processing units. Refiners would likely focus in improving the operations and maintenance of critical units which divert sulfur into gasoline, or remove sulfur. However, after this is done, the refinery would likely recoup at least some, or perhaps even all of the cost disbursed to make these improvements in refinery operations from other improvements in refining operations.

Another change which refiners could make in their refining operations is to invest in a gasoline sulfur analyzer. Such analyzers would enable them to meet the per-gallon cap at the lowest possible cost. Refiners normally have to send a gasoline sample out to a lab to determine the actual sulfur level. However, the lag time between when the sample was taken and when they receive the results provides refiners with some uncertainty on whether the gasoline it is producing is indeed meeting the cap standard. This uncertainty could cause refiners to produce gasoline with lower sulfur levels than necessary to ensure that the cap standard would be met. For this reason, refiners may choose to purchase a gasoline sulfur on-line analyzer. This analyzer would keep the refinery manager up to speed on the exact sulfur level in their gasoline. This information would empower refiners with confidence that they will consistently meet the cap standard. According to an analyzer manufacturer which makes such a device, the cost for a gasoline sulfur analyzer would be about 50,000 dollars, and to install it would cost another 5000 dollars. Compared to the capital and operating cost of desulfurizing gasoline, the cost for this addition would be trivial.

If the gasoline desulfurization unit were to break down, or if a number of other problems were to plague the refinery, the refinery would probably be producing gasoline which would exceed the cap standard. Thus the refinery manager would have to take action preventing the sale of off-specification gasoline. The most obvious near term solution would be to blend the gasoline blendstocks together which it can to produce on spec gasoline. If the FCC gasoline

hydrotreater went down, the rest of the gasoline blendstocks could probably be blended together to produce on-spec gasoline. However, a portion of the normal gasoline stream, which would be the FCC gasoline, would have to be dealt with until the hydrotreating unit could be brought back on line. There are several potential solutions to this problem. One would be to store the FCC gasoline blendstock until the unit was back on line. Then the stored blendstock could be either run through the desulfurization unit, or blended back with gasoline at a rate which would ensure that the gasoline would still meet the cap standard. If the refinery does not already have a spare tank in which it could store the high sulfur gasoline blendstock, then the refiner would have to build one. Another possibility would be to sell off the blendstock to another refiner, who had the excess desulfurization capacity to process it or blend it in with their gasoline. Since refiners design the desulfurization units using a safety design factor, this excess capacity can be used to process this excess feedstock.

b. Other Effects on the Refining Industry

If a gasoline sulfur program is finalized, oil companies are expected to take a number of steps to maximize their profitability in the period after the program is implemented. First, and foremost refiners will try to minimize their costs by investing in the most cost-effective refinery changes. Despite frugal choices, almost every refiner will face capital and increased operating costs, and the refiner will try to pay off those costs. The most obvious step to recover those costs would be to increase the price of gasoline. However, in a competitive market, the effect of an increase in refiners' cost on the price of gasoline depends on both the market supply and demand. If market demand is "inelastic" (not sensitive to changes in price), then one would expect the price of gasoline to rise by the full amount of the cost increase, and refiners would recover all their operating cost and incrementally recover their capital costs. Since gasoline demand is not perfectly inelastic, some reduction in demand would be expected due to the price increase in gasoline. This would lead to a corresponding small decrease in the price of gasoline, which would erode refiners' ability to recover their costs. In addition, changes in supply due to imports from abroad would change the supply curve which would also affect refiners' cost recovery; increased imports reduce domestic refinery cost recovery, while decreased imports increase cost recovery.

Overall, the U.S. refining industry is currently producing gasoline and other refined products at full capacity.[26] This situation, coupled with ever increasing demand for gasoline, would generally produce reasonable refining margins. However, increasing imports of gasoline over the past few years appears to be keeping prices lower, as refining margins have been relatively low on average over the past three to four years.

Both Canada and Europe are major exporters of gasoline and other refined products into the U.S. market. Stringent sulfur requirements in Europe, and similar proposed requirements in Canada, will phase-in about the same time as the proposed U.S. standards would phase in. These required improvements in fuel quality will increase costs in these areas, as well as in the U.S. This will support an increase in the price of gasoline in the U.S. sufficient to cover capital, as well as operating costs.

A significant amount of gasoline is also imported into the U.S. from the Middle East and South America. We do not expect gasoline sulfur standards to take effect in these gasoline exporting countries in the near future. Thus, refiners in these countries could reblend their gasoline to be able to export very low sulfur gasoline to the U.S., while selling higher sulfur gasoline elsewhere. Under this scenario, their costs could be significantly less than those of domestic refiners who essentially have to desulfurize their entire product. However, the potential volume of low sulfur gasoline would be limited. Also, these refiners also export to eastern Canada, which will likely have its own low sulfur specification. Thus, the ability of these importers to flood the market with inexpensive, low sulfur gasoline appears to be limited.

While margins may improve which would help domestic refiners recover the cost of meeting the proposed gasoline sulfur requirements, there are still differences between refiners which would cause the per-gallon cost for some to be higher than others. This may be due to: having to pay a premium for capital costs due to their location, starting from a higher sulfur baseline, or facing diseconomies of scale due to small size. In order to remain profitable, high cost refiners would be expected to take further steps to reduce their costs.

Refiners could adopt a whole array of changes which may help them meet the sulfur standard, at a reduced overall cost. These changes include changing crude oil supply, optimizing other feedstock use, cost cutting of existing operations, opting to use processing outside the refinery, improvements in transportation and marketing of product, and changing the consumer market.[27] Refiners could choose to merge their refining operations with other refiners. Merging of refinery downstream operations (the refining and marketing portions of the oil industry) is already occurring across the industry as a means to reduce administrative costs and optimizing the production and distribution of common products.[28] This practice has already been occurring because the return on investment for the refining portion of the industry has been low for some time.

It is possible that the projected per-gallon cost for a specific refinery to desulfurize gasoline may be high enough relative to their ability to pay that a refiner might conclude that it is in their best financial interest to sell the refinery. Over the last several decades, there have been numerous refinery sales as refiners have determined that they are no longer capable of making an acceptable level of profit, and, thus, have put the refinery up for sale.[29] Many of the refineries sold have been purchased by independents (refiners who are not vertically integrated). Because of their flexibility and the relative availability of crude oil and other feedstocks, such as residual oil, these independents have been able to profitably operate these refineries. If a buyer is not found, refiners might be compelled to close the refinery, if no provisions were available to prevent such closures.

However, this proposed rule contains multiple provisions which are intended to prevent refinery closures due to financial hardship. The small refiner provisions extend the time which small refiners would have to meet the sulfur standards. Additional time would allow them to improve their financial standing, obtain a loan or another financial source for their capital expenditures, and employ desulfurization technology developed later on or take advantages of improvements made with existing desulfurization technology. Similarly, refiners which do not

fall under the small refinery definition can enjoy some of these same temporal benefits through the Averaging, Banking and Trading program (ABT). The ABT program allows a refiner to phase-in the proposed program across its refineries to its best financial advantage, or gain even more leeway through trades for sulfur credits.

Based on this qualitative review of cost recovery by the refining industry and the benefits of the proposed small refiner and ABT provisions, we do not expect refineries to close as a result of the implementation of the proposed sulfur standards.

c. Refinery Energy and Global Warming Impacts

We estimated the increase in energy consumption in refineries expected to occur from desulfurizing gasoline to 30 ppm by analyzing the specific impact on PADD 3 refineries. Also, consistent with our cost estimation methodology, we performed the analysis presuming that only improved gasoline desulfurization technologies would be used. For this analysis, we first established a baseline energy consumption value for PADD 3 refineries using 1994 Energy Information Administration data, which is the most recent energy consumption data available. We increased the 1994 energy consumption by 2.05 percent per year until 1997, which is the base year of the analysis. (The value of 2.05 percent per year is the projected growth rate for gasoline consumption). This energy consumption calculation is summarized below in Table V-41.

Table V-41. Energy Consumed by PADD 3 Refineries in 1994, Projected to 1997

Energy Type	*Energy Consumed*	*BTU Value*	*MMMBTUs Consumed*
Crude Oil	0 MBbls	-	0
LPG	660 MBbls	3.64 MMBtu/Bbl	2399
Distillate	54 MBbls	5.83 MMBtu/Bbl	315
Residual Oil	998 MBbls	6.29 MMBtu/Bbl	6274
Still Gas	112,538 MBbls	6.00 MMBtu/Bbl FOE	675,200
Petroleum Coke	38,152 MBbls	6.02 MMBtu/Bbl FOE	229,800
Natural Gas	487,115 MM Cuft	1.03 MBtu/CuFt	501,200
Coal	0 MStTons	-	0
Purchased Electricity	20,602 MMKwH	3.41 MBtu/KwH	70.3
Purchased Steam	11,970 MMLbs	0.809 MBtu/Lb	9680
Hydrogen	68,962 MMScf	0.305 MBtu/Scf	21,000
Other Products	252 MBbls	6.00 MBtu/Bbl FOE	1510
Total in 1994			1,438,000
Total in 1997 (Estimated)			1,528,500

Table V-40 shows that the energy consumed by PADD 3 in 1997 is estimated to be 1,500 trillion BTUs.

The increase in energy consumed by desulfurization of the FCC gasoline is calculated by adding up the fuel gas, steam and electricity (in terms of British thermal units (BTUs)) consumed during the desulfurization. First there is the energy consumed running both CDTECH and Octgain processing units. Consistent with how the cost of desulfurization was estimated, each desulfurization technology was presumed to handle half the PADDs desulfurization needs. Then the octane and hydrogen demand had to be met. For both CDTECH and Octgain, extra reformer capacity in PADD 3 was presumed to produce the octane and hydrogen needed for desulfurization. The amount of additional reformer processing capacity needed was based on hydrogen demand, which produced more octane makeup than needed. This estimation methodology likely overestimates the energy consumed since most refiners would probably run

the reformers to make up the octane needed. They would then obtain the additional hydrogen needed from excess hydrogen going to plant gas, and make up the refinery plant gas energy loss due to the recovered hydrogen from cheap, unrefined petroleum streams, or by combusting natural gas. However, we had insufficient data for estimating hydrogen recovery from plant gas. Alternatively, reformers could obtain hydrogen from hydrogen plants which consume less energy per quantity of hydrogen produced than the reformer. Finally, half of the Octgain desulfurization processes installed are presumed to need splitters, or distillation columns, to fractionate the FCC gasoline. This additional energy demand is accounted for as well. This presumption may overestimate costs as well for two reasons. First, to get down to 30 ppm, many refiners would likely feed the entire feed to the Octgain unit, and not use a splitter. Second, the splitter data upon which we based our energy demand probably boils off the entire feed, which would not be necessary in this case since only the light ends may have to be boiled off for sending the heavier compounds to the Octgain desulfurization unit. A summary of the estimated CDTECH and Octgain energy and hydrogen demands in PADD 3 is summarized in Tables V-42 and V-43, respectively.

Table V-42. Estimated Yearly Energy and Hydrogen Demand of CDTECH Desulfurization Units in PADD 3

CDTECH Utility Demands	*Process Demand*	*Yearly Throughput*	*BTU Conversion Factor*	*Energy and Hydrogen Consumed*
Electricity	0.5 KwH/Bbl	240 MMBbls	3.41 MBtu/KwH	415 MMMBtu
Fuel Gas	55 MBtu/Bbl	240 MMBbls	-	13,400 MMMBtu
Hydrogen	69 Scf/Bbl	240 MMBbls	-	16,800 MMScf
Reformer				
Electricity	2.6 KwH/Bbl	18 MMBbls	3.41 MBtu/KwH	160 MMMBtu
Fuel Gas	0.048 FOE/Bbl	18 MMBbls	6 MMBtu/Bbl	5240 MMMBtu
Steam	75 Lb/Bbl	18 MMBbls	0.809 MBtu/Lb	1100 MMMBtu
Total				20,300 MMMBtu

Table V-43. Estimated Yearly Energy and Hydrogen Demand of OCTGAIN Desulfurization Units in PADD 3

OCTGAIN Utility Demands	*Process Demand*	*Yearly Throughput*	*BTU Conversion Factor*	*Energy and Hydrogen Consumed*
Electricity	3.6 KwH/Bbl	190 MMBbls	3.41 MBtu/KwH	2950 MMBtu
Fuel Gas	17 MBtu/Bbl	190 MMBbls	-	4080 MMMBtu
Steam	50 Lb/Bbl	190 MMBbls	0.809 MBtu/Lb	9710 MMMBtu
Hydrogen	125 Scf/Bbl	190 MMBbls	-	23,700 MMScf
Splitter			-	
Electricity	2.5 KwH/Bbl	190 MMBbls	3.41 MBtu/KwH	810 MMMBtu
Fuel Gas	0.015 FOE/Bbl	190 MMBbls	6 MM Btu/Bbl	8540 MMMBtu
Steam	10 Lb/Bbl	190 MMBbls	0.809 MBtu/Lb	770 MMMBtu
Reformer				
Electricity	2.6 KwH/Bbl	26 MMBbls	3.41 MBtu/KwH	230 MMMBtu
Fuel Gas	0.048 FOE/Bbl	26 MMBbls	6 MM Btu/Bbl	7400 MMMBtu
Steam	75 Lb/Bbl	26 MMBbls	0.809 MBtu/Lb	810 MMMBtu
Total				32,500 MMMBtu

As these tables show, the average increase in energy demand for the improved gasoline desulfurization technologies, including other changes needed in the refinery to desulfurize gasoline, is estimated to be about 53 trillion BTU's in 1997. This increase in energy use is about 3.4 percent higher than the baseline PADD 3 energy consumption. For the U.S. outside of California, the refining industry is estimated to consume 3000 trillion BTUs per year.[aa] Thus the increase in energy demand for the U.S. refining industry, based on PADD 3 and using the 3.4 percent factor calculated above, is estimated to be about 102 trillion BTUs per year. If the additional energy consumed by refiners producing low sulfur gasoline for importing gasoline into the U.S. is considered, the total increase in energy consumed increases to about 122 trillion

[aa]This estimate is based on the presumption that PADD 3 consumes 50 percent of the energy in the U.S. outside of California.

BTU's per year.

We next estimated the amount of global warming gas emissions that would be emitted to meet the proposed 30 ppm gasoline sulfur standard. The basis for the estimate is an estimate of carbon dioxide emissions emitted from the combustion of fuels, which is the source of most all refinery energy and, thus, is presumed to be the source of most all refinery emissions of carbon dioxide. The carbon dioxide emission factor is 65,000 grams of CO2 per million Btu of fuel consumed, which is based on the combustion of half natural gas and half liquid petroleum gas (LPG is presumed to emit the same quantity of carbon dioxide per volume fuel consumed as refinery plant gas).[30] For simplicity, this analysis assumes that all BTUs consumed in a refinery are produced by these fuel sources. On this basis, in 2004, CO2 emissions from PADD 3 refineries would increase by 3.4 million tons under the proposed 30 ppm sulfur standard. Across the entire domestic refining industry, carbon dioxide emissions in 2004 would increase by 6.9 million tons. Considering overseas refiners who export gasoline to the U.S., CO2 emissions would increase by 7.5 million tons in 2004, or 2.1 million tons (1.9 million metric tons) of carbon emissions.

This increase is a one-time step increase which represents 0.03 percent of the projected worldwide CO2 emissions inventory in 2004 which is 29.4 billion tons of CO2 per year. This increase also represents 1.2 percent of the total projected increase in worldwide CO2 emissions in 2004 over 2003, which would be 652 million tons. After the step increase, the CO2 emissions increase due to gasoline desulfurization for this program is expected to increase only at or slightly lower than the rate of increase in gasoline demand, which is about two percent. This further increase in CO2 emissions associated with gasoline desulfurization in 2005 and beyond would represent only 0.02 percent of the projected annual growth in worldwide CO2 emissions.

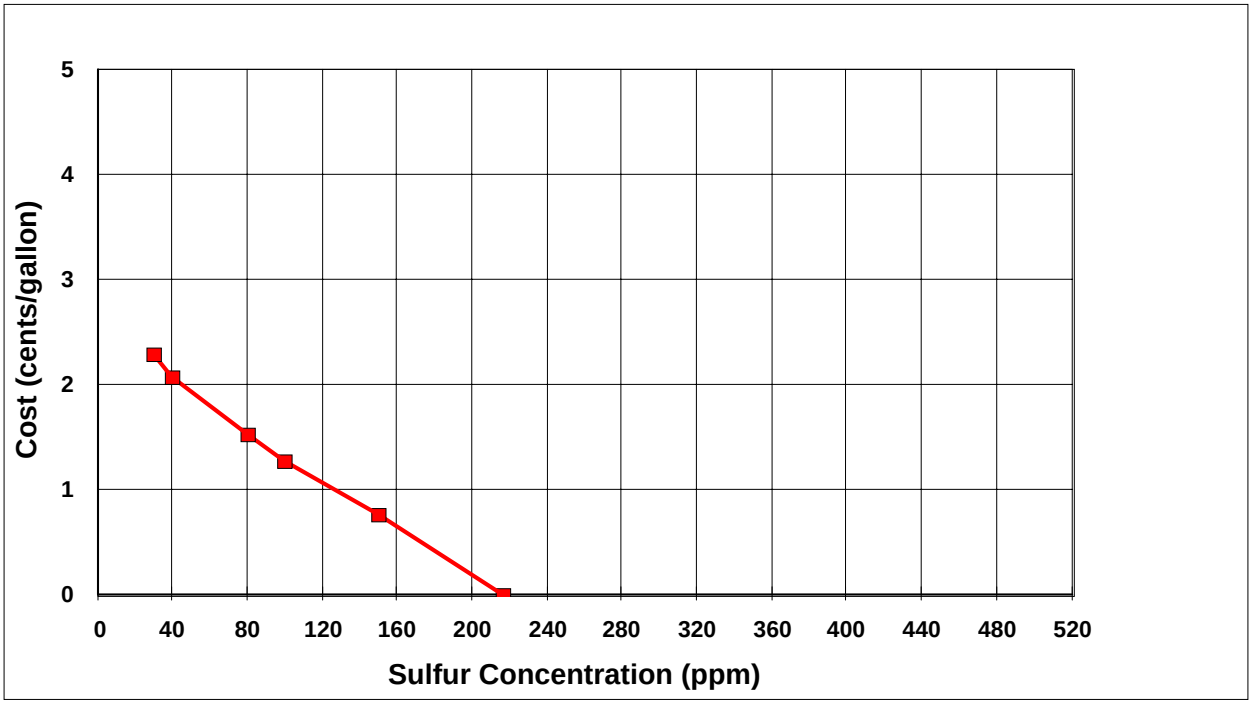

Figure V-2. Cost of Reducing Gasoline Sulfur in PADD 1
(Costs are Based on Improved Gasoline Desulfurization Technologies)

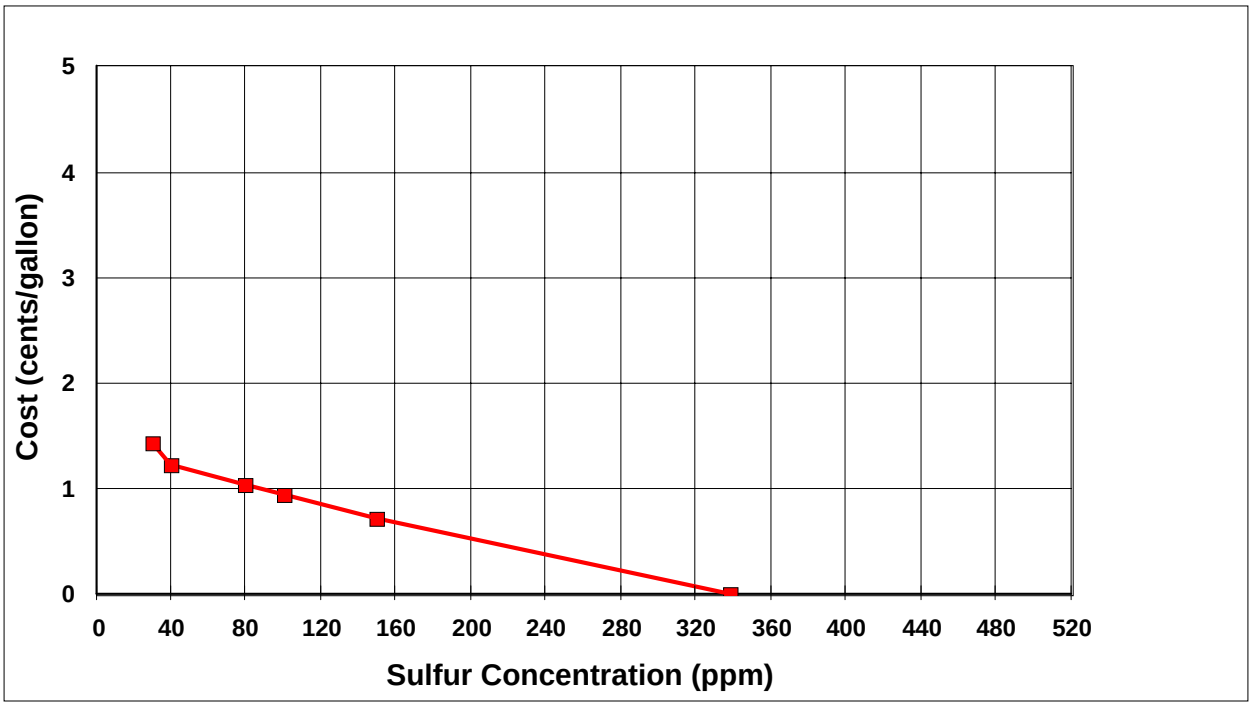

Figure V-3. Cost of Reducing Gasoline Sulfur in PADD 2
(Costs are Based on Improved Gasoline Desulfurization Technologies)

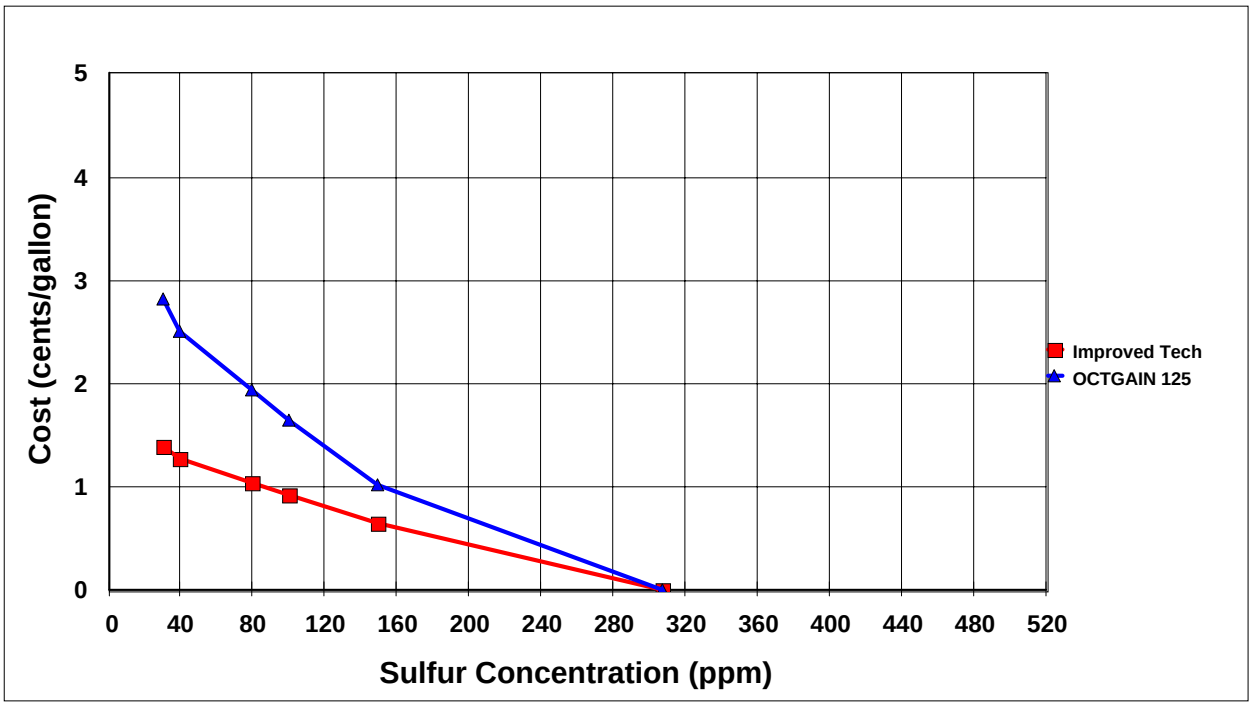

Figure V-4. Cost of Reducing Gasoline Sulfur in PADD 3
(Costs are Based on Improved Gasoline Desulfurization Technologies and Octgain 125)

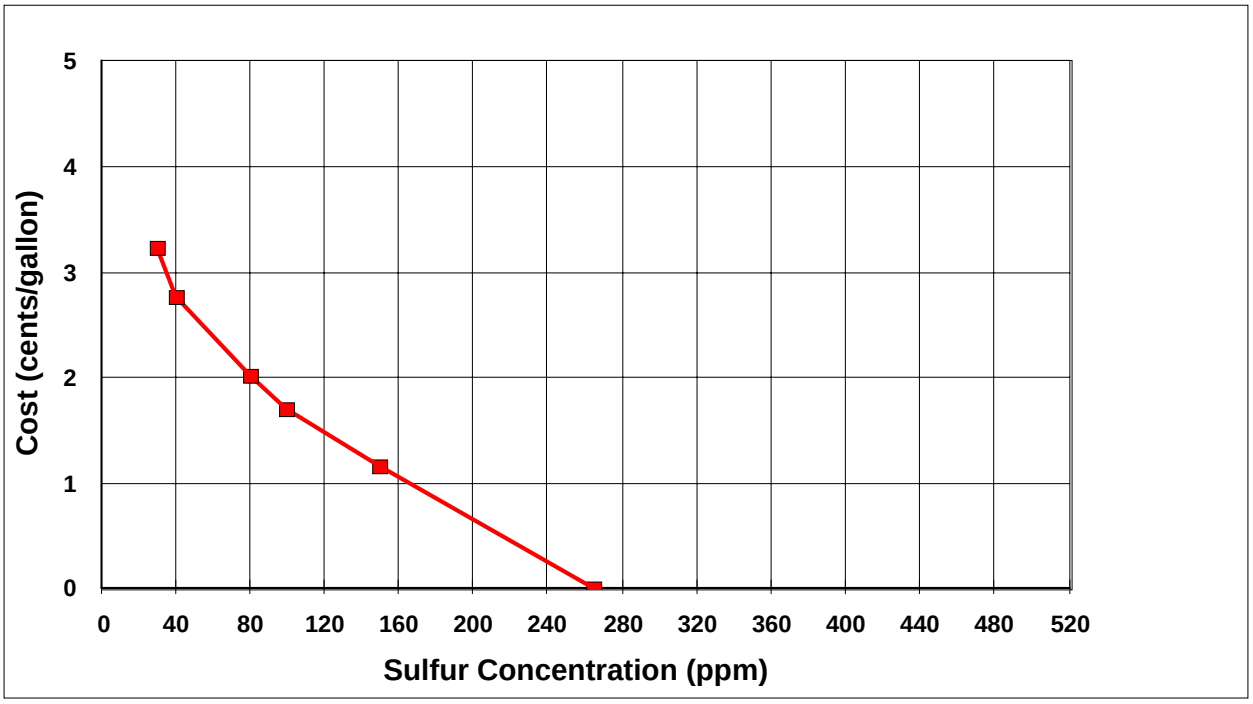

Figure V-5. Cost of Reducing Gasoline Sulfur in PADD 4
(Costs are Based on Improved Gasoline Desulfurization Technologies)

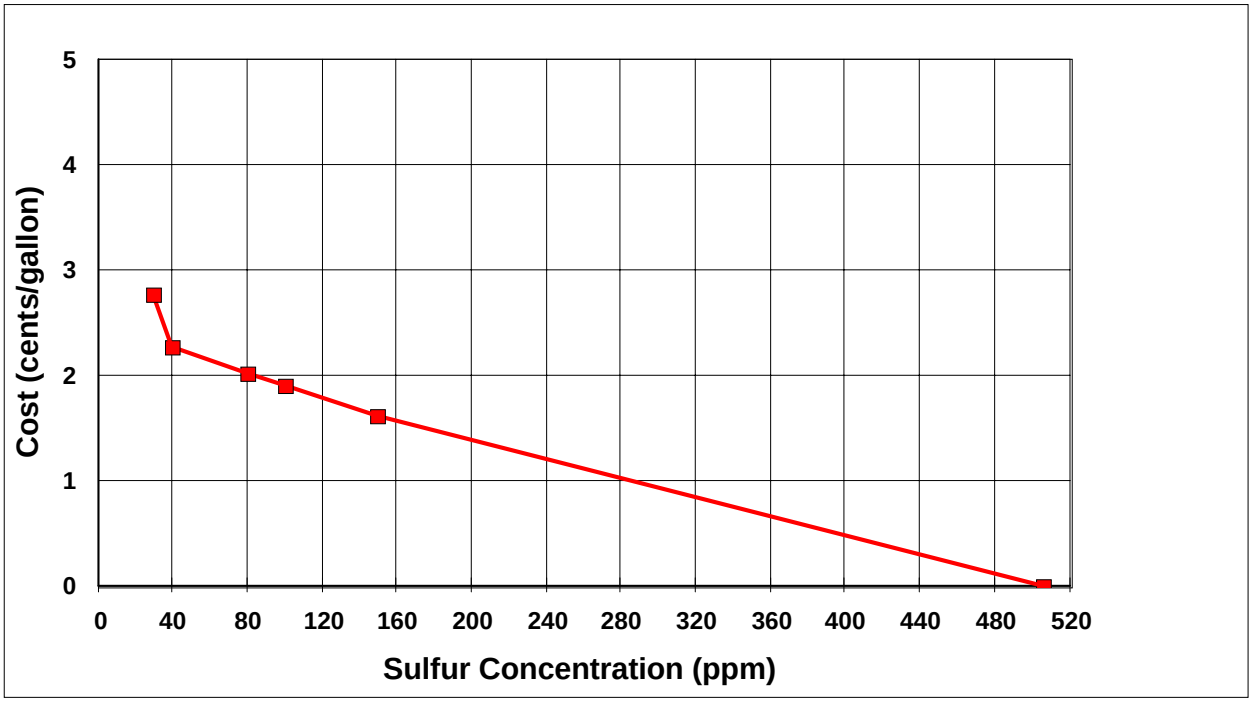

Figure V-6. Cost of Reducing Gasoline Sulfur in PADD 5 Outside of California
(Costs are Based on Improved Gasoline Desulfurization Technologies)

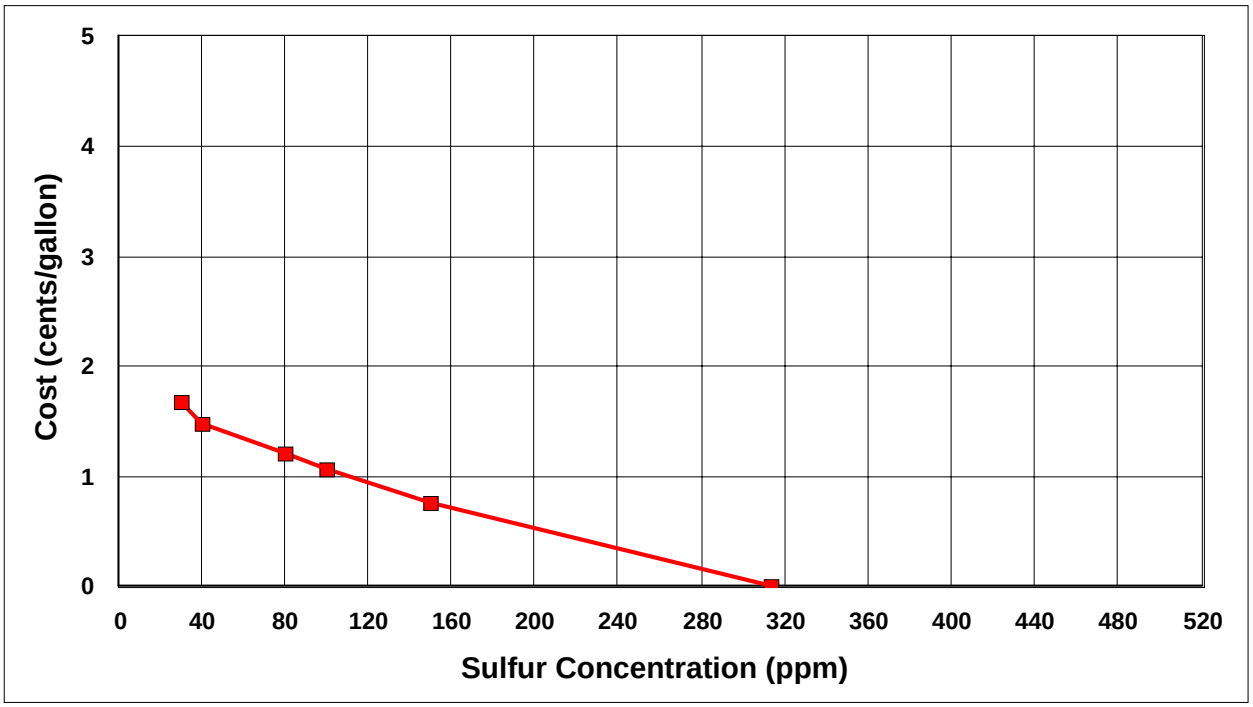

Figure V-7. National Cost of Reducing Gasoline Sulfur Outside of California
(Costs are Based on Improved Gasoline Desulfurization Technologies)

4. Per Vehicle Life-Cycle Fuel Costs

The additional cost of low sulfur gasoline is encountered by the average vehicle owner each time the fuel tank is refilled. The impacts of the gasoline sulfur standard on the average vehicle owner can therefore be calculated as the increased fuel production costs in cents per gallon, multiplied by the total number of gallons used by a vehicle over a particular timeframe. Thus we have calculated the in-use impact of our proposed gasoline sulfur standard on a per-vehicle basis for both a single year and for an entire vehicle's lifetime.

To estimate the cost of low sulfur gasoline in one year for a single vehicle, it is necessary to convert the annual miles traveled by a single vehicle into gallons of gasoline consumed. This conversion requires the use of an average fuel economy factor. Although the current fleet-average fuel economy is approximately 20.7 miles per gallon[31], this value is expected to change in the future for two reasons:

1) As the fleet turns over, those vehicles that were certified at lower fuel economy levels drop out of the in-use fleet.

2) The light-duty vehicle fraction of the fleet is projected to drop as more and more light-duty trucks come into the market.

We have projected that the light-duty vehicle portion of the fleet will level off to a fuel economy of about 24.2 miles per gallon during the next decade, while the light-duty truck portion of the fleet will level off to about 15.5 miles per gallon in the same timeframe. Using the projected long-term distribution of 40 percent LDV and 60 percent LDT in the fleet[32], we calculated the fleet-average fuel economy to be 19.0 miles per gallon.

In a single year, the average in-use light-duty vehicle travels approximately 11,500 miles[bb]. Applying the average fuel economy factor of 19.0 miles per gallon and the initial cost for low sulfur fuel of 1.68 ¢/gal leads us to a per-vehicle estimate of $10.17. This is the additional cost that the average vehicle owner will incur in the first year of the program due to the use of low sulfur gasoline.

The per-vehicle cost of low sulfur gasoline can also be calculated over the lifetime of a vehicle. However, to calculate a lifetime cost for the average in-use vehicle, it is necessary to account for the fact that individual vehicles experience different lifetimes in terms of years that they remain operational. This distribution of lifetimes is the vehicle survival rate distribution, for which we used data from the National Highway Transportation Safety Administration. The costs of low sulfur gasoline incurred over the lifetime of the average fleet vehicle can then be calculated as the sum of the costs in individual years as shown in the equation below:

[bb] Calculated from the annual miles traveled per vehicle for each year of a vehicle's life, multiplied by a distribution of vehicle survival rates by year. Annual miles travelled from "MOBILE6 Fleet Characterization Input Data," Tracie R. Jackson, Report Number M6.FLT.007. Estimate of 11,500 miles per year includes both LDV and LDT.

$$LFC = \sum [(AVMT)_i \times (SURVIVE)_i \times (C) \div (FE)]$$

Where:

LFC	= Lifetime fuel costs in $/vehicle
$(AVMT)_i$	= Annual vehicle miles travelled in year i of a vehicle's operational life[33]
$(SURVIVE)_i$	= Fraction of vehicles still operating after i years of service[34]
C	= Cost of low sulfur gasoline in $/gal
FE	= Fuel economy in miles per gallon. 24.2 for LDV, 15.5 for LDT
i	= Vehicle years of operation, counting from 1 to 25

The cost of low sulfur gasoline is a function of the year of refinery production as described in Section V.B.; the initial cost of 1.68 ¢/gal applies only in the first year of low sulfur gasoline production. In subsequent years, refiners are able to make use of their experience in order to lower their operating expenses. As a result of these declining fuel costs over time, we determined that it is appropriate to calculate total lifetime costs for two separate cases:

1) Near-term, representing a vehicle whose operational life begins at the same time that low sulfur gasoline production begins

2) Long-term, representing a vehicle whose operational life begins six years after low sulfur gasoline production begins

The sixth year for calculating long-term costs of low sulfur gasoline was chosen to be consistent with the sixth year of vehicle manufacture, when the capital cost amortization period ends. Details of the calculation of long-term vehicle costs are given in Section V.A.

We used the above equation to calculate lifetime fuel costs separately for LDV, LDT1, LDT2, LDT3, and LDT4. The results are shown in Table V-44.

Table V-44. Undiscounted Per-vehicle Costs of Low Sulfur Gasoline (In 1997 Dollars)

	Near-term ($)	*Long-term ($)*
LDV	83.36	78.15
LDT1, LDT2	178.52	167.56
LDT3, LDT4	192.13	180.28

We then weighted the per-vehicle costs for the individual vehicle categories in Table V-44 by the fleet fractions. As a result, the total cost incurred by the average in-use vehicle over its lifetime due to the use of low sulfur gasoline was calculated to be $142.53 on a near-term basis and $133.73 on a long-term basis.

An alternative approach to calculating lifetime per-vehicle costs of low sulfur gasoline is to discount future year costs. This approach leads to "net present value" lifetime fuel costs, and is a useful means for showing what the average vehicle owner would have to spend in the first year in order to pay for all future year fuel costs. It also provides a means for comparing the program's costs to its emission reductions in a cost-effectiveness analysis, as described in Section VI.

Discounted lifetime fuel costs are calculated in an analogous manner to the undiscounted values, except that each year of the summation is discounted at the average rate of 7%. The equation given above can be modified to include this annual discount factor:

$$LFC = \sum [\{(AVMT)_i \times (SURVIVE)_i \times (C) \div (FE)\}/(1.07)^{i-1}]$$

Once again, we calculated lifetime fuel costs separately for LDV, LDT1, LDT2, LDT3, and LDT4. These values are shown in Table V-45.

Table V-45. Discounted Per-vehicle Costs of Low Sulfur Gasoline (In 1997 Dollars)

	Near-term ($)	*Long-term ($)*
LDV	60.98	56.73
LDT1, LDT2	126.95	118.19
LDT3, LDT4	135.85	126.43

Once again, we then weighted the per-vehicle costs for the individual vehicle categories in Table V-45 by the fleet fractions. As a result, the total discounted cost incurred by the average in-use vehicle over its lifetime due to the use of low sulfur gasoline was calculated to be $101.92 on a near-term basis and $94.86 on a long-term basis.

A summary of all per-vehicle fuel costs described in this section is given in Table V-46 below.

Table V-46. Fleet Average Per-vehicle Costs Of Low Sulfur Gasoline (In 1997 Dollars)

	Cost per vehicle ($)
First year	10.17
Lifetime, undiscounted, near-term	142.53
Lifetime, undiscounted, long-term	133.73
Lifetime, discounted, near-term	101.92
Lifetime, discounted, long-term	94.86

5. Aggregate Annual Fuel Costs

Aggregate fuel costs are those costs associated with the increased cost per gallon of gasoline due to the proposed sulfur controls, multiplied by the total number of gallons of gasoline consumed in any given year by both highway and non-road sources. The total gallons of gasoline consumed by highway sources were calculated using the VMT projections used throughout the analyses within this document, along with projected fuel economy estimates (mpg) developed by Standard & Poor's Data Research International (DRI).[35] The resultant aggregate annual fuel costs are summarized in Table V-47. It is important to note that the capital costs associated with the proposed sulfur controls have been amortized for this analysis. The actual capital investment would occur up-front, prior to and during the initial years of the program, as described previously in this chapter.

Table V-47. Increased Annualized Fuel Cost as a Result of Today's Proposed Tier 2 Gasoline Sulfur Controls ($Million)

Calendar Year	*Including Non-Road and Excluding California*[cc]
2000	0
2004	2,255
2010	2,127
2015	2,156
2020	2,270

a. Methodology

The DRI develops projected fuel economy estimates for passenger cars (EPA's LDVs), light trucks under 10,000 pounds, and heavy trucks over 10,000 pounds. The VMT projections developed by EPA are for light-duty vehicles (LDV), light-duty trucks (LDT -- under 8500 pounds), and heavy-duty gasoline (over 8500 pounds). Because of the inconsistency in stratifying the fleet, the DRI fuel economy estimates for light trucks (under 10,000 pounds) were used for both the EPA LDT (under 8500 pound) and for EPA's heavy-duty gasoline trucks from 8500 to 10,000 pounds. The DRI fuel economy estimates for over 10,000 pound trucks were then used for EPA's over 10,000 pound heavy-duty gasoline trucks.

The stratification of EPA VMT projections between the 8500 to 10,000 trucks and the over 10,000 trucks was done by using both DRI and EPA data. The DRI projections for the 2000 calendar year show that of all gasoline trucks, light and heavy, 2.1 percent are in the over 10,000 pound category. EPA projections show that of all gasoline trucks, light-duty and heavy-duty, 9.1 percent are in the over 8500 pound category. Using these two projected population percentages, the heavy-duty VMT projections were allocated 77 percent to the 8500 to 10,000 category, and 23 to the over 10,000 category. The same calculation was carried out and used for each calendar year from 2000 to 2020, when the split is projected at 86 percent and 14 percent, respectively. These results are shown in Table V-48.

The DRI fuel economy estimates also include both gasoline and diesel vehicles and trucks. As a result, the truck fuel economy estimates may be slightly higher than a gasoline-only estimate, as diesel vehicles and trucks tend to have higher fuel economy numbers than do gasoline vehicles and trucks. There should be little effect on the fuel economy estimates for

[cc]The aggregate fuel costs used in the economic impact analysis of today's proposal include gasoline consumed by non-road sources and exclude gasoline consumed in the State of California.

passenger cars, because DRI estimates that 99.7 percent of passenger cars will be gasoline fueled in the 2000 calendar year (although 96.5 percent in the 2020 calendar year). Even for light trucks under 10,000 pounds, where more diesels would be expected, DRI estimates a split of 96 percent gasoline in the 2000 calendar year and 92.8 percent in the 2020 calendar year. Therefore, the effect of diesel vehicles and trucks on the DRI under 10,000 pound fuel economy estimates is considered negligible due to their low populations.

The effect of diesels on the over 10,000 pound heavy truck fuel economy estimates is also considered negligible, at least where the total gasoline consumption is concerned. Although the diesel population is relatively high in this category, where DRI estimates diesels at roughly 68 percent of the over 10,000 trucks, their effect is considered negligible because of the insignificant amount of gasoline consumed by trucks over 10,000 pounds (less than 0.02 percent) relative to the gasoline consumed by vehicles and trucks under 10,000 pounds.

The projected VMT values within each category (LDV, LDT, HDG<10,000, and HDG>10,000) were then divided by the corresponding DRI projected fuel economy estimates to derive the gasoline consumption for each category per year. These values were then added, in each given year, to derive the total highway gasoline consumption for each year from 2004 to 2020. The results are shown in Table V-49.

b. Explanation of Results

The aggregate fuel costs used in the economic impact analysis of today's proposal include the non-road contribution but exclude gasoline consumed within the State of California. The total nationwide highway gasoline consumption was adjusted by eliminating 11 percent to exclude the California contribution.[dd] The non-road contribution to the gasoline consumption was then added in by multiplying the highway contribution by 6.4 percent, as non-road sources are estimated to use 6.4 percent of the amount consumed by highway sources.[36] The highway gasoline consumption, including the non-road contribution and excluding the California contribution, was then multiplied by the per gallon increase due to the proposed sulfur control requirements to arrive at the estimated aggregate fuel cost for each individual year. The results are shown in Table V-50.

The aggregate fuel costs used in the economic impact analysis of today's proposal include non-road sources because gasoline used to power these sources will incur the increased per gallon cost, but exclude California because today's proposal will not impact the cost of gasoline in the State of California. The aggregate fuel costs used in the economic impact analysis include Alaska and Hawaii as gasoline in those states will incur the increased per gallon cost.

The aggregate fuel costs decrease during the early years due to the decreasing per gallon

[dd]Based on EPA VMT estimates that California accounts for approximately 11 percent of nationwide VMT.

cost associated with improved refining techniques and the pay off of amortized capital costs. The aggregate costs then increase in later years due both to the reinvestment in refinery equipment (increased capital costs), which increases the per gallon cost, and because VMT is projected to increase every year, which results in increasing fuel consumption.

Table V-48. Stratification of Heavy-Duty Gasoline Fleet using Vehicle Count Projections (Counts are in Millions of Vehicles)

CY	S&P DRI <10k (1)	S&P DRI >10k (1)	S&P DRI total truck	S&P DRI %>10k	AMD <6k (2)	AMD 6k-8500 (2)	AMD <8500	AMD 8500-14k (2)	AMD >14k (2)	AMD Total HDG	AMD Total Truck	AMD %>8500	%HDG 8500-10K	%HDG >10k
1997/6	72.03	1.88	73.91											
2000	83.74	1.76	85.50	2.1%	54.91	19.52	74.43	5.22	2.26	7.48	81.91	9.1%	77.5%	22.5%
2001	87.42	1.74	89.16	2.0%	56.91	20.23	77.14	5.41	2.34	7.75	84.89	9.1%	78.6%	21.4%
2002	89.94	1.73	91.67	1.9%	58.94	20.95	79.89	5.60	2.43	8.03	87.92	9.1%	79.4%	20.6%
2003	92.46	1.71	94.17	1.8%	61.00	21.68	82.68	5.81	2.52	8.33	91.01	9.2%	80.2%	19.8%
2004	94.98	1.69	96.68	1.8%	63.09	22.43	85.52	6.02	2.61	8.63	94.15	9.2%	80.9%	19.1%
2005	99.85	1.70	101.55	1.7%	64.97	23.09	88.06	6.15	2.67	8.82	96.88	9.1%	81.6%	18.4%
2006	102.37	1.68	104.05	1.6%	66.62	23.68	90.30	6.28	2.72	9.00	99.30	9.1%	82.2%	17.8%
2007	104.89	1.67	106.56	1.6%	68.29	24.28	92.57	6.42	2.78	9.20	101.77	9.0%	82.7%	17.3%
2008	107.41	1.65	109.06	1.5%	69.98	24.87	94.85	6.55	2.84	9.39	104.24	9.0%	83.2%	16.8%
2009	109.93	1.63	111.57	1.5%	71.68	25.48	97.16	6.70	2.90	9.60	106.76	9.0%	83.7%	16.3%
2010	113.32	1.68	115.00	1.5%	73.24	26.03	99.27	6.78	2.94	9.72	108.99	8.9%	83.6%	16.4%
2011	114.79	1.68	116.47	1.4%	74.24	26.39	100.63	6.87	2.98	9.85	110.48	8.9%	83.8%	16.2%
2012	116.27	1.68	117.94	1.4%	75.26	26.75	102.01	6.96	3.02	9.98	111.99	8.9%	84.0%	16.0%
2013	117.74	1.67	119.41	1.4%	76.27	27.11	103.38	7.04	3.05	10.09	113.47	8.9%	84.2%	15.8%
2014	119.21	1.67	120.89	1.4%	77.30	27.48	104.78	7.13	3.09	10.22	115.00	8.9%	84.4%	15.6%
2015	122.67	1.67	124.34	1.3%	78.23	27.81	106.04	7.19	3.12	10.31	116.35	8.9%	84.8%	15.2%
2016	124.14	1.67	125.81	1.3%	78.83	28.02	106.85	7.24	3.14	10.38	117.23	8.9%	85.0%	15.0%
2017	125.62	1.67	127.28	1.3%	79.44	28.24	107.68	7.29	3.16	10.45	118.13	8.8%	85.2%	14.8%
2018	127.09	1.66	128.75	1.3%	80.05	28.46	108.51	7.35	3.18	10.53	119.04	8.8%	85.4%	14.6%
2019	128.56	1.66	130.23	1.3%	80.66	28.67	109.33	7.40	3.21	10.61	119.94	8.8%	85.6%	14.4%
2020	128.39	1.66	130.05	1.3%	81.28	28.89	110.17	7.45	3.23	10.68	120.85	8.8%	85.6%	14.4%

(1) From S&P DRI World Energy Service U.S. Outlook, Table 17, April 1998; see memo fr. T.Sherwood to Docket A-97-10, 3/22/99

(2) Draft MOBILE6 Fleet Characterization Input Data, OMS/AMD/Jackson, August 1998; uses count projections where 99.2% of LDTs are gasoline & 0.8% are diesel in both the 2000CY & the 2020CY; see memo fr. T.Sherwood to Docket A-97-10, 3/22/99

Table V-49. Calculation of Gasoline Consumption

					PassCar			LDT<8500				HDG 8500-10k					HDG>10k			Totals	
CY	AMD <8500 VMT ex CA,AL,HI Bmiles (1)	<8500 VMT nation Bmiles (2)	%Car (1)	%Truck (1)	AMD PassCar VMT nation Bmiles (3)	S&P DRI PassCar mpg (4)	PassCar Gasoline Consump nation Bgal	AMD LDT VMT nation Bmiles (5)	LDT Gasoline VMT nation Bmiles (6)	S&P DRI <10k Truck mpg (4)	LDT <8500 Gasoline Consump nation Bgal	AMD HDG VMT ex CA,AL,HI Bmiles (1)	HDG VMT nation Bmiles (2)	8500-10k HDG VMT nation Bmiles (7)	S&P DRI <10k Truck mpg (4)	8500-10k Gasoline Consump nation Bgal	>10k HDG VMT nation Bmiles (7)	S&P DRI >10k mpg (4)	>10k Gasoline Consump nation Bgal	EPA Total Hwy Gasoline Consump nation Bgal	S&PDRI Hwy Gasoline Consump nation Bgal (4), (8)
1997																					120.94
2000	2160	2455	54.7%	45.3%	1342	21.2	63.30	1112	1104	15.9	69.41	0.518	0.589	0.456	15.9	0.03	0.133	7.1	0.02	132.76	132.72
2001	2210	2511	53.1%	46.9%	1333	21.3	62.59	1178	1169	16.0	73.05	0.533	0.606	0.476	16.0	0.03	0.130	7.1	0.02	135.69	134.90
2002	2250	2557	51.5%	48.5%	1318	21.4	61.43	1239	1229	16.1	76.17	0.548	0.623	0.494	16.1	0.03	0.128	7.2	0.02	137.65	137.07
2003	2290	2602	49.9%	50.1%	1300	21.6	60.19	1302	1292	16.3	79.38	0.563	0.640	0.513	16.3	0.03	0.127	7.2	0.02	139.62	139.25
2004	2330	2648	48.4%	51.6%	1281	21.7	58.91	1367	1356	16.4	82.60	0.578	0.657	0.531	16.4	0.03	0.125	7.2	0.02	141.56	141.43
2005	2380	2705	46.8%	53.2%	1266	21.9	57.81	1438	1427	16.5	86.48	0.593	0.674	0.550	16.5	0.03	0.124	7.4	0.02	144.34	142.44
2006	2420	2750	45.2%	54.8%	1244	22.0	56.41	1506	1494	16.6	89.81	0.610	0.693	0.569	16.6	0.03	0.124	7.4	0.02	146.27	144.62
2007	2460	2795	43.6%	56.4%	1220	22.2	54.95	1576	1563	16.8	93.17	0.627	0.713	0.589	16.8	0.04	0.123	7.5	0.02	148.18	146.79
2008	2510	2852	42.0%	58.0%	1199	22.3	53.67	1653	1640	16.9	96.95	0.645	0.733	0.610	16.9	0.04	0.123	7.5	0.02	150.67	148.97
2009	2550	2898	40.6%	59.4%	1177	22.5	52.35	1720	1707	17.1	100.07	0.662	0.752	0.630	17.1	0.04	0.122	7.5	0.02	152.47	151.15
2010	2600	2955	39.4%	60.6%	1164	23.2	50.15	1791	1777	17.3	102.70	0.679	0.772	0.645	17.3	0.04	0.126	7.5	0.02	152.91	151.56
2011	2650	3011	38.3%	61.7%	1153	23.4	49.19	1859	1844	17.5	105.63	0.690	0.784	0.657	17.5	0.04	0.127	7.5	0.02	154.88	152.47
2012	2710	3080	37.3%	62.7%	1149	23.7	48.58	1930	1915	17.6	108.71	0.705	0.801	0.673	17.6	0.04	0.128	7.5	0.02	157.34	153.38
2013	2770	3148	36.5%	63.5%	1149	23.9	48.07	1999	1983	17.8	111.59	0.721	0.819	0.690	17.8	0.04	0.129	7.6	0.02	159.71	154.29
2014	2882	3275	35.8%	64.2%	1172	24.1	48.57	2103	2086	17.9	116.35	0.736	0.836	0.706	17.9	0.04	0.130	7.6	0.02	164.98	155.20
2015	2888	3282	35.2%	64.8%	1155	24.6	46.93	2127	2110	18.2	115.95	0.752	0.855	0.725	18.2	0.04	0.130	7.6	0.02	162.94	157.48
2016	2940	3341	34.7%	65.3%	1158	24.8	46.64	2183	2165	18.4	117.91	0.767	0.872	0.741	18.4	0.04	0.131	7.6	0.02	164.61	158.39
2017	3000	3409	34.2%	65.8%	1167	25.1	46.57	2242	2224	18.5	120.02	0.783	0.890	0.758	18.5	0.04	0.132	7.6	0.02	166.65	159.30
2018	3060	3477	33.9%	66.1%	1178	25.3	46.59	2299	2280	18.7	121.98	0.798	0.907	0.774	18.7	0.04	0.133	7.7	0.02	168.62	160.21
2019	3130	3557	33.6%	66.4%	1195	25.5	46.82	2362	2343	18.9	124.19	0.814	0.925	0.791	18.9	0.04	0.134	7.7	0.02	171.07	161.12
2020	3190	3625	33.4%	66.6%	1211	25.5	47.47	2414	2395	19.0	126.06	0.829	0.942	0.806	19.0	0.04	0.136	7.8	0.02	173.59	161.66

(1) OMS/AMD/Koupal; %Car & %Truck represent % of Light-duty VMT

(2) CA = 11% of nation; CA,AK,HI= 12% of nation

(3) Multiplies <8500 VMT nation by %Car

(4) From S&P DRI World Energy Service U.S. Outlook, Table 17 (mpg values include diesel), April 1998; see memo fr. T.Sherwood to Docket A-97-10, 3/22/99

(5) Multiplies <8500 VMT nation by %Truck

(6) Draft MOBILE6 Fleet Characterization Input Data, OMS/AMD/Jackson, August 1998; uses count projections where 99.2% of LDTs are gasoline & 0.8% are diesel in both the 2000CY & the 2020CY;
see memo fr. T.Sherwood to Docket A-97-10, 3/22/99

(7) Uses S&P DRI data for % of all gas trucks >10k, and AMD data for % of all gas trucks >8500, then calculates % of all >8500 gas trucks in the 8500-10k category, and % of all >8500 gas trucks in the >10k category.

(8) Presented for comparison only. Discrepancy in later years due mainly to AMD's larger LDT VMT share (67% of LD VMT) vs S&P (~53% of <10k VMT)

Table V-50. Aggregate Annualized Fuel Costs per Year from 2004 to 2020

CY	EPA Total Hwy Gasoline Consump nation Bgal	Total Hwy Gasoline Consumption excluding CA Bgal (1)	Non-road Gasoline Consumption excluding CA Bgal (2)	Tier2 Cost ex CA & incl NonRoad $B (3)
1997				
2000	132.76	118.16	7.56	0
2001	135.69	120.76	7.73	0
2002	137.65	122.51	7.84	0
2003	139.62	124.26	7.95	0
2004	141.56	125.99	8.06	2.255
2005	144.34	128.47	8.22	2.276
2006	146.27	130.18	8.33	2.136
2007	148.18	131.88	8.44	2.138
2008	150.67	134.09	8.58	2.147
2009	152.47	135.70	8.68	2.147
2010	152.91	136.09	8.71	2.127
2011	154.88	137.84	8.82	2.129
2012	157.34	140.03	8.96	2.142
2013	159.71	142.14	9.10	2.154
2014	164.98	146.83	9.40	2.204
2015	162.94	145.01	9.28	2.156
2016	164.61	146.50	9.38	2.158
2017	166.65	148.32	9.49	2.166
2018	168.62	150.07	9.60	2.172
2019	171.07	152.25	9.74	2.264
2020	173.59	154.50	9.89	2.270

(1) CA = 11% of total nation; CA,AK,HI = 12% of nation

(2) OMS/VPCD/Todd Sherwood; NonRoad fraction = 6.4%;
see memo to Docket A-97-10, 2/19/99

(3) OMS/FED/Wyborny; Tier2 $/gal increase

CY	Adj Cost $/gal	CY	Adj Cost $/gal
2004	0.01682	2013	0.01424
2005	0.01665	2014	0.01411
2006	0.01542	2015	0.01397
2007	0.01523	2016	0.01385
2008	0.01505	2017	0.01372
2009	0.01487	2018	0.01360
2010	0.01469	2019	0.01398
2011	0.01452	2020	0.01381
2012	0.01438		

C. Combined Vehicle and Fuel Costs

Sections A. and B. of this section provide detailed cost analyses for Tier 2 vehicles and low sulfur gasoline, respectively. The following sums the costs to consumers to provide total incremental costs of the Tier 2 program. The per vehicle costs are provided first, followed by the total annual nationwide costs.

1. Combined Costs Per Vehicle

Table V-51 provides a summation of our estimated incremental per vehicle costs, including increased costs for Tier 2 vehicles and for low sulfur gasoline over the life of the vehicles. We use the cost estimates for our cost-effectiveness analysis presented in the following Chapter. As described in the previous sections, we expect these costs to decrease over time as manufacturers make production improvements and recover fixed costs. Table V-51 provides estimates of near-term costs, which represent costs in the first years of the program, and long-term costs which account for the cost decreases.

Table V-51. Total Incremental Per Vehicle Costs to Consumers Over the Life of a Tier 2 Vehicle

	LDV ($)	*LDT1 ($)*	*LDT2 ($)*	*LDT3 ($)*	*LDT4 ($)*
Near-term Costs					
Vehicle costs	80	73	136	274	270
Fuel costs*	61	127	127	136	136
Total	141	200	263	410	406
Long-term Costs					
Vehicle costs	50	47	103	218	213
Fuel costs*	57	118	118	126	126
Total	107	165	221	344	339

* Discounted lifetime fuel costs in 1997 dollars

2. Combined Total Annual Nationwide Costs

Figure V-8 and Table V-52 summarize EPA's estimates of total annual costs to the nation

both for Tier 2 vehicles and low sulfur gasoline.[ee] The capital costs have been amortized for these analyses. The actual capital investment would occur up-front, prior to and during the initial years of the program, as described previously in this chapter. The fuel costs shown are for all gasoline consumed nationwide, including both on-highway and nonroad. Annual aggregate vehicle costs change as Tier 2 vehicle sales are phased-in and projected per-vehicle costs and annual sales change over time. The aggregate fuel costs change as projected per gallon costs and annual fuel consumption change over time. Increases in fuel consumption over time are generally off-set by decreases in per gallon costs. The methodology we used to derive the aggregate costs are described in detail in the sections A.3. and B.5. of this chapter. As shown below, total annual costs increase over the phase-in period and peak at about $3.7 billion. Annual costs then drop to about $3.5 billion, largely due to decreases in vehicle costs. Costs increase gradually after 2012 due to the stabilization of vehicle costs in the long-term and projected increases in vehicle sales and fuel consumption.

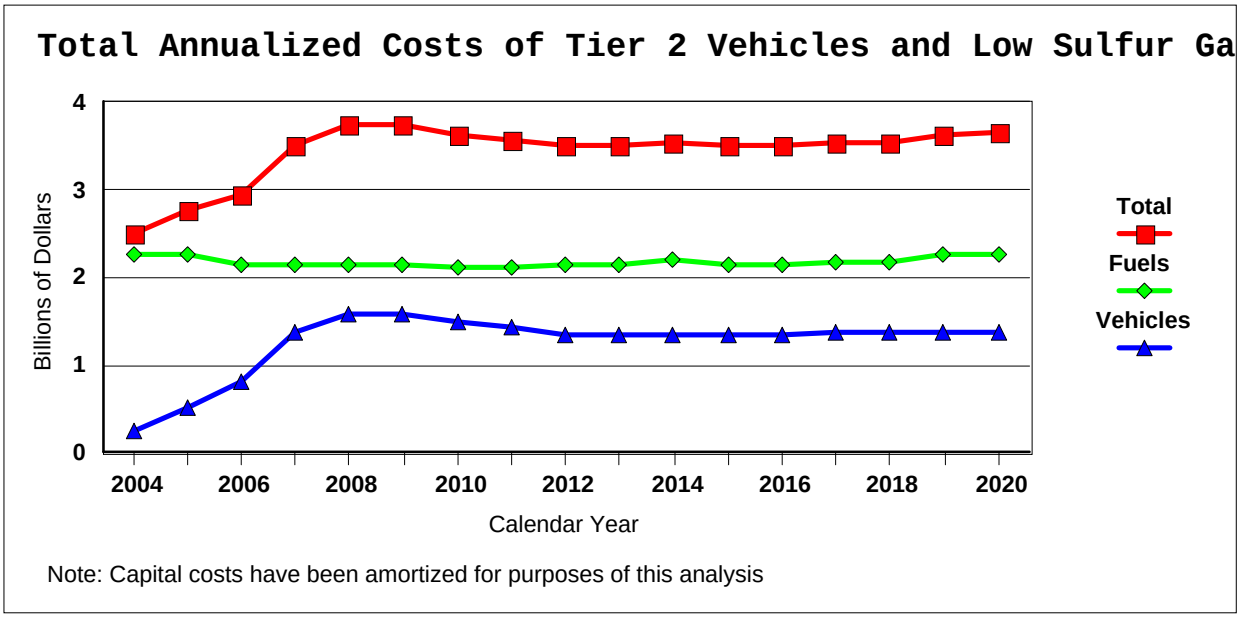

Figure V-8. Total Annualized Costs of Tier 2 Vehicles and Low Sulfur Gasoline.

[ee] Excluding vehicles and fuel sold in California.

Table V-52. Total Annualized Costs to the Nation for Tier 2 Vehicles and Low Sulfur Gasoline ($million)

Calendar Year	*Vehicle Costs ($)*	*Fuel Costs ($)*	*Total ($)*
2004	$257	$2,255	$2,512
2005	$506	$2,276	$2,782
2006	$815	$2,136	$2,951
2007	$1,365	$2,138	$3,503
2008	$1,589	$2,147	$3,736
2009	$1,587	$2,147	$3,734
2010	$1,496	$2,127	$3,623
2011	$1,427	$2,129	$3,556
2012	$1,359	$2,142	$3,501
2013	$1,348	$2,154	$3,502
2014	$1,346	$2,204	$3,550
2015	$1,352	$2,156	$3,508
2016	$1,359	$2,158	$3,517
2017	$1,366	$2,166	$3,532
2018	$1,373	$2,172	$3,545
2019	$1,380	$2,264	$3,644
2020	$1,387	$2,270	$3,657

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Chapter VI: Cost-Effectiveness

This section will present the cost-effectiveness analysis we completed for the combined Tier 2 exhaust, Tier 2 evaporative, and gasoline sulfur standards. This analysis relies in part on cost information from Section V and emissions information from Section III to estimate the cost-effectiveness of the standards in terms of dollars per ton of total NOx + NMHC emission reductions. Finally, this Section compares the cost-effectiveness of the new provisions with the cost-effectiveness of other NOx and NMHC control strategies from previous and potential future EPA emission control programs.

A. Overview of the Analysis

The cost-effectiveness analysis conducted for our proposed standards focused on the costs and emission reductions associated with a single vehicle meeting the Tier 2 emission standards, and operating on low sulfur fuel. Both costs and emission reductions were calculated over the life of the vehicle and then discounted at a rate of seven percent. Costs and emission reductions were measured relative to an NLEV baseline and average sulfur levels in the absence of sulfur controls. The calculations were performed separately for each vehicle class and the results weighted according to the expected fleet mix. Details on our approach to cost-effectiveness follow.

1. Temporal and Geographic Applicability

We have taken a per-vehicle approach to our cost-effectiveness calculations that produces $/ton values representing any controlled vehicle, no matter where that vehicle operates. In effect, this means that emission reductions in both attainment and nonattainment areas are included in our cost-effectiveness analysis. We believe that this is appropriate. Both the Tier 2 vehicle and gasoline sulfur programs are proposed to apply nationwide, so that the same emission reductions will occur regardless of where the vehicle operates. Attainment area emission reductions also produce health benefits. In general, the benefits of NMHC reductions in ozone attainment areas include reductions in emissions of air toxics, reductions in the contribution from NMHC emissions to the formation of fine particulate matter, and reductions in damage to agricultural crops, forests, and ecosystems from ozone exposure. Emission reductions in attainment areas help to maintain clean air as the economy grows and new pollution sources come into existence. Also, ozone health benefits can result from reductions in attainment areas, although the most certain health effects from ozone exposure below the NAAQS appear to be both transient and reversible. The closure letter from the Clean Air Science Advisory Committee (CASAC) for the recent review of the ozone NAAQS states that there is no apparent threshold for biological responses to ozone exposure[1].

In the Regulatory Impact Analysis for a recent rulemaking for highway heavy-duty diesel engine standards[2], EPA also presented a regional ozone control cost-effectiveness analysis in

which the total life-cycle cost was divided by the discounted lifetime NOx + NMHC emission reductions adjusted for the fraction of emissions that occur in the regions expected to impact ozone levels in ozone nonattainment areas. (Air quality modeling indicates that these regions include all of the states that border on the Mississippi River, all of the states east of the Mississippi River, Texas, California, and any remaining ozone nonattainment areas west of the Mississippi River not already included.) The results of that analysis show that the regional cost-effectiveness values were 13 percent higher than the nationwide cost-effectiveness values. Because of the small difference between the two results, EPA is presenting only nationwide cost-effectiveness results for this analysis.

Despite the fact that a per-vehicle approach to cost-effectiveness allows us to avoid the arbitrary choice of a specific year in which to conduct the analysis, there is some value in examining different points in time after the program is first implemented. The costs of the program will be higher immediately after it is implemented than they will be after several years, since both vehicle manufacturers and refiners can take advantage of decreasing capital and operating costs over time. For the purposes of this proposed rulemaking, therefore, we will present cost-effectiveness of our proposed program on both a near-term and long-term basis. More details concerning per-vehicle costs are given in Section VI.B.1.

2. Baselines

There are two broad approaches to cost-effectiveness that can be taken, each of which requires a different baseline. These two approaches can be termed "incremental" and "average." Both incremental and average approaches to cost-effectiveness provide a measure of how much more stringent than the existing standards our proposed standards can be before they cease to be cost-effective.

An incremental approach to cost-effectiveness requires that we evaluate a number of different potential standards, each of which is compared to the potential standards closest to it. Using this approach, the cost-effectiveness of our proposed standards would be calculated with respect to another set of potential standards which is less stringent than our proposed standards. In this way, the $/ton values represent the last increment of control, highlighting any nonlinearities that exist in either the costs or emission reductions.

Incremental cost-effectiveness will produce different $/ton values than an average approach to cost-effectiveness only if the costs or emission reductions are nonlinear. In the case of our proposed standards, both the emission reductions and the fuel costs are nearly linear, though the vehicle costs do contain some nonlinearity.

An average approach to cost-effectiveness, on the other hand, requires that we compare the costs and emission reductions associated with our proposed standards to those for the previous set of standards that are being met by manufacturers. In this case, the $/ton values represent the full range of control from the last applicable standard to our proposed standards.

Since today's proposed program includes both fuel standards and vehicle standards, it was necessary for us to define a baseline for both fuels and vehicles. For fuels, there are no previous controls applicable to sulfur (apart from an ASTM limit of 1000 ppm). As a result, we have determined that the sulfur baseline should represent the national average sulfur level that would exist at the time our proposed sulfur standard would go into effect. The national average sulfur content of current conventional gasoline is approximately 330 ppm. We are not projecting the sulfur level of conventional gasoline to change over the next ten years in the absence of specific sulfur controls. For Phase II reformulated gasoline (RFG), the average sulfur content is projected to be 150 ppm in the summer and 300 ppm in the winter[ff]. Based on seasonal volume data, we estimate that 40 vol% of the annual pool is summer gasoline, with the remainder being winter gasoline, producing an annual Phase II RFG sulfur level of 240 ppm. Because estimating the number of areas that will continue to be in the RFG program by the middle of the next decade is highly speculative, we have assumed that the current volume split between RFG and conventional gasoline will continue indefinitely. Thus we estimated that Phase II RFG will account for 26.7 percent of the total gasoline pool. As a result, we calculated the national average sulfur level for the next decade to be 305 ppm. This is the baseline sulfur level used in our calculations.

For the exhaust emission standards applicable to light-duty vehicles and trucks, there are two potentially valid baselines that could be used. The Clean Air Act (CAA) suggests that Tier 2 vehicle standards should be compared to the previous set of federal light-duty standards, termed Tier 1 standards. However, the language does not explicitly require that the cost-effectiveness determination use Tier 1 standards as the baseline. Since the passage of the CAA Amendments of 1990, the National Low Emission Vehicle (NLEV) program has gone into effect. NLEV includes light-duty standards that are more stringent that Tier 1 for LDV, LDT1, and LDT2. NLEV did not exist in 1990 and was not envisioned by the authors of the CAA Amendments of 1990. Had NLEV existed, either in concept or as a formal program, we believe that it could have been identified in the CAA as the point of comparison for evaluating Tier 2 standards. In addition, NLEV standards represent the most recent set of standards with which manufacturers must comply. For our proposal, therefore, we have decided to make NLEV the baseline on which the vehicle side of our cost-effectiveness calculations are based. Further, these NLEV vehicles would be SFTP compliant since they would be sold in 2004 (the first year of our proposed Tier 2 program).

The NLEV program did not include new standards for evaporative emissions, and so cannot be used as the baseline for evaluating the cost-effectiveness of our proposed Tier 2 evaporative emission standards. Instead, the 2.0 gram/test standards under the enhanced evaporative procedure, initially implemented in 1996, have been used as the baseline.

B. Costs

[ff] Based on a consensus opinion of the multi-party Phase II RFG Implementation Team, and summarized in a report entitled, "Phase II RFG Report on Performance Testing." Contact: Deborah Wood, Office of Mobile Sources.

The costs used in our cost-effectiveness calculations are the sum of the costs of compliance with the Tier 2 exhaust, Tier 2 evaporative, and gasoline sulfur standards on a per-vehicle basis. Costs are given in 1997 dollars, and result from discounting over the lifetime of a vehicle at a seven percent discount rate. In addition, all costs represent the fleet-weighted average of light-duty vehicles and trucks.

1. Near and Long-Term Cost Accounting

Since the costs of complying with both the Tier 2 exhaust and gasoline sulfur standards will vary over time, we determined that it is appropriate to consider both near-term and long-term costs in our cost-effectiveness analysis. First, the capital costs associated with the manufacture of vehicles that meet the proposed Tier 2 standards are generally amortized over five years. Thus in the sixth year of production, a portion of the capital costs become zero and the total costs of production drop. Manufacturers also gain knowledge about the best way to meet new standards as time goes on, and as a result their operating costs decrease over time. As described in a recent rulemaking setting standards for non-road compression ignition engines, we have determined that the cost-implications of this "learning curve" can be estimated as a 20 percent drop in operating costs in the third year of production.

Thus near-term costs represent the highest costs of the program, as they include all capital costs and no cost savings due to the manufacturer's learning curve. Long-term costs, on the other hand, represent the lowest costs of the program which occur after a portion of capital cost amortizations have ended and all learning curve cost savings have been accounted for. For the purposes of this proposed rulemaking, therefore, we will present cost-effectiveness of our proposed program on both a near-term and long-term basis.

Because of our per-vehicle approach to cost-effectiveness, near-term and long-term costs are not associated with any specific year of our proposed Tier 2 program. For instance, the costs associated with our proposed gasoline sulfur control program will decline steadily due to rotating capital expenditures and continuous improvements in catalyst design. Vehicle costs, however, decline over a different schedule. Not only are the vehicle-related capital costs amortized over five years instead of the longer, rotating schedule for gasoline sulfur, but the phase-in schedule for the Tier 2 exhaust standards varies depending on vehicle class. Therefore, the near-term costs actually represent a conservative view of the costs of our proposed program, since they consider the highest vehicle and fuel costs as if they occurred at the same time for all vehicle classes. The long-term costs, on the other hand, represent the case for some later year of the Tier 2/gasoline sulfur program in which a majority of the fleet is meeting our proposed standards. In this case, the phase-in schedule for light-duty vehicles and trucks is no longer evident in the fleet mix, a portion of capital cost amortizations have ended, and most learning curve cost savings will have been taken into account. Details about the calculation of near and long-term vehicle and fuel costs can be found in Sections V.A.1 and V.B.2.

2. Vehicle and Fuel Costs

The per-vehicle costs used in our cost-effectiveness calculations were derived and presented in the preceding sections. Vehicle costs were presented in Table V-12 for the five vehicle categories affected by our proposed standards. For the purposes of calculating cost-effectiveness, we first subtracted out the costs attributable to compliance with our proposed evaporative emission standards, then weighted the remaining costs for those five individual vehicle categories by the expected fleet fractions to obtain fleet-average costs for our proposed exhaust emissions standards. Also, we treated first-year production costs as the "near-term" costs, and sixth-year production costs as the "long-term" costs. Costs associated with compliance with our proposed evaporative emission standards were constant across all vehicle classes at $4.10 per vehicle. For low sulfur gasoline, we used the discounted lifetime costs presented in Table V-41. The costs used in our cost-effectiveness calculations are repeated in Table VI-1.

Table VI-1. Fleet-average, Per-vehicle Costs Used in Cost-effectiveness

	Vehicle-exhaust ($)	*Vehicle-evap ($)*	*Fuel ($)*	*Total costs ($)*
Near-term	124.04	4.10	101.92	230.06
Long-term	89.47	4.10	94.86	188.43

Note that the total costs in Table VI-1 were used for establishing "uncredited" cost-effectiveness values. As described in the next section, the costs from Table VI-1 were also adjusted to produce "credited" cost-effectiveness values.

3. Cost Crediting for PM and SO_2

The object of our cost-effectiveness analysis is to compare the costs to the emission reductions in an effort to assess the program's efficiency in helping to attain and maintain the NAAQS. Thus we recognize that the primary purpose of our proposed standards is to reduce emissions of hydrocarbon and oxides of nitrogen emissions from the affected vehicles. That is why we determined that cost-effectiveness should be calculated on the basis of total NOx + NMHC emissions. However, we also believe that reductions in other pollutants which produce health or welfare benefits should be included in the cost-effectiveness assessment, since they also represent a value of our proposed program.

The reduction in gasoline sulfur levels that would result from our proposed standards will necessarily result in reductions in sulfur-containing compounds that exit the tailpipe. These compounds are limited to sulfur dioxide (SO_2) and sulfate particulate matter. To account for reductions in emissions of these two pollutants in our cost-effectiveness calculations, we have calculated a second set of $/ton values in which we credit some of the costs to SO_2 and direct sulfate PM, with the remaining costs being used to calculate $/ton NOx+NMHC. As a result, we

have produced both "credited" and "uncredited" $/ton NOx+NMHC values; the former takes into account the SO_2 and direct PM emission reductions associated with our proposed standards, while the latter does not.

Cost-effectiveness values for the control of SO_2 and direct PM represent conservative estimates of the cost of measures that will need to be implemented in the future in order for all areas to reach attainment. Such cost-effectiveness values are therefore an appropriate source for estimating the amount of the costs to credit to these pollutants. As a result, we credited some costs to SO_2 and direct PM through the application of cost-effectiveness ($/ton) values for these two pollutants withdrawn from other sources.

In concept, we would consider the most expensive program needed to reach attainment a good representation of the ultimate value of PM or SO_2. However, in this rulemaking, we chose to simplify by using more conservative approaches to establish crediting values for PM and SO_2. The potential future programs evaluated as part of the NAAQS revisions rulemaking (discussed in more detail in Section VI.D below) provided a reasonable source for identifying the value of SO_2 and direct PM in terms of their cost-effectiveness.

Out of the nine SO_2 control programs evaluated in the NAAQS revisions rule, eight were actually used in the modeling of ambient concentrations of PM based on their contribution to secondary PM (sulfate) levels in PM nonattainment areas. The modeling showed that these eight programs, along with other PM control programs as described above, permitted 70 percent of counties not meeting the annual 8-hour PM standard to come into attainment. The cost-effectiveness of the eight SO_2 control programs ranged from $1600/ton to $111,500/ton. In this particular rulemaking, rather than attempt to identify a more precise credit value for SO_2 based on the last measures needed for attainment, we have for simplicity's sake used the average cost effectiveness of the eight SO_2 control programs, calculated to be $4800 a ton. This average value of $4800/ton was used in the crediting of some costs to SO_2, and represents a conservative valuation of SO_2.

The NAAQS revisions rule also evaluated PM control strategies, accounting for both PM_{10} and $PM_{2.5}$. The average cost-effectiveness for the PM control strategies considered in the NAAQS revisions rule ranged from $2,400/ton (for PM_{10}) to $12,900/ton (for $PM_{2.5}$). However, a recent rulemaking setting standards for urban busses[3] determined that the cost-effectiveness of PM control for these heavy-duty diesel engines was $10,000 - $16,000/ton. In this particular rulemaking, rather than attempt to identify an more precise credit value for PM based on the last measures needed for attainment, we have for simplicity's sake used $10,000/ton as a conservative but reasonable crediting value for PM for our proposed standards.

The cost crediting was applied after all costs associated with compliance with our proposed standards were calculated and summed. The per-vehicle tons reduced of both direct PM and SO_2 were multiplied by the respective cost-effectiveness values of $10,000/ton and $4800/ton (see Sections VI.C.3 and VI.C.4 below for tons calculations). As a result, $53.73 of the total costs were apportioned to SO_2, while $3.96 was apportioned to direct PM. These amounts are independent of whether we are considering a near-term or long-term cost-

effectiveness calculation, since the total tons reduced for these two compounds is the same, on a per-vehicle basis, in any year of the program. A summary of the costs used in our cost-effectiveness calculations is given below in Table VI-2.

Table VI-2. Fleet Average Per-vehicle Costs Used in Cost-effectiveness

	Near-term costs ($)	*Long-term costs ($)*
Total uncredited costs	230.06	188.43
SO_2 credit allocation	-53.73	-53.73
Direct PM credit allocation	-3.96	-3.96
Total credited costs	172.37	130.74

C. Emission Reductions

In order to determine the overall cost-effectiveness of the standards we are proposing, it was necessary to calculate the lifetime tons of each pollutant reduced on a per vehicle basis. This section will describe the steps involved in these calculations. In general, emission reductions were calculated for NOx, NMHC, primary PM, and SO_2 in a manner analogous to the discounted lifetime fuel costs described in Section V.B.4.

1. NOx and NMHC

Our proposed standards are intended primarily to reduce emissions of NOx and NMHC. We have determined that the cost-effectiveness of our proposed standards should be determined for both NOx and NMHC. Several past rulemakings which produced reductions in both of these pollutants have taken an approach to cost-effectiveness that sums the NOx and NMHC emission reductions. This approach leads to $/ton NOx+NMHC. In addition, many standards for mobile sources have been established in terms of NOx+NMHC caps. Thus we believe that this approach to cost-effectiveness is appropriate for our proposed Tier 2 standards as well, because we are proposing more stringent exhaust standards for both NOx and NMHC (separately). This approach also allows for a direct comparison to previous programs for which NOx and NMHC were summed in the cost-effectiveness analyses.

The discounted lifetime tonnage numbers for NOx, exhaust NMHC, and evaporative NMHC were based on average in-use emission levels developed for EPA's proposed MOBILE6 on-highway inventory model. These in-use emission levels were expressed in terms of average gram/mile emissions for each year in a vehicle's life, up to 25 years. From this basis, lifetime tonnage estimates were developed using the following procedure:

1) Annual mileage accumulation levels proposed for MOBILE6 were applied to the in-use emission rates for each year in a vehicle's life to generate total mass emissions produced in each year by that vehicle.

2) The resultant mass emissions were multiplied by the probability of survival in the appropriate year, known as the "survival" rate, from estimates for cars and trucks published by NHTSA[4].

3) A seven percent annual discount factor, compounded from the first year of the vehicle's life, was then applied for each year to allow calculation of net present value lifetime emissions.

Converting to tons and summing across each year results in the total discounted lifetime per-vehicle tons. This calculation can be described mathematically as follows:

$$LE = \sum [\{(AVMT)_i \times (SURVIVE)_i \times (ER)_i \times (K)\}/(1.07)^{i-1}]$$

Where:

LE	= Discounted lifetime emissions in tons/vehicle
$(AVMT)_i$	= Annual vehicle miles traveled in year i of a vehicle's operational life
$(SURVIVE)_i$	= Probability of vehicle survival after i years of service
$(ER)_i$	= Emission rate, g/mi in year i of a vehicle's operational life
K	= Conversion factor, 1.102×10^{-6} tons/gram
i	= Vehicle years of operation, counting from 1 to 25

For NOx and exhaust NMHC, we generated discounted lifetime tonnage values for each vehicle class (LDV, LDT1, LDT2, LDT3, LDT4) using the above equation. This was done separately for the baseline and control cases. The baseline case included the NLEV vehicle program (LEV for LDV, LDT1 and LDT2; Tier 1 for LDT3 and LDT4) and the in-use fuel program (RFG in the appropriate areas, modeled at 150 ppm sulfur for the summer; conventional gasoline in the remaining areas, modeled at 330 ppm sulfur). The control case entailed the Tier 2 vehicle program (0.07 g NOx/mi and 0.09 g NMHC/mi for all vehicle classes) and fuel program (30 ppm nationwide). Baseline and controlled sulfur levels also included the maximum sulfur levels that would be seen by a vehicle over its lifetime in order to estimate the impacts of catalyst irreversibility as described in Section VI.C.2 below. Thus the actual number of sulfur cases was four: two for the average baseline and control sulfur levels, and two more for the maximum baseline and control sulfur levels. For each permutation of vehicle and fuel program, tonnage estimates were also developed for IM and non-IM areas to allow generation of a nationwide composite tonnage estimate. The tonnage values that we calculated according to this procedure are presented in Appendix VI-A.

Before using the tonnage values to calculate the cost-effectiveness of our proposed program, it was necessary for us to combine the values for IM vs. no-IM areas and RFG vs. conventional gasoline areas in an effort to represent the national scope of our proposed program.

The weighting factors were based on an analysis of the fraction of the population in the 47 state area (U.S. excluding California, Alaska, and Hawaii) which was located within or outside of IM and RFG areas[5]. We also made a distinction between summer and winter RFG, since summer-grade Phase II RFG having approximately 150 ppm sulfur will be used for only 40 percent of the year, while winter-grade Phase II RFG having approximately 300 ppm sulfur will be used for the remaining 60 percent of the year. 1998 population data was used to determine these population fractions by state, and then nationwide weighting factors were produced from the sum of these fractional by-state populations. The geographical results are shown in Table VI-3.

For evaporative NMHC, we based the baseline tonnage values on gram/mile emissions projected by MOBILE5b. To model our control case, we projected the gram/mile emissions using the version of MOBILE5b which was modified to reflect the benefits of our proposed Tier 2 controls. We used gram/mile emission factors from 2030 to reflect a baseline fleet consisting entirely of Enhanced Evaporative vehicles, and a control fleet consisting of essentially all Tier 2 vehicles[6]. The evaporative tonnage values are presented in Appendix VI-B.

Table VI-3. Weighting Factors for NOx and NMHC Lifetime Tonnage Values

RFG program area?	*IM program area?*	*Fraction of population*
Yes	Yes	0.248
Yes	No	0.019
No	Yes	0.228
No	No	0.505

The final step before calculating the cost-effectiveness of our proposed program was to weight the discounted lifetime tonnage values for each vehicle class by their respective fraction of the fleet. These fractions were developed based on our projection that LDT sales will stabilize at 60 percent of the light-duty market by 2008. This value is based on sales data projected by auto manufacturers for 1998 model year certification. Table VI-4 presents the final weighting factors we used to develop fleet-average tonnage values.

Table VI-4. Vehicle Class Sales Weighting Factors

LDV	0.4
LDT1	0.11
LDT2	0.34
LDT3	0.10
LDT4	0.05

The final discounted lifetime tonnage values in the absence of sulfur irreversibility effects for an average fleet vehicle meeting either the standards for NLEV or our proposed Tier 2 standards are shown in Tables VI-5 and VI-6, respectively.

Table VI-5. Fleet-average, Per-vehicle Discounted Lifetime Tons for the NLEV Baseline

Sulfur (ppm)	*NOx (tons)*	*Exhaust NMHC (tons)*	*Evap NMHC (tons)*
800[gg]	0.13925	0.03623	0.04192
305	0.11295	0.03285	0.04192

Table VI-6. Fleet-average, Per-vehicle Discounted Lifetime Tons for Proposed Tier 2 Standards

Sulfur (ppm)	*NOx (tons)*	*Exhaust NMHC (tons)*	*Evap NMHC (tons)*
80	0.03557	0.02366	0.03887
30	0.02738	0.02247	0.03887

The values in Tables VI-5 and VI-6 were not used in the cost-effectiveness calculations directly. Instead, the effects of irreversibility were first calculated according to the methodology described in Section VI.C.2 below using the tonnage values from the tables above.

[gg] Tonnage values at 800 ppm and 80 ppm sulfur were used for estimating the impacts of irreversibility. See Section VI.C.2 for details.

2. Irreversibility

As described in Appendix B, we believe that vehicles meeting the SFTP and/or NLEV standards will exhibit an increased tendency towards sulfur poisoning of their catalysts. As a result of sulfur poisoning, catalyst efficiency is reduced and emissions increase. Since all vehicles are currently certified on low sulfur fuel, current in-use emissions can be expected to be higher than certification levels.

The increased emissions that result when an SFTP-compliant NLEV or Tier 2 vehicle is run on high sulfur fuel is a function of the "sulfur sensitivity" of the catalyst. This aspect of sulfur poisoning has been taken into account in our cost-effectiveness analysis by virtue of the fact that the change in lifetime tons reduced is a function of our proposed gasoline sulfur standard. The impacts of the sulfur sensitivities on emissions for pre-SFTP and post-SFTP compliant vehicles are described in an EPA Technical Report[7].

However, one aspect of sulfur poisoning requires special treatment in our cost-effectiveness analysis. In SFTP-compliant vehicles, some sulfur poisoning due to the use of high sulfur fuel often extends well beyond the time that high sulfur fuel is actually used. When an SFTP-compliant vehicle returns to using low sulfur gasoline after having been operated on high sulfur fuel, a degree of poisoning remains. This effect is termed "irreversibility," and is described in detail in Appendix B. We have estimated that the irreversibility effect for SFTP-compliant vehicles will be about 50 percent, meaning that 50 percent of the emission reductions that would otherwise occur when changing from high to low sulfur fuel are lost due to permanent sulfur poisoning of the catalyst. That is to say, 50 percent of the sensitivity effect is permanent or “irreversible” regardless of the fuel sulfur level.

Since our cost-effectiveness analysis makes use of emissions summed over the life of a vehicle, we must account for the fact that there may have been hundreds of refuelings in that time frame with repeated switches between low and high sulfur fuel. Since the higher sulfur fuels will be widely available, we expect vehicles to be exposed to such fuels early in their lives. As a result, the irreversibility effect will be present for most of these vehicles' lifetimes. Irreversibility effects on lifetime emissions can then be calculated as the difference between lifetime emissions at high sulfur fuel and lifetime emissions at the average fuel sulfur level.

While it is possible that the irreversibility effect can be reduced or eliminated under certain driving conditions, such as high temperature/high load driving, we believe that this is unlikely for SFTP-compliant vehicles. The data regarding catalyst cleanup conditions for future vehicles is quite limited. Lacking data to support the recovery of full catalyst functionality, our analysis treats irreversibility as a permanent effect.

Under our proposed gasoline sulfur program, the average sulfur level will be 30 ppm and the maximum allowable level will be 80 ppm. Per-vehicle lifetime emissions at these two sulfur levels were used to determine the effect of irreversibility on Tier 2 vehicles. The Tier 2 lifetime tonnage values for NOx and exhaust NMHC at 30 ppm, which included the effects of

irreversibility and which was actually used in our cost-effectiveness analysis, was calculated from the following equation:

$$ILE_{30} = (IE) \times (LE_{80} - LE_{30}) + LE_{30}$$

Where:

ILE_{30} = Irreversibility-impacted, discounted lifetime emissions of Tier 2 vehicles at 30 ppm sulfur in tons/vehicle, for each vehicle class
IE = Irreversibility impact, 0.50
LE_{80} = Discounted lifetime emissions of Tier 2 vehicles at 80 ppm sulfur in tons/vehicle, for each vehicle class
LE_{30} = Discounted lifetime emissions of Tier 2 vehicles at 30 ppm sulfur in tons/vehicle, for each vehicle class

For the NLEV vehicles forming our baseline, the average sulfur level was established as 305 ppm as described in Section VI.A.3 above. Apart from an ASTM maximum allowable value of 1000 ppm, there is no regulated in-use maximum value for gasoline sulfur. However, after the year 2000, we project that more than 95 percent of gasoline will contain sulfur levels below 800 ppm. We have therefore chosen 800 as the maximum sulfur level on which NLEV vehicles will be operated. It could be argued that 1000 ppm is a more appropriate value to represent the maximum (or even higher, as a few in-use batches of gasoline exceed the ASTM limit). We believe that a maximum of 800 ppm is more representative of the maximum sulfur level that the average NLEV vehicle will be operated on, since very few vehicles will ever see sulfur levels as high as 1000 ppm.

Per-vehicle lifetime emissions at 305 ppm and 800 ppm were used to determine the effect of irreversibility on vehicles meeting NLEV standards. Unlike for Tier 2 vehicles, however, NLEV standards only apply to LDV, LDT1, and LDT2, while LDT3 and LDT4 meet Tier 1 standards as well as the SFTP. As discussed in Appendix B, we believe that irreversibility applies to any SFTP-compliant vehicle, including Tier 1 vehicles produced after the year 2000. Thus the calculations followed the same procedure as that used for Tier 2 vehicles:

$$ILE_{305} = (IE) \times (LE_{800} - LE_{305}) + LE_{305}$$

Where:

ILE_{305} = Irreversibility-impacted, discounted lifetime emissions of SFTP-complaint NLEV vehicles at 305 ppm sulfur in tons/vehicle, for each vehicle class
IE = Irreversibility impact, 0.50
LE_{800} = Discounted lifetime emissions of NLEV vehicles at 800 ppm sulfur in tons/vehicle, for each vehicle class
LE_{305} = Discounted lifetime emissions of NLEV vehicles at 305 ppm sulfur in tons/vehicle, for each vehicle class

After assessing the impact of irreversibility on both Tier 2 and NLEV vehicles, we were able to develop a final set of discounted lifetime tonnage values that were actually used in our cost-effectiveness analysis. These values are given in Table VI-7.

Table VI-7. Fleet-average, Per-vehicle Discounted Lifetime Tons Used in Cost-effectiveness Analysis

	NOx (tons)	*Exhaust NMHC (tons)*	*Evap NMHC (tons)*	*Total NOx + NMHC (tons)*
Baseline: NLEV at 305 ppm	0.12610	0.03454	0.04192	0.20256
Proposal: Tier 2 at 30 ppm	0.03148	0.02307	0.04020	0.09475

3. Primary Particulate Matter

Vehicles meeting our proposed standards will produce reductions in both primary and secondary particulate matter. As described in Section VI.B.3 above, we are accounting for reductions in primary (sulfate) PM in our cost-effectiveness analysis. Although secondary PM reductions are not being accounted for in our cost-effectiveness analysis, they have been included in our analysis of the health and welfare benefits of our proposed program, as described in Section VII.

Primary PM emission reductions result from the removal of sulfur in gasoline, which produces a commensurate reduction in the amount of sulfate PM emitted from the tailpipe. To calculate the reduction, we have assumed that sulfate PM accounts for 1 percent of all sulfur exiting the tailpipe on a molar basis. Primary sulfate PM exists almost entirely as sulfuric acid, and is generally hydrated. We have assumed seven hydrations, consistent with the approach taken in the development of EPA's NON-ROAD emissions model.

Discounted lifetime tons of primary PM reduced as a result of our proposed gasoline sulfur standard are calculated according to the following equation:

$$LE = \sum [\{(AVMT)_i \times (SURVIVE)_i \div (FE) \times (D) \times (SUL) \times (F) \times (MC) \times (K)\}/(1.07)^{i-1}]$$

Where:

LE = Discounted lifetime emissions of primary PM in tons/vehicle
$(AVMT)_i$ = Annual vehicle miles traveled in year i of a vehicle's operational life
$(SURVIVE)_i$ = Fraction of vehicles still operating after i years of service
FE = Fuel economy by vehicle class (see Section VI.B.4)

D	= Density of gasoline, 6.17 lb/gal
SUL	= Change in gasoline sulfur concentration, 2.75×10^{-4} lb sulfur/lb fuel (275 ppm)
F	= Fraction of total sulfur which exits the tailpipe as primary PM, 0.01
MC	= Molar conversion factor, 7 lb sulfuric acid per lb sulfur
K	= Conversion factor, 5.0×10^{-4} tons/lb
i	= Vehicle years of operation, counting from 1 to 25

After applying the above equation separately for each vehicle class and weighting the resulting tonnage values according to the factors presented in Table VI-4, we determined that the fleet-average, per-vehicle discounted lifetime tons of primary PM reduced is 0.000396. This is the value that was used to determine the PM-based credit that was applied to the total costs as described in Section VI.B.3 and summarized in Table VI-2.

4. Sulfur Dioxide

The sulfur contained in gasoline exists the tailpipe as either sulfuric acid, a component of primary particulate matter, or as sulfur dioxide (SO_2). As described in Section VI.C.2 above, we have assumed that sulfate PM, as hydrated sulfuric acid, accounts for 1 percent of all sulfur exiting the tailpipe on a molar basis. Thus the remaining 99 percent of sulfur exiting the tailpipe is in the form of SO_2.

Discounted lifetime tons of SO_2 reduced as a result of our proposed gasoline sulfur standard are calculated according to the following equation:

$$LE = \sum [\{(AVMT)_i \times (SURVIVE)_i \div (FE) \times (D) \times (SUL) \times (F) \times (MC) \times (K)\}/(1.07)^{i-1}]$$

Where:

LE	= Discounted lifetime emissions of SO_2 in tons/vehicle
$(AVMT)_i$	= Annual vehicle miles traveled in year i of a vehicle's operational life
$(SURVIVE)_i$	= Fraction of vehicles still operating after i years of service
FE	= Fuel economy by vehicle class (see Section VI.B.4)
D	= Density of gasoline, 6.17 lb/gal
SUL	= Change in gasoline sulfur concentration, 2.75×10^{-4} lb sulfur/lb fuel (275 ppm)
F	= Fraction of total sulfur which exits the tailpipe as SO_2, 0.99
MC	= Molar conversion factor, 2 lb SO_2 per lb sulfur
K	= Conversion factor, 5.0×10^{-4} tons/lb
i	= Vehicle years of operation, counting from 1 to 25

After applying the above equation separately for each vehicle class and weighting the resulting tonnage values according to the factors presented in Table VI-4, we determined that the fleet-average, per-vehicle discounted lifetime tons of SO_2 reduced is 0.01119. This is the value that was used to determine the SO_2-based credit that was applied to the total costs as described in Section VI.B.3 and summarized in Table VI-2.

D. Results

We calculated the cost-effectiveness of our proposed standards for Tier 2 exhaust, Tier 2 evaporative, and gasoline sulfur as the total per-vehicle, discounted lifetime costs divided by the total per-vehicle, discounted lifetime tons reduced. Costs are given in Table VI-2. The tons reduced are calculated from the values in Table VI-7 as the difference between our NLEV baseline at our baseline sulfur level of 305 ppm, and our proposed Tier 2 standards at our proposed sulfur standard of 30 ppm. The results are given in Table VI-8.

Table VI-8. Cost-effectiveness of the Proposed Standards

	Credited costs ($)	*Uncredited costs ($)*	*Tons NOx+NMHC*	*Credited $/ton*	*Uncredited $/ton*
Near term	172.37	230.06	0.10781	1599	2134
Long term	130.74	188.43	0.10781	1213	1748

We also evaluated the cost effectiveness of a number of alternative control options using the methodology described in this Section. The options evaluated were:

- The proposed Tier 2 emission standards with no reduction in gasoline sulfur levels;

- The proposed Tier 2 emission standards with the sulfur controls proposed by API and NPRA, which include average sulfur standards of 150 ppm in the NOx Control Region (nominally the eastern two-thirds of the U.S.) and 300 ppm elsewhere (i.e., the West) starting in 2004;

- The proposed Tier 2 emission standards with average sulfur standard of 30 ppm in API/NPRA NOx Control Region and 150 ppm in the West starting in 2004;

- The proposed Tier 2 emission standards with an 80 ppm nationwide sulfur standard starting in 2004;

- The proposed 30 ppm nationwide sulfur standard with California Phase 2 LEV emission standards (excluding the ZEV mandate); because these standards change from year to year, we chose to evaluate the 2010 model year standards;

All of these alternative control options are evaluated relative to the same baseline which was used to evaluate the cost effectiveness of the proposed Tier 2 and sulfur standards. The results are shown in Table VI-9 below.

Table VI-9. Alternative program options evaluated by EPA

	Credited costs ($)	*Uncredited costs ($)*	*Tons NOx+NMHC*	*Credited $/ton*	*Uncredited $/ton*
Tier 2 vehicle standards with 80 ppm nationwide					
Near term	155.37	202.58	0.09921	1566	2042
Long term	115.63	162.84	0.09921	1166	1641
Tier 2 vehicle standards with no change in sulfur					
Near term	128.14	128.14	0.07319	1751	1751
Long term	93.57	93.57	0.07319	1278	1278
Tier 2 vehicle standards with 150 ppm in API region, 300 ppm in non-API region					
Near term	136.80	161.81	0.08719	1569	1856
Long term	99.89	124.90	0.08719	1146	1433
Tier 2 vehicle standards with 30 ppm in API region, 150 ppm in non-API region					
Near term	165.20	216.57	0.10263	1610	2110
Long term	124.51	175.88	0.10263	1213	1714
California LEV-II NMOG emission standards with 30 ppm nationwide					
Near term	205.02	262.70	0.11168	1836	2352
Long term	158.75	216.43	0.11168	1421	1938

As can be seen, the cost effectiveness of the five alternatives are all quite similar to that of the proposed program. The long-term credited cost per ton of the alternatives are all within $50 per ton of that for the proposed program, with the exception of the California LEV-II NMOG standards. The long-term credited cost effectiveness of this program is roughly $150 per ton higher than that of the proposed program. For reasons cited elsewhere in this Draft RIA and in the preamble to the proposed rule, EPA chose not to propose any of these alternative control programs in lieu of the proposed standards.

Because the primary purpose of cost-effectiveness is to compare our proposed program to alternative programs, we made a comparison between the values in Table VI-8 and the cost-effectiveness of other programs. Table VI-10 summarizes the cost effectiveness of several recent EPA actions for controlled emissions from mobile sources.

Table VI-10. Cost-effectiveness of Previously Implemented Mobile Source Programs (Costs Adjusted to 1997 Dollars)

Program	*$/ton NOx+NMHC*
2004 Highway HD Diesel stds	300
Non-road Diesel engine stds	410-650
Tier 1 vehicle controls	1,980-2,690[gg]
NLEV	1,859
Marine SI engines	1,128-1,778
On-board diagnostics	2,228

By comparing the values from Table VI-8 to those in Table VI-10, we can see that the cost effectiveness of the Tier 2/gasoline sulfur standards falls within the range of these other programs. Engine-based standards (the 2004 highway heavy-duty diesel standards, the non-road diesel engine standards and the marine spark-ignited engine standards) have generally been less costly than our proposed Tier 2/gasoline sulfur standards. Vehicle standards, most similar to today's proposal, have comparable or higher values than our proposed Tier 2/gasoline sulfur program.

The primary advantage of making comparisons to previously implemented programs is that their cost-effectiveness values were based on a rigorous analysis and are generally accepted as representative of the efficiency with which those programs reduce emissions. Unfortunately, previously implemented programs can be poor comparisons because they may not be representative of the cost-effectiveness of potential future programs. For instance, it is tempting to look at the engine standards and conclude that more reductions at a similar low cost effectiveness should still be available. This is especially true for the two largest categories (highway and non-road diesel engines) where new standards have been adopted that were highly cost effective. However, cost effectiveness was not a limiting consideration in either case. Rather, the level of the standards selected was based on technical feasibility in the time available.

We do not believe that significant further control is available from highway or non-road

[gg] Cost-effectiveness of Tier 1 standards was originally calculated separately for NOx and NMHC. A combined cost-effectiveness was recalculated for our proposal. See internal memorandum from David Korotney to Docket A-97-10, "Calculation of Tier 1 vehicle cost-effectiveness in terms of $/ton NOx+NMHC," document number II-B-03.

diesel engines through more stringent standards at the cost effectiveness levels shown in Table VI-10. Based on current knowledge, the next generation of controls for these diesel engines would require advanced after-treatment devices, still in the research and development phase. Such controls have not yet been employed and when they become available will be more costly and will have difficulty functioning without changes to diesel fuel.

On the vehicle side, the last two sets of standards were Tier 1 and NLEV, which had cost effectiveness comparable to or higher than our proposed Tier 2/gasoline sulfur standards. Compared to engines, these levels reflect the advanced (and more expensive) state of vehicle control technology, where standards have been in effect for a much longer period than for engines. Based on these results, Tier 2/gasoline sulfur appears to be a logical and consistent next step in vehicle control.

The most complete source of information on the cost-effectiveness of potential future programs is the rulemaking which revised the PM and ozone National Ambient Air Quality Standards (NAAQS). The Regulatory Impact Analysis (RIA) associated with that rulemaking contained a listing of potential future emission control programs and their cost-effectiveness[8]. The listing categorizes control programs by mobile, point, and area source strategies for a total of 236 potential future programs. Although the majority of the programs in this list would most likely be implemented on a local or regional basis, they still provide the most complete information available on alternative programs and their associated cost-effectiveness.

Of the 236 potential future programs in the NAAQS RIA, 112 produced NOx reductions with an average cost-effectiveness of $13,000/ton, while 55 programs produced NMHC reductions with an average cost-effectiveness of $5,000/ton. These values confirm that future controls will be more expensive than past controls. In fact, for the purposes of evaluating the capability of potential future controls for bringing all areas into attainment, an upper limit of $10,000/ton was established. As a result of the analyses conducted in the context of the NAAQS revisions rulemaking, it was determined that some areas would be willing to pay up to $10,000/ton for local control measures in order to achieve attainment.

We recognize that the cost effectiveness calculated for our proposed program is not strictly comparable to the $10,000/ton limit established in the NAAQS analyses since the technologies identified there can be targeted at the specific nonattainment areas of concern, while the proposed Tier 2/gasoline sulfur program would apply nationwide. However, we are not using cost effectiveness to portray Tier 2 as a control strategy to select as an alternative to local controls because of its lower cost effectiveness. Rather, the program we are proposing today is likely one of several programs, both national and local in nature, that will be necessary for attainment and maintenance of the NAAQS.

In summary, given the array of controls that will have to be implemented to make progress toward attaining and maintaining the NAAQS, we believe that the weight of the evidence from alternative means of providing substantial NOx + NMHC emission reductions indicates that our Tier 2/gasoline sulfur proposal is cost-effective. This is true from the perspective of other mobile source control programs or from the perspective of other stationary

source technologies that might be considered.

APPENDIX VI-A : Discounted Lifetime Tonnage Values for Exhaust Emissions

Standard	Veh clas	IM case	Sulfur	Fuel	NOx tons	NMHC tons
NLEV	LDT1	IM	30	Conventional	0.04614	0.01839
NLEV	LDT1	IM	80	Conventional	0.06296	0.01989
NLEV	LDT1	IM	330	Conventional	0.10032	0.02252
NLEV	LDT1	IM	800	Conventional	0.13343	0.02424
NLEV	LDT1	IM	30	RFG	0.04494	0.01565
NLEV	LDT1	IM	80	RFG	0.06132	0.01694
NLEV	LDT1	IM	150	RFG	0.07523	0.01787
NLEV	LDT1	IM	300	RFG	0.09463	0.01901
NLEV	LDT1	IM	800	RFG	0.12953	0.02061
NLEV	LDT1	No IM	30	Conventional	0.06646	0.03540
NLEV	LDT1	No IM	80	Conventional	0.08716	0.03669
NLEV	LDT1	No IM	330	Conventional	0.13312	0.03906
NLEV	LDT1	No IM	800	Conventional	0.18824	0.04059
NLEV	LDT1	No IM	30	RFG	0.06478	0.03000
NLEV	LDT1	No IM	80	RFG	0.08495	0.03110
NLEV	LDT1	No IM	150	RFG	0.10209	0.03192
NLEV	LDT1	No IM	300	RFG	0.12597	0.03297
NLEV	LDT1	No IM	800	RFG	0.16619	0.03424
NLEV	LDT2	IM	30	Conventional	0.07705	0.02205
NLEV	LDT2	IM	80	Conventional	0.08783	0.02329
NLEV	LDT2	IM	330	Conventional	0.10639	0.02535
NLEV	LDT2	IM	800	Conventional	0.11983	0.02668
NLEV	LDT2	IM	30	RFG	0.07503	0.01878
NLEV	LDT2	IM	80	RFG	0.08552	0.01984
NLEV	LDT2	IM	150	RFG	0.09307	0.02059
NLEV	LDT2	IM	300	RFG	0.10225	0.02147
NLEV	LDT2	IM	800	RFG	0.11660	0.02271
NLEV	LDT2	No IM	30	Conventional	0.09894	0.03943
NLEV	LDT2	No IM	80	Conventional	0.11092	0.04051
NLEV	LDT2	No IM	330	Conventional	0.13155	0.04241
NLEV	LDT2	No IM	800	Conventional	0.14896	0.04306
NLEV	LDT2	No IM	30	RFG	0.09642	0.03344
NLEV	LDT2	No IM	80	RFG	0.10809	0.03436
NLEV	LDT2	No IM	150	RFG	0.11650	0.03502
NLEV	LDT2	No IM	300	RFG	0.12671	0.03586
NLEV	LDT2	No IM	800	RFG	0.14218	0.03688
NLEV	LDT3	IM	30	Conventional	0.15696	0.05429
NLEV	LDT3	IM	80	Conventional	0.15929	0.05585
NLEV	LDT3	IM	330	Conventional	0.17147	0.06451
NLEV	LDT3	IM	800	Conventional	0.18512	0.07818
NLEV	LDT3	IM	30	RFG	0.15282	0.04632
NLEV	LDT3	IM	80	RFG	0.15508	0.04765
NLEV	LDT3	IM	150	RFG	0.15830	0.04960
NLEV	LDT3	IM	300	RFG	0.16546	0.05410
NLEV	LDT3	IM	800	RFG	0.17755	0.06646
NLEV	LDT3	No IM	30	Conventional	0.18307	0.07525
NLEV	LDT3	No IM	80	Conventional	0.18545	0.07659
NLEV	LDT3	No IM	330	Conventional	0.19794	0.08400
NLEV	LDT3	No IM	800	Conventional	0.22195	0.09850
NLEV	LDT3	No IM	30	RFG	0.17836	0.06396
NLEV	LDT3	No IM	80	RFG	0.18068	0.06510

NLEV	LDT3	No IM	150	RFG	0.18399	0.06677
NLEV	LDT3	No IM	300	RFG	0.19134	0.07062
NLEV	LDT3	No IM	800	RFG	0.20478	0.08046
NLEV	LDT4	IM	30	Conventional	0.23321	0.06443
NLEV	LDT4	IM	80	Conventional	0.23669	0.06632
NLEV	LDT4	IM	330	Conventional	0.25494	0.07682
NLEV	LDT4	IM	800	Conventional	0.28329	0.09441
NLEV	LDT4	IM	30	RFG	0.22703	0.05498
NLEV	LDT4	IM	80	RFG	0.23042	0.05659
NLEV	LDT4	IM	150	RFG	0.23525	0.05895
NLEV	LDT4	IM	300	RFG	0.24598	0.06442
NLEV	LDT4	IM	800	RFG	0.27546	0.08026
NLEV	LDT4	No IM	30	Conventional	0.26188	0.08646
NLEV	LDT4	No IM	80	Conventional	0.26534	0.08807
NLEV	LDT4	No IM	330	Conventional	0.28349	0.09702
NLEV	LDT4	No IM	800	Conventional	0.30934	0.11431
NLEV	LDT4	No IM	30	RFG	0.25512	0.07351
NLEV	LDT4	No IM	80	RFG	0.25849	0.07489
NLEV	LDT4	No IM	150	RFG	0.26330	0.07690
NLEV	LDT4	No IM	300	RFG	0.27397	0.08155
NLEV	LDT4	No IM	800	RFG	0.30272	0.09452
NLEV	LDV	IM	30	Conventional	0.03043	0.01124
NLEV	LDV	IM	80	Conventional	0.04183	0.01224
NLEV	LDV	IM	330	Conventional	0.06714	0.01400
NLEV	LDV	IM	800	Conventional	0.08982	0.01517
NLEV	LDV	IM	30	RFG	0.02963	0.00957
NLEV	LDV	IM	80	RFG	0.04073	0.01043
NLEV	LDV	IM	150	RFG	0.05016	0.01106
NLEV	LDV	IM	300	RFG	0.06330	0.01182
NLEV	LDV	IM	800	RFG	0.08723	0.01291
NLEV	LDV	No IM	30	Conventional	0.03939	0.01892
NLEV	LDV	No IM	80	Conventional	0.05250	0.01983
NLEV	LDV	No IM	330	Conventional	0.08161	0.02146
NLEV	LDV	No IM	800	Conventional	0.11664	0.02264
NLEV	LDV	No IM	30	RFG	0.03839	0.01605
NLEV	LDV	No IM	80	RFG	0.05116	0.01683
NLEV	LDV	No IM	150	RFG	0.06201	0.01740
NLEV	LDV	No IM	300	RFG	0.07713	0.01812
NLEV	LDV	No IM	800	RFG	0.10329	0.01903
Tier 2	LDT1	IM	30	Conventional	0.02183	0.01839
Tier 2	LDT1	IM	80	Conventional	0.02903	0.01989
Tier 2	LDT1	IM	330	Conventional	0.04500	0.02252
Tier 2	LDT1	IM	800	Conventional	0.05863	0.02470
Tier 2	LDT1	IM	30	RFG	0.02128	0.01565
Tier 2	LDT1	IM	80	RFG	0.02828	0.01694
Tier 2	LDT1	IM	150	RFG	0.03424	0.01787
Tier 2	LDT1	IM	300	RFG	0.04253	0.01901
Tier 2	LDT1	IM	800	RFG	0.05683	0.02055
Tier 2	LDT1	No IM	30	Conventional	0.04163	0.03540
Tier 2	LDT1	No IM	80	Conventional	0.05338	0.03669
Tier 2	LDT1	No IM	330	Conventional	0.07948	0.03906
Tier 2	LDT1	No IM	800	Conventional	0.11031	0.04041
Tier 2	LDT1	No IM	30	RFG	0.04060	0.03000
Tier 2	LDT1	No IM	80	RFG	0.05206	0.03110
Tier 2	LDT1	No IM	150	RFG	0.06180	0.03192
Tier 2	LDT1	No IM	300	RFG	0.07537	0.03297
Tier 2	LDT1	No IM	800	RFG	0.09735	0.03416
Tier 2	LDT2	IM	30	Conventional	0.02033	0.01832
Tier 2	LDT2	IM	80	Conventional	0.02685	0.01982

Tier 2	LDT2	IM	330	Conventional	0.04133	0.02242
Tier 2	LDT2	IM	800	Conventional	0.05357	0.02459
Tier 2	LDT2	IM	30	RFG	0.01982	0.01559
Tier 2	LDT2	IM	80	RFG	0.02617	0.01687
Tier 2	LDT2	IM	150	RFG	0.03157	0.01780
Tier 2	LDT2	IM	300	RFG	0.03909	0.01893
Tier 2	LDT2	IM	800	RFG	0.05191	0.02045
Tier 2	LDT2	No IM	30	Conventional	0.04101	0.03535
Tier 2	LDT2	No IM	80	Conventional	0.05236	0.03663
Tier 2	LDT2	No IM	330	Conventional	0.07756	0.03898
Tier 2	LDT2	No IM	800	Conventional	0.10723	0.04033
Tier 2	LDT2	No IM	30	RFG	0.04000	0.02996
Tier 2	LDT2	No IM	80	RFG	0.05106	0.03105
Tier 2	LDT2	No IM	150	RFG	0.06047	0.03187
Tier 2	LDT2	No IM	300	RFG	0.07357	0.03291
Tier 2	LDT2	No IM	800	RFG	0.09464	0.03413
Tier 2	LDT3	IM	30	Conventional	0.02730	0.02130
Tier 2	LDT3	IM	80	Conventional	0.03626	0.02302
Tier 2	LDT3	IM	330	Conventional	0.05614	0.02602
Tier 2	LDT3	IM	800	Conventional	0.07307	0.02848
Tier 2	LDT3	IM	30	RFG	0.02661	0.01813
Tier 2	LDT3	IM	80	RFG	0.03533	0.01960
Tier 2	LDT3	IM	150	RFG	0.04274	0.02066
Tier 2	LDT3	IM	300	RFG	0.05307	0.02197
Tier 2	LDT3	IM	800	RFG	0.07083	0.02369
Tier 2	LDT3	No IM	30	Conventional	0.05087	0.04114
Tier 2	LDT3	No IM	80	Conventional	0.06519	0.04260
Tier 2	LDT3	No IM	330	Conventional	0.09700	0.04528
Tier 2	LDT3	No IM	800	Conventional	0.13467	0.04681
Tier 2	LDT3	No IM	30	RFG	0.04961	0.03486
Tier 2	LDT3	No IM	80	RFG	0.06358	0.03611
Tier 2	LDT3	No IM	150	RFG	0.07544	0.03703
Tier 2	LDT3	No IM	300	RFG	0.09198	0.03822
Tier 2	LDT3	No IM	800	RFG	0.11874	0.03979
Tier 2	LDT4	IM	30	Conventional	0.02970	0.02152
Tier 2	LDT4	IM	80	Conventional	0.03954	0.02326
Tier 2	LDT4	IM	330	Conventional	0.06139	0.02631
Tier 2	LDT4	IM	800	Conventional	0.08008	0.02883
Tier 2	LDT4	IM	30	RFG	0.02894	0.01831
Tier 2	LDT4	IM	80	RFG	0.03853	0.01981
Tier 2	LDT4	IM	150	RFG	0.04667	0.02089
Tier 2	LDT4	IM	300	RFG	0.05802	0.02221
Tier 2	LDT4	IM	800	RFG	0.07763	0.02398
Tier 2	LDT4	No IM	30	Conventional	0.05402	0.04138
Tier 2	LDT4	No IM	80	Conventional	0.06935	0.04286
Tier 2	LDT4	No IM	330	Conventional	0.10338	0.04559
Tier 2	LDT4	No IM	800	Conventional	0.14375	0.04714
Tier 2	LDT4	No IM	30	RFG	0.05268	0.03506
Tier 2	LDT4	No IM	80	RFG	0.06763	0.03633
Tier 2	LDT4	No IM	150	RFG	0.08032	0.03728
Tier 2	LDT4	No IM	300	RFG	0.09802	0.03848
Tier 2	LDT4	No IM	800	RFG	0.12673	0.04006
Tier 2	LDV	IM	30	Conventional	0.01364	0.01124
Tier 2	LDV	IM	80	Conventional	0.01831	0.01224
Tier 2	LDV	IM	330	Conventional	0.02868	0.01400
Tier 2	LDV	IM	800	Conventional	0.03766	0.01556
Tier 2	LDV	IM	30	RFG	0.01328	0.00957
Tier 2	LDV	IM	80	RFG	0.01783	0.01043
Tier 2	LDV	IM	150	RFG	0.02170	0.01106

Tier 2	LDV	IM	300	RFG	0.02709	0.01182
Tier 2	LDV	IM	800	RFG	0.03653	0.01293
Tier 2	LDV	No IM	30	Conventional	0.02237	0.01892
Tier 2	LDV	No IM	80	Conventional	0.02905	0.01983
Tier 2	LDV	No IM	330	Conventional	0.04389	0.02146
Tier 2	LDV	No IM	800	Conventional	0.06155	0.02244
Tier 2	LDV	No IM	30	RFG	0.02181	0.01605
Tier 2	LDV	No IM	80	RFG	0.02832	0.01683
Tier 2	LDV	No IM	150	RFG	0.03386	0.01740
Tier 2	LDV	No IM	300	RFG	0.04157	0.01812
Tier 2	LDV	No IM	800	RFG	0.05435	0.01930

APPENDIX VI-B : Discounted Lifetime Tonnage Values for Evaporative Emissions

Standard	Veh class	IM case	Fuel	NMHC tons
2.0 gpt enhanced	LDT1	IM	Conventional	0.02835
2.0 gpt enhanced	LDT1	IM	RFG	0.01793
2.0 gpt enhanced	LDT1	No IM	Conventional	0.06791
2.0 gpt enhanced	LDT1	No IM	RFG	0.03537
2.0 gpt enhanced	LDT2	IM	Conventional	0.02835
2.0 gpt enhanced	LDT2	IM	RFG	0.01793
2.0 gpt enhanced	LDT2	No IM	Conventional	0.06791
2.0 gpt enhanced	LDT2	No IM	RFG	0.03537
2.0 gpt enhanced	LDT3	IM	Conventional	0.03216
2.0 gpt enhanced	LDT3	IM	RFG	0.01972
2.0 gpt enhanced	LDT3	No IM	Conventional	0.08730
2.0 gpt enhanced	LDT3	No IM	RFG	0.04301
2.0 gpt enhanced	LDT4	IM	Conventional	0.03216
2.0 gpt enhanced	LDT4	IM	RFG	0.01972
2.0 gpt enhanced	LDT4	No IM	Conventional	0.08730
2.0 gpt enhanced	LDT4	No IM	RFG	0.04301
2.0 gpt enhanced	LDV	IM	Conventional	0.02184
2.0 gpt enhanced	LDV	IM	RFG	0.01208
2.0 gpt enhanced	LDV	No IM	Conventional	0.04722
2.0 gpt enhanced	LDV	No IM	RFG	0.02268
Tier 2	LDT1	IM	Conventional	0.02612
Tier 2	LDT1	IM	RFG	0.01622
Tier 2	LDT1	No IM	Conventional	0.06595
Tier 2	LDT1	No IM	RFG	0.03389
Tier 2	LDT2	IM	Conventional	0.02612
Tier 2	LDT2	IM	RFG	0.01622
Tier 2	LDT2	No IM	Conventional	0.06595
Tier 2	LDT2	No IM	RFG	0.03389
Tier 2	LDT3	IM	Conventional	0.02994
Tier 2	LDT3	IM	RFG	0.01797
Tier 2	LDT3	No IM	Conventional	0.08551
Tier 2	LDT3	No IM	RFG	0.04168
Tier 2	LDT4	IM	Conventional	0.02994
Tier 2	LDT4	IM	RFG	0.01797
Tier 2	LDT4	No IM	Conventional	0.08551
Tier 2	LDT4	No IM	RFG	0.04168
Tier 2	LDV	IM	Conventional	0.02028
Tier 2	LDV	IM	RFG	0.01101
Tier 2	LDV	No IM	Conventional	0.04567
Tier 2	LDV	No IM	RFG	0.02158

Chapter VI. References

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2. "Final Regulatory Impact Analysis: Control of Emissions of Air Pollution from Highway Heavy-Duty Engines." September 16, 1997. Alan Stout, U.S. EPA, OAR/OMS/EPCD.

3. "Control of Air Pollution from New Motor Vehicles and New Motor Vehicle Engines; Particulate Emission Regulations for 1993 Model Year Buses, Particulate Emission Regulations for 1994 and Later Model Year Urban Buses, Test Procedures for Urban Buses, and Oxides of Nitrogen Emission Regulations for 1998 and Later Model Year Heavy-Duty Engines." March 24,1993. 58 FR 15781.

4. “Updated Vehicle Survivability and Travel Mileage Schedules”, November 1995, U.S. Department of Transportation / National Highway Traffic Safety Administration (NHTSA). Tables 10-13. EPA Air Docket A-97-10.

5. See memorandum from David J. Korotney to EPA Air Docket A-97-10, "Nationwide and regional population fractions," document No. II-B-07.

6. “Development of Light-Duty Emission Inventory Estimates in the Notice of Proposed Rulemaking for Tier 2 and Sulfur Standards”, Koupal. EPA Report No. EPA420-R-99-005.

7. "Development of Light-Duty Emission Inventory Estimates in the Notice of Proposed Rulemaking for Tier 2 and Sulfur Standards," Koupal. EPA Air Docket A-97-10.

8. Regulatory Impact Analysis for final rule revising the NAAQS for PM and ozone. Appendix B, "Summary of control measures in the PM, regional haze, and ozone partial attainment analyses." Contact: Scott Mathias, U.S. EPA, OAR/OAQPS.

Chapter VII: Benefit-Cost Analysis

While relative cost-effectiveness is the principal economic policy criterion established for potential Tier 2 standards in the Clean Air Act, further insight regarding the merits of the proposed standards can be provided by benefit-cost analysis (BCA). In its traditional application, BCA estimates the economic "efficiency" of proposed standards by defining and quantifying the various expected consequences and representing those consequences in terms of dollars. Expressing the effects of the potential standards in dollar terms provides a means for comparing the expected benefits of our proposed standards to the expected costs.

The basic question we sought to answer in the BCA was: "What are the net yearly economic benefits to society of the reduction in mobile source emissions likely to be achieved by today's proposed standards?" In designing an analysis to answer this question, we adopted an analytical structure and sequence similar to that used in the so-called "Section 812 studies"[hh] to estimate the total benefits and costs of the entire Clean Air Act. Moreover, we used many of the same data sets, models, and assumptions actually used in the Section 812 studies and/or the recent Regulatory Impact Analyses (RIAs) for the PM and Ozone NAAQS, and the NO_x SIP Call.[ii] By adopting the major design elements, data sets, models, and assumptions developed for recent RIAs, we have largely relied on methods which have already received review by other Federal Agencies, and the public. Furthermore, the data sets adopted from the Section 812 studies have received extensive review by the independent Science Advisory Board and the public.

The BCA that we performed for our proposed standards can be thought of as having four parts, each of which will be discussed separately in the Sections that follow. These four steps are:

1. Calculation of the impact that our proposed standards will have on the nationwide inventories for NOx, NMHC, SO_2, and PM.

2. Air quality modeling to determine the changes in ambient concentrations of various pollutants that will result from our proposed standards.

3. A benefits analysis to determine the changes in human health and welfare, both in terms of number of incidences and monetary value, that result from the changes in ambient concentrations of various pollutants.

[hh] The "Section 812 studies" refers to (1) USEPA, Report to Congress: The Benefits and Costs of the Clean Air Act, 1970 to 1990, October 1997 (also known as the "Section 812 Retrospective); and (2) the first in the ongoing series of prospective studies estimating the total costs and benefits of the Clean Air Act, expected to be published later in 1999.

[ii] "Regulatory Impact Analysis for the NO_x SIP Call, FIP, and Section 126 Petitions" September 1998, EPA-452/R-98-003

4. Calculation of the costs of our proposed standards for purposes of comparison to the monetized benefits.

Our BCA does contain a number of limitations common to all BCAs. Critical limitations on the availability, validity, or reliability of data; limitations in the scope and capabilities of environmental and economic effect models; and controversies and uncertainties surrounding key underlying scientific and economic literature all contribute to an inability to estimate the economic effects of environmental policy changes in exact and unambiguous terms. Under these circumstances, we consider it most appropriate to view BCA as a tool to inform, but not dictate, regulatory decisions such as the ones reflected in today's proposal. The limitations of the assessment of benefits will be discussed in each of the following Sections as appropriate.

Despite these important uncertainties, we believe the preliminary BCA is indicative of the range of benefits and costs associated with the standards proposed today. This is because the analysis focuses on estimating the economic effects of the changes in air quality conditions expected to result from today's proposed rules, rather than focusing on developing a precise prediction of the absolute levels of air quality likely to prevail at some particular time in the future. An analysis focusing on the changes in air quality can give useful insights into the likely economic effects of emissions reductions of the magnitude expected to result from today's proposed rule.

A. Emissions

In order to determine the air quality impact of our proposed standards, we first calculated the reductions in vehicle emissions that are expected to occur as a result of those standards, and then determined the impact of those emission reductions on the nationwide[jj] inventories for NOx, NMHC, SO2, and PM. This Section describes how these inventory impacts were determined.

Our analysis used the Section 812 post-CAAA scenario for 2010 as the baseline emission estimates. This baseline inventory was also used to produce the control inventory through the application of the estimated changes in emissions associated with our proposed Tier 2 rule.[kk] We also updated the fugitive dust PM_{10} and $PM_{2.5}$ emissions for the Section 812 inventory using the National Pollutant Inventory in order to reflect significant changes to the base year methodologies for fugitive dust categories. These changes reduced the estimates of primary PM emissions. Fugitive dust PM_{10} and $PM_{2.5}$ emitters whose 1990 emissions estimates were revised include agricultural tilling, paved and unpaved roads, prescribed burning, construction activity,

[jj] For the purposes of air quality modeling, 'nationwide' is taken to mean the contiguous 48-states. Also, the proposed Tier 2/gasoline sulfur standards are assumed to have no effect on vehicle emissions in California, though air quality in California may be affected through meteorological boundary conditions.

[kk] Preparation of the baseline inventory is described in some detail by Woolfolk et al. (1998). E.H. Pechan (1999) provide emissions data reflecting the incorporation of the Tier 2 rule.

and wind erosion.

The Tier 2/gasoline sulfur program we are proposing has various emission-related components which begin at various times and in some cases phase in over time. This means that during the early years of the program there will not be a consistent match between costs and benefits. This is due to the fact that the full vehicle cost is incurred at the time of vehicle purchase, while the fuel cost along with the emission reductions and benefits occur throughout the lifetime of the vehicle. In order to more appropriately match the costs and emission reductions of our proposed program, therefore, our BCA assumes some future year when the fleet is fully turned over. For today's proposal this stability does not occur until well into the future. However, for the purpose of the benefit calculations, we have no available baseline data set beyond the year 2010, since the Section 812 inventory was developed only for this year. We have therefore made adjustments to allow the use of 2010 as a surrogate for a future year in which the fleet consists entirely of Tier 2 vehicles.

For emissions, we calculated reductions by treating 2010 as if the fleet had already turned over. We did this by applying the control case emission reductions from a fully turned over fleet (for the year 2040) to the fleet mileages for this year. Clearly, this approach does not, nor is it intended to, predict actual expected emission reductions for 2010. This is not its purpose. It is intended to portray the characteristics of the vehicle fleet after it is fully turned over, within the constraint that 2010 was the latest year for which we could perform the analysis.

The resulting analysis represents a snapshot of benefits and costs in a future year in which the light-duty fleet consists entirely of Tier 2 vehicles. As such, it depicts the maximum emission reductions (and resultant benefits) and among the lowest costs that would be achieved in any one year by the program on a "per mile" basis. (Note, however, that net benefits would continue to grow over time beyond those resulting from this analysis, but only because of growth in vehicle miles traveled.) Thus, based on the long-term costs for a fully turned over fleet, the resulting benefit-cost ratio will be close to its maximum point (for those benefits which we have been able to value).

At the time that we undertook the development of the benefit estimates for this rule, we did not have quantitative estimates of the VOC emission reductions that would result from the evaporative emission standards in the proposal. Therefore, the benefit estimates do not include the value of the evaporative emission standard. Consistent with this, the program cost estimates also exclude the evaporative emission control cost. Since the evaporative emission reductions and costs are both relatively small compared to the rest of the program, they are not expected to significantly affect the overall cost-benefit ratio.

For the purposes of assessing benefits, we estimated that the proposed Tier 2/gasoline sulfur standards would reduce NMHC emissions by 214,443 tons and NO_x emissions 1,789,318 tons for a hypothetical fully turned-over fleet of light-duty gasoline vehicles and trucks (Korotney, 1998). These reductions would occur in all States except California, which already meets this standard. Measured from the Section 812 2010 post-CAA scenario emission estimates for highway vehicles, these reductions translate into a 6.1 percent and 48.9 percent

annual reduction in VOC and NO_x emissions, respectively, for these States and vehicle categories. These percent reductions were used to estimate the 47-State VOC and NO_x emission reductions from light-duty vehicles and trucks in every county. Reductions (based on percent VOC) were also used to estimate the soluble organic aerosol (SOA) emissions.

A reduction to the SO_2 inventory was also made to account for expected gasoline sulfur reduction. SO_2 reductions are based on reducing the gasoline sulfur content from 330 parts per million (ppm) to 30 ppm. There are some uncertainties introduced by the SO_2 emission estimation methods. For one, the baseline emission estimates do not account for the lower sulfur levels in Federal or California reformulated gasoline. Thus, the baseline emission estimates likely overestimate gasoline vehicle emitted SO_2 nationwide by about 10 percent (in comparison to the combined conventional + reformulated gasoline baseline sulfur of 305 ppm, as described in Section VI.A.2), and in California by a factor of 10 (in comparison to their average sulfur limit of 30 ppm). These differences are expected to have only a modest impact on SO_2 benefits attributed to the Tier 2 rule, however, because no motor vehicle SO_2 benefit was estimated for California, and 47 State benefits are only slightly overstated in Federal reformulated gasoline areas.

Table VII-1 summarizes the emissions inventories in the 47 contiguous states for both the baseline and control scenarios.

Table VII-1. Emission Estimates by Vehicle Type and Reductions Associated with Adoption of the Tier 2 Rule

Continental U.S. minus California -- Section 812 2010 CAA Highway Vehicle Emissions								
Vehicle type	*VOC*	*NO_x*	*CO*	*SO_2*	*PM_{10}*	*$PM_{2.5}$*	*SOA*	*NH_3*
Light duty gas vehicle	2,197,781	2,296,033	22,746,343	153,912	65,117	37,491	13,406	271,483
Light duty gas truck 1	743,149	750,514	7,681,457	55,797	20,062	12,010	4,533	70,314
Light duty gas truck 2	574,236	609,133	5,947,424	28,430	10,072	6,095	3,503	32,084
Heavy duty gas vehicle	136,919	272,760	1,526,289	12,416	5,840	3,837	1,000	2,564
Motorcycle	40,697	14,467	221,551	396	453	227	248	45
Light duty diesel vehicle[a]	7	24	22	0	0	0	0	0
Light duty diesel trucks	365	870	819	58	65	50	9	1
Heavy duty diesel vehicle	139,013	1,297,002	2,123,937	107,054	78,764	65,856	3,295	439
2010 baseline emissions	3,832,166	5,240,802	40,247,842	358,062	180,372	125,566	25,994	376,930
Reductions due to Tier 2 rule	214,443	1,789,318	0	228,137	0	0	1,308	0
47-state emission estimates under Tier 2 rule	3,617,723	3,451,484	40,247,842	129,925	180,372	125,566	24,686	376,930
California emissions								
Light duty gas vehicle	65,841	106,110	965,593	24,105	10,198	5,872	402	42,528
Light duty gas truck 1	17,450	33,335	304,932	8,177	2,936	1,752	106	10,302
Light duty gas truck 2	8,756	22,425	154,846	4,167	1,474	892	53	4,701
Heavy duty gas vehicle	5,250	23,561	112,979	1,635	769	507	38	338
Motorcycle	3,647	2,030	24,311	60	68	37	22	7
Light duty diesel vehicle	2	7	11	0	0	0	0	0
Light duty diesel trucks	39	146	198	13	14	11	1	0
Heavy duty diesel vehicle	12,740	145,980	84,364	13,013	9,599	8,030	302	53
California emissions for baseline and under Tier 2	113,725	333,595	1,647,234	51,170	25,059	17,101	925	57,930
48-state emission estimates for control scenario	3,731,448	3,785,079	41,895,076	181,095	205,431	142,667	25,611	434,860

[a]Future year emissions of SO_2, PM_{10}, $PM_{2.5}$, SOA, and NH_3 from light-duty diesel vehicles are projected to be zero due to low projected vehicle mile traveled (VMT) levels.

B. Air Quality Impacts

EPA has used a regional-scale version of the Urban Airshed Model (UAM-V) to estimate ozone air quality. Our analysis uses a Source-Receptor Matrix (S-R Matrix) based on the Climatological Regional Dispersion Model (CRDM) is used to estimate nitrogen deposition, PM air quality, and visibility degradation.

Section VII.B.1 covers the estimation of ozone air quality using UAM-V. Section VII.B.2 covers the estimation of particulate matter air quality, and Section VII.B.3 discusses the estimation of nitrogen deposition. Finally, Section VII.B.4 covers the estimation of visibility degradation.

1. Ozone Air Quality Estimates

EPA used the emissions inputs with a regional-scale version of UAM-V to estimate ozone air quality. Because it accounts for spatial and temporal variations as well as differences in the reactivity of emissions, the UAM-V is useful for evaluating the air-quality effects of the Tier 2 rule.[ll]

Our analysis applies the modeling system for a base-year of 1990 and for two future-year scenarios: a 2010 baseline and a control scenario. As discussed later, we used the two separate years because ambient air quality observations from 1990 are used to calibrate the model. The UAM-V modeling system requires a variety of input files that contain information pertaining to the modeling domain and simulation period. These include gridded, day-specific emissions estimates and meteorological fields, initial and boundary conditions, and land-use information.

The model divides the U.S. into two regions: East and West. The model then segments the area in each region into grids, each of which has several layers of air conditions that are considered in the analysis. Using this data, the UAM-V model generates predictions of hourly ozone concentrations for every grid. We then used the results of this process to develop 2010 ozone profiles at monitor sites by applying derived adjustment factors to the actual 1990 ozone data at each monitor site. For areas (grids) without ozone monitoring data, we interpolated ozone values using data from monitors surrounding the area. After completing this process, we calculated daily and seasonal ozone metrics as inputs for the health and agriculture benefits analysis. The Sections below provide a more detailed discussion of each of the steps in this evaluation and a summary of the results.

[ll] Douglas and Iwamiya (1999) provide further information on the UAM-V modeling used in this analysis.

a. Modeling Domain

For the eastern U.S., the domain is the same as the eastern U.S. domain used in EPA's (1998b) recent analysis, "Regulatory Impact Analysis for the NO_x SIP Call, FIP, and Section 126 Petitions." The domain encompasses most of the eastern U.S. and consists of two grids, as illustrated in Figure VII-1. The shaded area of Figure VII-1 uses a relatively fine grid of 12 km, which consists of seven vertical layers. The unshaded area of Figure VII-1 has less resolution, as it uses a 36 km grid, which consists of five vertical layers. The top of the modeling domain is 4000 meters above ground level, for both the shaded and unshaded regions.

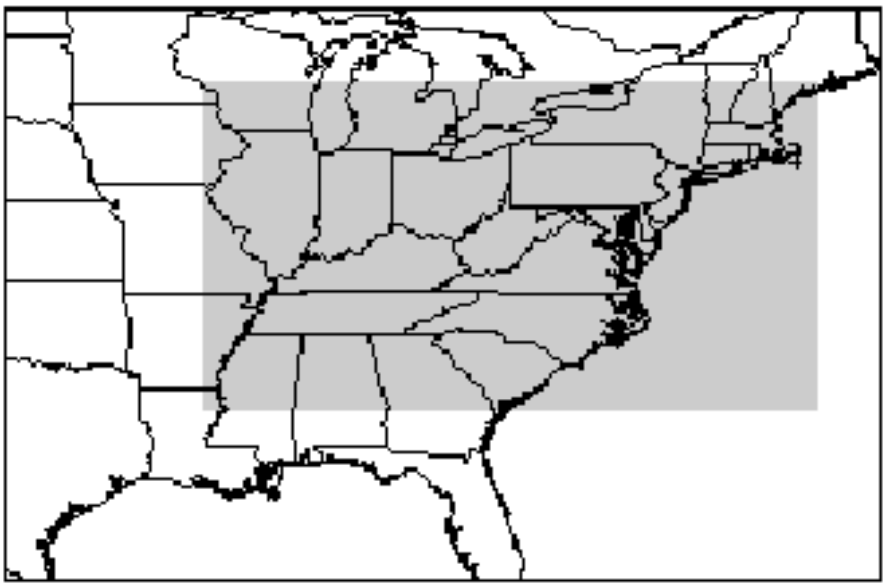

Figure VII-1. UAM-V Modeling Domain for Eastern U.S.

The modeling domain used to obtain results for the western U.S. comprises the contiguous 48 states. Note that although the domain includes the entire contiguous 48 states, results using this domain configuration were only used to estimate the effects of the Tier 2 rule in the West (defined as the region not shown in Figure VII-1). The domain extends from 126 degrees west longitude to 66 degrees west longitude, and from 24 degrees north latitude to 52 degrees north latitude. The analysis used a grid cell size of 2/3 longitude by ½ latitude (approximately 56 by 56 km) resulting in a 90 by 56 grid (5,040 cells) for each vertical layer, with eight vertical layers in all.

b. Simulation Periods

A simulation period is generally characterized by high ozone concentrations in one or more portions of the U.S.; exceedances of the 1-hour National Ambient Air Quality Standard for ozone were recorded at monitors during these periods. This study used three multi-day simulation periods to prepare the future-year ozone profiles. For the eastern U.S. ozone analysis, we modeled two simulation periods: 20-30 July 1993 and 7-18 July 1995. For the western U.S. the simulation period was 1-10 July 1990.

c. UAM-V Model Output

Standard output from the UAM-V modeling system includes: (1) hourly, surface-layer ozone concentrations (provided as hourly averages) for each grid cell; and (2) instantaneous ozone values for all grid cells and layers for each hour of the simulation. This study extracted hourly, surface-layer ozone concentrations for each grid-cell from the file containing hourly average ozone values. We then used this information to calculate a set of adjustment factors for forecasting 2010 ozone concentrations, as described in the following Section.

d. Converting Episode Estimates to Full-Season Profiles

The UAM-V runs generate surface layer hourly average ozone concentration estimates for the limited modeled episodes which are used in conjunction with actual 1990 concentrations to generate ozone concentrations for the entire ozone season.[mm] We mapped individual monitors onto the gridded UAM-V output, and used the modeled concentrations of the corresponding grid cells to calculate an adjustment factor.

We multiplied hourly ozone concentrations for 1990 by the adjustment factors to estimate 2010 ozone concentrations. Using the calculated adjustment factors and the observed monitor concentrations, we created a data set containing modified observed hourly ozone concentrations for each of the two scenarios. The Technical Support Document for this analysis details the steps involved.

[mm] The five-month ozone season for this analysis is defined as May to September for health benefits. For agricultural benefits for some crops, the relevant growing season extends into April and into October and November. In this analysis, no changes in ozone concentrations are assumed to occur outside the five-month ozone season. However, the ozone metric used to estimate certain crop yield benefits requires that the baseline level of ozone concentrations be estimated for months outside the five-month ozone season.

e. Extrapolating from Monitored to Unmonitored Locations

To model whole U.S., we needed ozone data for every location. Since actual ozone data is only available from limited monitor sites, we needed a method to extrapolate to unmonitored locations, in order to estimate the effects of several ozone-related health and welfare effects.[nn] Given available ozone monitoring data, we obtained ozone measures (e.g., daily average) for each location in the contiguous 48 states in two steps: (1) we converted hourly data to an ozone measure of interest, such as the daily average, and (2) we used monitor-specific ozone measures to extrapolate ozone measures to a grid of eight km by eight km population grid-cells. The conversion from hourly data to ozone measures of interest is straightforward. The estimation of ozone measures at each grid-cell uses a Voronoi Neighbor Averaging (VNA) spatial interpolation procedure.[oo]

The VNA procedure interpolates air quality estimates from the monitors to the center of each population grid-cell. The VNA procedure is a generalization of planar interpolation. Rather than limit the selection of monitors to, say, three, VNA identifies the set of monitors that best "surrounds" the center of each grid-cell. The result of VNA is illustrated in Figure VII-2. VNA determines the set of monitors that best surround the grid-cell by identifying which monitor is closest (considering both angular direction and horizontal distance) in each direction from the grid-cell center. Each selected monitor will likely be the closest monitor for multiple directions. The set of monitors found using this approach forms a polygon around the grid-cell center.

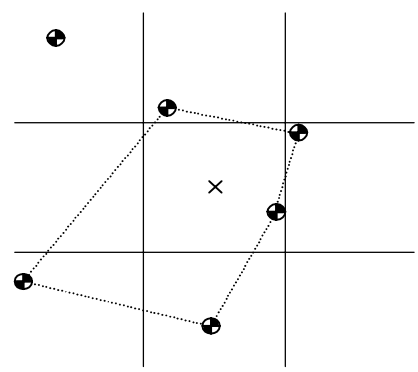

Figure VII-2. VNA Spatial Interpolation

The analysis of ozone impacts on agriculture adjusts the VNA approach slightly. Because calculating the benefits for this welfare category is best accomplished by using air

[nn]The Technical Support Document (Abt Associates, 1999) has a map of the location of ozone monitors in the U.S. The map shows that some areas of the country do not have many ozone monitors in close proximity to each other.

[oo]Interpolation between monitors is conducted using the same method as used by Abt Associates (1998) for the NO_x SIP call analysis; previously termed the "convex polygon" method, it is more accurately described as Voronoi Neighbor Averaging (VNA) spatial interpolation, which will be used throughout this document.

quality data at the county level, we used the VNA approach to estimate ozone measures for the center of each county, rather than the eight km by eight km population grid-cell level. To provide estimates for all counties, the analysis includes monitors that are up to 400 km from a county centroid. (Using a shorter distance would result in some county centroids not receiving an estimate.)

f. Ozone Air Quality Results

A summary of the ozone air quality profiles used to assess the benefits of the proposed standards is presented in Table VII-2. The change in seasonal ozone values across the U.S. ranges from an increase of 0.0016 ppm to -0.0028 ppm from the base case to the control, with a spatial average of -0.0008 ppm. The population-weighted average change is somewhat lower, -0.0004 ppm, which reflects that urban regions have smaller reductions in ozone than less populated rural regions. The air quality technical support document for this Regulatory Impact Assessment (RIA) (Abt Associates, 1999) contains maps showing the base case ozone concentrations and ozone concentration changes for the control scenario. These maps only convey information about the five-month ozone season used for the health benefits analysis. The change in the ozone index used in the agriculture analysis (termed “SUM06" and defined in Table VII-2) ranges from -0.0132 to 0.0087 ppm, with a spatial average of -0.0025 ppm and a population weighted average of -0.0026 ppm.

Table VII-2. Summary of UAM-V Derived Hourly Ozone Air Quality

Statistic	*2010 Base Case*[a]	*Change*[a]	*Percent Change*
Seasonal Average			
Minimum (ppm) [b]	0.0168	- 0.0028	-16.7%
Maximum (ppm) [b]	0.0611	0.0016	2.6%
Spatial Average (ppm)	0.0305	- 0.0008	-2.6%
Population-Weighted Average (person-ppm) [c]	0.0302	- 0.0004	-1.3%
Seasonal SUM06[d]			
Minimum (ppm) [b]	0.0000	- 0.0132	0.0%
Maximum (ppm) [b]	0.1052	0.0087	8.3%
Spatial Average (ppm)	0.0122	- 0.0025	-20.5%
Population-Weighted Average (person-ppm) [c]	0.0193	- 0.0026	-13.5%

[a] All values are calculated at the county centroid, using VNA spatial interpolation and allowing all monitors with a maximum distance of 400 km. The change is defined as the control case value minus the base case value.

[b] The base case minimum (maximum) is the value for the county with the lowest (highest) seasonal average, where the season is defined as May through September and all hours are included in the calculation. The change relative to the base case picks the minimum (maximum) from the set of changes in all counties.

[c] Calculated by summing the product of the projected 2010 county population and the estimated 2010 county centroid seasonal (or SUM06) ozone concentration, and then dividing by the total population.

[d] SUM06 is defined as the cumulative sum of hourly ozone concentrations over 0.06 ppm that occur from 8am to 8pm in the months of May through September.

2. PM Air Quality Estimates

Changes in concentrations of PM have an important effect on people's health and welfare. Our analysis uses the S-R Matrix model to evaluate the air quality effects of the Tier 2 rule. The S-R Matrix reflects the relationship between annual average PM concentration values at a single receptor in each county (a hypothetical monitor sited at the county population centroid) and the contribution by PM species to this concentration from each emission source (E.H. Pechan, 1996). The modeled receptors include all U.S. county centroids plus receptors in ten Canadian provinces and 29 Mexican cities/states. The methodology used in this RIA for estimating PM air quality concentrations using the S-R Matrix is similar to the method used in the July 1997 PM and Ozone NAAQS RIA (U.S. EPA, 1997e). Below is a detailed discussion of the steps taken to run the S-R Matrix and to derive the resulting changes in PM air quality.

a. Climatological Regional Dispersion Model

The CRDM uses assumptions similar to the Industrial Source Complex Short Term model (ISCST3), an EPA-recommended short range Gaussian dispersion model. CRDM incorporates terms for wet and dry deposition and chemical conversion of SO_2 and NO_x to PM, and uses climatological summaries (annual average mixing heights and joint frequency distributions of wind speed and direction) from 100 upper air meteorological sites throughout North America. The analysis used meteorological data for 1990 coupled with emissions data from version 2.0 of the 1990 National Particulate Inventory to develop the S-R Matrix.

b. Development of the S-R Matrix

To develop the S-R Matrix, we modeled a nationwide total of 5,944 sources (i.e., industrial point, utility, area, nonroad, and motor vehicle) of primary and precursor emissions with CRDM. In addition, we modeled secondary organic aerosols formed from anthropogenic and biogenic VOC emissions, as well as natural sources of PM_{10} and $PM_{2.5}$ (i.e., wind erosion and wild fires). We modeled emissions of SO_2, NO_x, and ammonia in order to calculate ammonium sulfate and ammonium nitrate concentrations, the primary particulate forms of sulfate and nitrate. The CRDM produced a matrix of transfer coefficients for each of these primary and precursor emissions. These coefficients can be applied to the emissions of any unit (area source or individual point source) to calculate a particular source's contribution to a county receptor's total annual average PM_{10} or $PM_{2.5}$ concentration. Each individual unit in the inventory is associated with one of the modeled source types (i.e., area, point sources with effective stack height of 0 to 250 m, 250 m to 500 m, and individual point sources with effective stack height above 500 m) for each county.

The relative concentrations in the atmosphere of ammonium sulfate and ammonium nitrate depend on complex chemical reactions. In the presence of sulfate and nitric acid (the gas phase oxidation product of NO_x), ammonia reacts preferentially with sulfate to form particulate ammonium sulfate rather than react with nitric acid to form particulate ammonium nitrate. We adjusted the S-R Matrix transfer coefficients to reflect concentrations of secondarily-formed particulates (Latimer, 1996). First, we multiplied the transfer coefficients for SO_2, NO_x, and ammonia by the ratios of the molecular weights of sulfate/SO_2, nitrate/nitrogen dioxide and ammonium/ammonia to obtain concentrations of sulfate, nitrate and ammonium.[pp] Ammonium nitrate forms under conditions of excess ammonium and low temperatures. For each county receptor, the sulfate-nitrate-ammonium equilibrium is estimated based on the following simplifying assumptions:

[pp] Ratio of molecular weights: Sulfate/SO_2= 1.50; nitrate/nitrogen dioxide = 1.35; ammonium/ammonia = 1.06.

1. All sulfate is neutralized by ammonium;
2. Ammonium nitrate forms only when there is excess ammonium;
3. Because ammonium nitrate forms only under relatively low temperatures, annual average particle nitrate concentrations are divided by four assuming that sufficiently low temperatures are present only one-quarter of the year.

Finally, we calculated the total particle mass of ammonium sulfate and ammonium nitrate.[qq]

c. Fugitive Dust Adjustment Factor

The 1990 CRDM predictions for fugitive dust are not consistent with measured ambient data. The CRDM-predicted average fugitive dust contribution to total $PM_{2.5}$ mass is 31 percent in the East and 32 percent in the West (as cited in: U.S. EPA, 1998b, p. 3-15). Monitoring data from the IMPROVE network show that minerals (i.e., crustal material) comprise approximately five percent of $PM_{2.5}$ mass in the East and approximately 15 percent of $PM_{2.5}$ mass in the West (U.S. EPA, 1996b). These disparate results suggest a systematic overestimate in the fugitive dust contribution to total PM. This overestimate is further complicated by the recognition that the 1990 National Particulate Inventory (NPI) significantly overestimates fugitive dust emissions. The most recent National Emissions Trends inventory indicates that the NPI overestimates fugitive dust PM_{10} and $PM_{2.5}$ emissions by 40 percent and 73 percent respectively[rr] (U.S. EPA, 1997d).

To address this bias, we applied a multiplicative factor of 0.25 nationally to fugitive dust emissions as a reasonable first-order attempt to reconcile differences between modeled predictions of $PM_{2.5}$ and actual ambient data. This is the same adjustment that was used in the NO_x SIP call analysis (U.S. EPA, 1998b). This adjustment results in a fugitive dust contribution to modeled ambient $PM_{2.5}$ concentrations of 10 percent to 17 percent.[ss] Even after this adjustment the fugitive dust fraction of total eastern $PM_{2.5}$ mass is 10.4 percent, which is still greater than the five percent indicated by IMPROVE monitors. However, given that the adjustment factor appears to bring the modeled fugitive dust contribution to $PM_{2.5}$ mass more

[qq] To calculate total particle mass of ammonium sulfate and ammonium nitrate, the anion concentrations of sulfate and nitrate are multiplied by 1.375 and 1.290 respectively.

[rr] Natural and man-made fugitive dust emissions account for 86 percent of PM_{10} emissions and 59 percent of $PM_{2.5}$ emissions in the most recent 1990 estimates in the National Emission Trends Inventory.

[ss] See U.S. EPA (1997b, page 6-5) for a map delineating modeling regions. Using 0.25 multiplicative factor, fugitive dust as percentage of $PM_{2.5}$ mass for: Central U.S. = 17.2 percent; Eastern U.S.= 10.4 percent; Western U.S.= 10.6 percent. By comparison, without using a multiplicative factor, fugitive dust as a percentage of $PM_{2.5}$ mass for: Central U.S. = 44.6 percent; Eastern U.S. = 30.9 percent; Western U.S. = 31.5 percent.

within the range of values reported from monitoring data, we adjusted the fugitive dust contribution to total PM that is estimated by the S-R Matrix by this factor. This factor still may result in an overprediction of the fugitive dust contribution.

d. Normalizing S-R Matrix Results to Measured Data

In an attempt to further ensure comparability between S-R Matrix results and measured annual average PM values, the analysis calibrated the S-R results using factors developed for the PM and Ozone NAAQS RIA (U.S. EPA, 1997e). For the NAAQS RIA, a "calibration factor" was developed for each monitored county.[tt] This analysis calibrated all S-R Matrix predictions regardless of overprediction or underprediction relative to monitored values. We applied this factor equally across all particle species contributing to the annual average PM value at a county-level receptor.

The calibration procedure employed 1993 - 1995 PM_{10} ambient monitoring data from the AIRS database following the assumptions of data completeness discussed above. The PM_{10} data represent the annual average of design value monitors averaged over three years (U.S. EPA, 1997f). We eliminated the standardization for temperature and pressure from this concentration data based upon proposed revisions to the reference method for PM_{10}.[uu]

Because there is little $PM_{2.5}$ monitoring data available, we developed a general linear model to predict $PM_{2.5}$ concentrations directly from the 1993 - 1995 PM_{10} values (U.S. EPA, 1996a). The analysis used a SAS™ general linear model (i.e., GLM) procedure to predict $PM_{2.5}$ values as a function of season, region, and measured PM_{10} value. We then used these derived $PM_{2.5}$ data to calibrate model predictions of annual average $PM_{2.5}$.

[tt] The normalization procedure was conducted for county-level modeled PM_{10} and $PM_{2.5}$ estimates falling into one of four air quality data tiers. The tiering scheme reflects increasing relaxation of data completeness criteria and therefore increasing uncertainty for the annual design value (U.S. EPA, 1997c). Nationwide, Tier 1 monitored counties cover the 504 counties with at least 50 percent data completeness and therefore have the highest level of certainty associated with the annual design value. Tier 2 monitored counties cover 100 additional counties with at least one data point (i.e., one 24-hour value) for each of the three years during the period 1993 -1995. Tier 3 monitored counties cover 107 additional counties with missing monitoring data for one or two of the three years 1993 - 1995. In total, Tiers 1, 2 and 3 cover 711 counties currently monitored for PM_{10} in the 48 contiguous states. In 1997 the PM_{10} monitoring network consisted of approximately 1600 individual monitors with a coverage of approximately 711 counties in the 48 contiguous states. Tier 4 covers the remaining 2369 non-monitored counties.

[uu] See Appendix J - Reference Method for PM_{10} , Final Rule for National Ambient Air Quality Standards for Particulate Matter (Federal Register, Vol. 62, No. 138, p. 41, July 18, 1997).

e. Development of Annual Median $PM_{2.5}$ Concentrations

The CRDM procedure does not directly produce estimates of daily 24-hour average PM concentrations or annual median PM concentrations. Some health benefits have concentration-response (C-R) functions that rely on estimates of either the daily 24-hour average or annual median concentrations. Using historical data, EPA therefore developed 24-hour average estimates corresponding to the 99th percentile value for PM_{10} and the 98th percentile value for $PM_{2.5}$ reflecting forms of PM_{10} and $PM_{2.5}$ daily standards.

Peak-to-mean ratios (i.e., ratio of the 24-hour average value to annual average value) are established from actual PM_{10} monitor data for 1993 to 1995. For PM_{10}, the peak value is defined exactly the way it is for the new PM_{10} NAAQS, i.e., the value corresponding to the 99th percentile value of the distribution of actual daily 24-hour average PM_{10} values. For $PM_{2.5}$, the peak value is also defined exactly the way it is for the new $PM_{2.5}$ NAAQS, i.e., the value corresponding to the 98th percentile value of the distribution of estimated daily 24-hour average $PM_{2.5}$ values. In this analysis, we assumed that these historical peak-to-mean ratios hold for the 2010 model year, and applied them to the annual average PM estimates generated by the S-R Matrix.

Starting with the annual mean and peak values developed from the S-R Matrix, we used maximum likelihood to estimate the parameters of a distribution that are most consistent with the S-R Matrix results. Using the parameters of the distribution, we then estimated the annual median concentration and other representative concentrations in the distribution (e.g., 5th percentile).

f. PM Air Quality Results

Table VII-3 provides a summary of the predicted ambient PM_{10} and $PM_{2.5}$ concentrations used in this study. The concentration changes are generally very small. The technical support document for this RIA (Abt Associates, 1999) contains maps showing the base case PM concentrations and PM concentration changes generated.

Table VII-3. Summary of S-R Matrix Derived PM Air Quality

Statistic	*2010 Base Case*	*Change*[a]	*Percent Change*
PM_{10}			
Minimum Annual Mean PM_{10} (Fg/m^3) [b]	5.96	-0.64	-10.7%
Maximum Annual Mean PM_{10} (Fg/m^3) [b]	63.18	0.00	0.0%
Average Annual Mean PM_{10} (Fg/m^3)	22.46	-0.14	-0.6%
Population-Weighted Average Annual Mean PM_{10} (person-Fg/m^3) [c]	28.31	-0.20	-0.7%
$PM_{2.5}$			
Minimum Annual Mean $PM_{2.5}$ (Fg/m^3) [b]	0.86	-0.64	-74.4%
Maximum Annual Mean $PM_{2.5}$ (Fg/m^3) [b]	28.02	0.00	0.0%
Average Annual Mean $PM_{2.5}$ (Fg/m^3)	10.75	-0.14	-1.3%
Population-Weighted Average Annual Mean $PM_{2.5}$ (person-Fg/m^3) [c]	13.00	-0.20	-1.5%

[a] The change is defined as the control case value minus the base case value.

[b] The base case minimum (maximum) is the value for the county with the lowest (highest) annual average. The change relative to the base case picks the minimum (maximum) from the set of changes in all counties.

[c] Calculated by summing the product of the projected 2010 county population and the estimated 2010 county PM concentration, and then dividing by the total population in the 48 contiguous states.

3. Nitrogen Deposition Estimates

The analysis used RADM to generate nitrogen deposition estimates. The RADM was developed over a ten year period, 1984 - 1993, under the auspices of the National Acid Precipitation Assessment Program (NAPAP), to address policy and technical issues associated with acidic deposition. The model provides a scientific basis for predicting changes in deposition and air quality resulting from changes in precursor emissions and to predict the levels of acidic deposition in certain sensitive receptor regions. To do so requires that RADM be a multipollutant model that predicts the oxidizing capacity of the atmosphere, including the prediction of ozone, and chemical transformations involving oxides of sulfur and nitrogen.

NAPAP has extensively documented the development, application, and evaluation of the RADM (Chang et al., 1987; Chang et al., 1990; Dennis et al., 1990). Several recent studies of acidic deposition have used RADM, including EPA's 1995 *Acid Deposition Standard Feasibility Study Report to Congress* (U.S. EPA, 1995), EPA's 1997 *Deposition of Air Pollutants to the Great Waters* Report to Congress (U.S. EPA, 1997a), work estimating the nitrogen deposition airshed of the Chesapeake Bay watershed (Dennis, 1997), and in the NO_x SIP call (U.S. EPA,

1998a)

RADM estimates deposition in units of kilograms per hectare (kg/ha). The model estimates wet deposition in the form of SO_4^{2-}, NO_3^-, NH_3, H^+. It estimates dry deposition in the form of SO_2, SO_4 as aerosol, O_3, HNO_3, NO_2, H_2O_2. The model then maps the deposition estimates to specific East Coast and Gulf Coast estuaries and their watersheds, which are subject to eutrophication problems. Land-deposited nitrogen in each watershed is multiplied by a factor of 10 percent to obtain the nitrogen load delivered via export (pass-through) to the corresponding estuary.

Table VII-4 provides a summary of the change in nitrogen deposition estimates for selected estuaries as a result of the Tier 2 rule[1]. The results represent a 10.8 percent reduction in the average annual deposition across these estuaries.

Table VII-4. Summary of 2010 Nitrogen Deposition in Selected Estuaries (million kg/year)

Estuary	*2010 Base Case*	*Change*[a]	*Percent Change*
Albemarle/Pamlico Sound	11.87	-1.27	-10.7%
Cape Cod Bay	3.96	-0.42	-10.6%
Chesapeake Bay	18.05	-1.91	-10.6%
Delaware Bay	3.37	-0.34	-10.1%
Delaware Inland Bays	0.44	-0.04	-9.1%
Gardiners Bay	1.24	-0.13	-10.5%
Hudson River/Raritan Bay	3.95	-0.45	-11.4%
Long Island Sound	5.78	-0.66	-11.4%
Massachusetts Bay	1.33	-0.14	-10.5%
Narragansett Bay	1.17	-0.12	-10.3%
Sarasota Bay	0.37	-0.04	-10.8%
Tampa Bay	2.27	-0.28	-12.3%
All Selected Estuaries	53.8	-5.8	-10.8%

[a] Change is defined here as the emissions level after implementing the Tier 2 rule minus the base case emissions.

4. Visibility Degradation Estimates Using the S-R Matrix

Visibility degradation is often directly proportional to decreases in light transmittance in the atmosphere. Scattering and absorption by both gases and particles decrease light transmittance. To quantify changes in visibility, our analysis used a light-extinction coefficient, based on the work of Sisler (1996), which shows the total fraction of light that is decreased per unit distance.

The light extinction coefficient accounts for the scattering and absorption of light by both particles and gases, and a number of factors are included in its estimation. Because fine particles are much more efficient at light scattering than coarse particles, the analysis specifies several fine particle species, whereas coarse particles are kept as one category. Fine particles with significant light-extinction efficiencies include sulfates, nitrates, organic carbon, elemental carbon (soot), and soil (Sisler, 1996).

Once we determined the light-extinction coefficient, we calculated a unitless visibility index, called a "deciview," which we used in the valuation of visibility. The deciview metric provides a linear scale for perceived visual changes over the entire range of conditions, from clear to hazy. Under many scenic conditions, the average person can generally perceive a change of one deciview.

The analysis generated visibility degradation estimates in "recreational" (e.g., federally designated Class I areas such as national parks and recreation areas) and "residential" (non-Class I areas) areas at the county level using the results of the S-R Matrix. The visibility benefits analysis (see Section VII.C) distinguishes between general regional visibility degradation and visibility degradation in certain Federally-designated Class I areas (i.e., national parks, forests, recreation areas, wilderness areas, etc.). Therefore we separated visibility degradation estimates into "residential" and "recreational" categories depending upon the geographic area covered by the estimate, and summed from the county-level to one of six regions (defined in part by the underlying study) and the nation.

Table VII-5 provides a summary of the visibility degradation estimates in terms of deciviews. The valuation methodology for recreational visibility requires separate treatment of visibility changes in the different regions in the U.S. Table VII-5 provides residential and recreational visibility degradation estimates for each region. All predicted visibility changes are small (less than one deciview), with the largest changes occurring in the Southeast and Northeast. The air quality technical support document for this RIA (Abt Associates, 1999) contains maps showing the base case visibility degradation and visibility degradation changes.

Table VII-5. Summary of 2010 Visibility Degradation Estimates (deciviews)

Visibility Degradation	*2010 Base Case*	*Change*[a]	*Percent Change*
Southeast			
Annual Average--Residential	23.44	-0.19	-0.8%
Annual Average--Recreational[b]	21.65	-0.23	-1.1%
Southwest			
Annual Average--Residential	17.89	-0.08	-0.4%
Annual Average--Recreational[b]	18.69	-0.08	-0.4%
California & Nevada			
Annual Average--Residential	19.29	-0.04	-0.2%
Annual Average--Recreational[b]	19.93	-0.06	-0.3%
Northeast			
Annual Average--Residential	21.80	-0.17	-0.8%
Annual Average--Recreational[b]	17.66	-0.06	-0.3%
North Central			
Annual Average--Residential	18.55	-0.11	-0.6%
Annual Average--Recreational[b]	19.13	-0.08	-0.4%
Northwest			
Annual Average--Residential	20.70	-0.21	-1.0%
Annual Average--Recreational[b]	21.65	-0.15	-0.7%
National			
Annual Average--Residential	21.77	-0.16	-0.7%
Annual Average--Recreational[b]	19.51	-0.09	-0.5%

[a] The change is defined as the control case deciview level minus the base case deciview level.
[b] Recreational visibility averages are from the 41 Class I areas used in the benefits analysis. See Table VII-14 for list of Class I areas.

C. Benefits Assessment

The changes in ozone, PM, nitrogen oxides, and visibility levels described in Section VII.B will result in changes in the health and welfare impacts associated with elevated ambient concentrations of these pollutants. This Section describes the methods for estimating the

physical magnitude and monetary value of these impacts.

Section VII.C.1 provides an overview of the benefits methodology. Section VII.C.2 discusses issues in estimating health effects. Section VII.C.3 discusses methods and provides estimated values for avoided incidences and monetary benefits for ozone- and PM-related health effects. Section VII.C.4 discusses methods and provides estimated values for air pollution-related welfare effects. Section VII.C.5 discusses the aggregation of health and welfare benefits, and presents an estimate of total benefits. Section VII.C.6 presents sensitivity analyses, and Section VII.C.7 discusses potential benefit categories that are not quantified due to data and/or methodological limitations, and provides a list of analytical uncertainties, limitations, and biases.

1. Overview of Benefits Estimation

Most of the specific methods and information used in this benefit analysis are similar to those used in the §812 Retrospective of the Benefits and Costs of the Clean Air Act and forthcoming §812 Prospective EPA Reports to Congress, which were reviewed by EPA's Science Advisory Board (U.S. EPA, 1997g), as well as the approach used by EPA in support of revising the ozone and PM NAAQS (U.S. EPA, 1997e; U.S. EPA, 1997h) and the Regional NOx SIP call (U.S. EPA, 1998b). Prior to describing the details of the approach for the benefits analysis, it is useful to provide an overview of the approach. The overview is intended to help the reader better identify the role of each issue described later in this Section.

The general term "benefits" refers to any and all outcomes of the regulation that contribute to an enhanced level of social welfare. The value of "benefits" refers to the dollar value associated with all the expected positive impacts of the regulation; that is, all regulatory outcomes that lead to higher social welfare. If the benefits are associated with market goods and services, the monetary value of the benefits is approximated by the sum of the predicted changes in "consumer (and producer) surplus." If the benefits are non-market benefits (such as the risk reductions associated with environmental quality improvements), however, other methods of measuring benefits must be used as discussed in the text. The total value of such a good is the sum of the dollar amounts that all those who benefit are willing to pay.

In addition to benefits, regulatory actions may also lead to unintended nonmarket costs, that some might term "disbenefits." An example of a disbenefit of reduced ozone concentrations is that there will be less protection from UV radiation. In order to quantify the impact of a regulatory action, both the benefits and disbenefits should be included. However, like many benefits, disbenefits are difficult to quantify. EPA's approach is to present as complete a set of quantified estimates of benefits and disbenefits as possible, given the state of science at the time of the analysis.

This conceptual economic foundation raises several relevant issues and potential

limitations for the benefits analysis of the regulation. First, the standard economic approach to estimating environmental benefits is anthropocentric– all benefits values arise from how environmental changes are perceived and valued by people. Thus, all near-term as well as temporally distant future physical outcomes associated with reduced pollutant loadings need to be predicted and then translated into the framework of present-day human activities and concerns. Second, as noted below, it is not possible to quantify or to value all of the benefits resulting from environmental quality improvements.

Conducting a benefits analysis for anticipated changes in air emissions is a challenging exercise, as it requires a series to steps to be specified and understood. Figure VII-3 illustrates these steps, which include: (1) institutional relationships and policy-making; (2) the technical feasibility of pollution abatement; (3) the physical-chemical properties of air pollutants and their consequent linkages to biological or ecological responses in the environment, and (4) human responses and values associated with these changes.

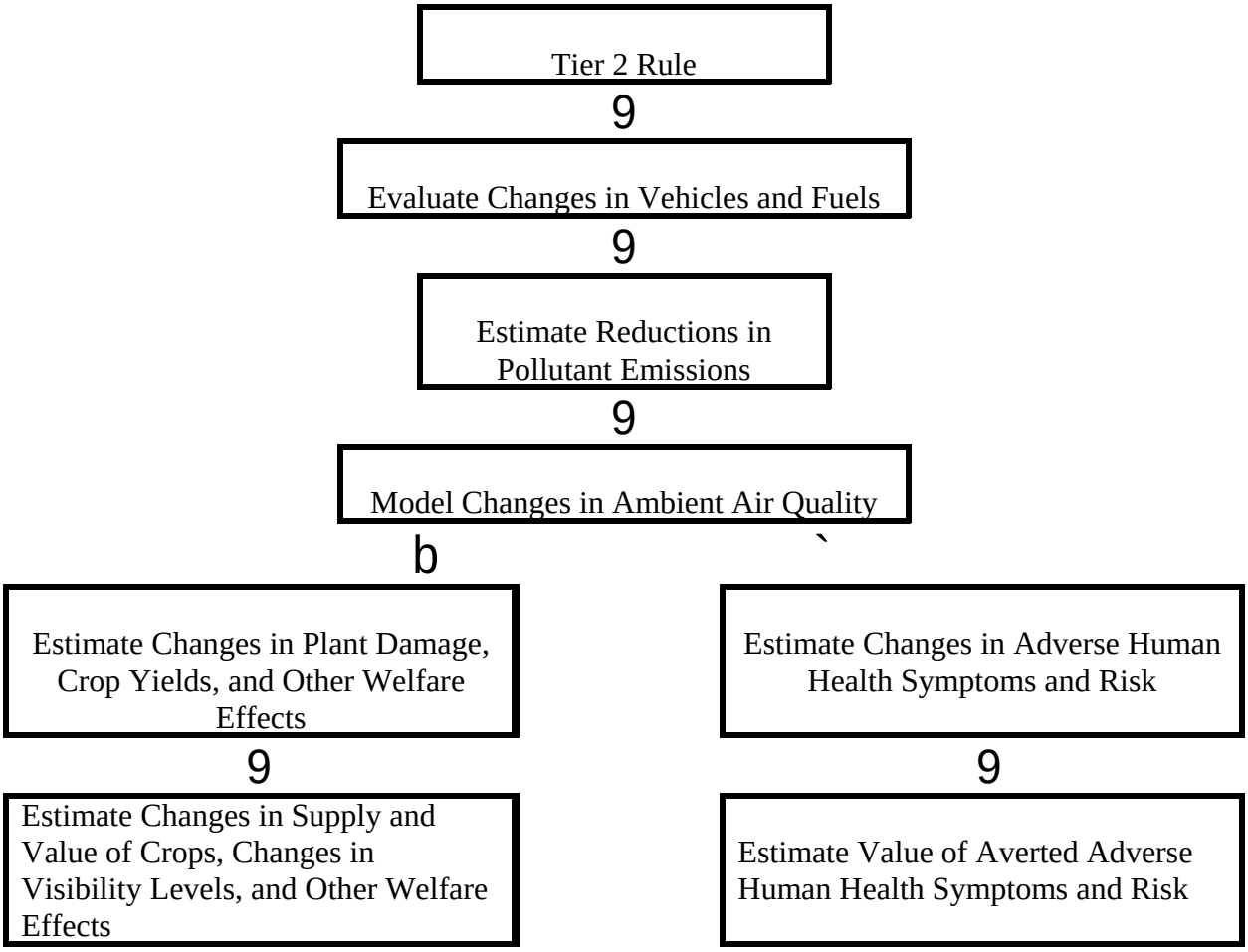

Figure VII-3. Example Benefits Analysis Method

Our analysis mainly uses a "damage function" approach to estimate the adverse physical effects from air pollution that will be avoided in the United States due to implementation of the emission reductions required by the Tier 2 rule.[vv] This approach examines individual physical effects, such as, say, hospital admissions, that may be affected by reductions in specific pollutants. The total value for a given physical effect is simply the product of the number of incidences avoided and the value per incidence avoided. The damage function approach assumes that the benefits from individual effects are additive and independent, i.e., benefits for one effect do not depend on benefits for a separate effect. Alternative approaches include market-based measures include: hedonic prices, which measure the total value of a reduction in

[vv]The exception to this is the estimation of nitrogen deposition benefits, which uses an avoided cost approach.

air pollution using a single metric, such as the price of a house, or contingent valuation, which asks individuals for their total willingness to pay (WTP) for a reduction in air pollution. If the single metric approach successfully captures the full WTP for a reduction in air pollution, then the damage function approach should yield an estimate that is less than or equal to the estimate from the single metric approach. All monetized estimates of benefits presented are in 1997 dollars.[ww]

Some of the estimates of the economic value of avoided health and welfare effects are derived from contingent valuation (CV) studies. Concerns about the reliability of value estimates that come from CV studies have dominated debates about the methodology, since research has shown that bias can be introduced easily into these studies, especially if they are not carefully done. Accurately measuring willingness to pay for avoided health and welfare losses depends on the reliability and validity of the data collected. There are several issues to consider when evaluating study quality, including but not limited to 1) whether the sample estimates of WTP are representative of the population WTP, 2) whether the good to be valued is comprehended and accepted by the respondent, 3) whether the WTP elicitation format is designed to minimize strategic responses, 4) whether WTP is sensitive to respondent familiarity with the good, to the size of the change in the good, and to income, 5) whether the estimates of WTP are broadly consistent with other estimates of WTP for similar goods, and (6) the extent to which responses are consistent with established economic principles. This benefits analysis does not attempt to list the individual strengths and weaknesses of each CV study used. However, in some instances, such as for valuation of chronic bronchitis and residential visibility, when the CV study reliability is questionable, we adopt alternative estimates as conservative measures of benefits, which are presented in the low-end estimate of the range of monetized benefits. In other instances, for example the study used to value changes in visibility at Class I areas, we recognize potential weaknesses, but do not alter the estimates presented in the study.

In this analysis, the valuation of avoided incidences of health effects and avoided degradation of welfare effects relies on benefits transfer. The benefits transfer approach takes values or value functions generated by previous research and transfers them from the study to the policy of interest. For example, we obtained the value of reduced mortality from a distribution of values of statistical life based on 26 wage-risk and contingent valuation studies. None of the values for the health and welfare categories valued in this benefit analysis were generated specifically in the context of the Tier 2 rule. The validity of this approach relies on the correlation between attributes of the policy and the studies from which the values were obtained. Where possible, we selected studies that valued effects matching those in the policy analysis.

[ww]Recent analyses have been presented in 1990 dollars, such as the NO_x SIP call (U.S. EPA, 1998b) and the §812 Retrospective of the Benefits and Costs of the Clean Air Act (U.S. EPA, 1997g). The method of adjusting from 1990 dollars to 1997 dollars depends on the basis of the benefits estimates. Benefits estimates based on cost-of-illness are adjusted by using the consumer price indexes (CPI-Us) for medical care, while benefits estimates based directly on estimates of WTP have been adjusted using the CPI-U for "all items."

When studies were not available that exactly matched the studied effect and the policy effect, we selected studies that matched as closely as possible, and note the differences (and where known, potential drawbacks to their application) in the text.

The first step in a benefits analysis using this approach is the identification of the types or categories of benefits associated with the anticipated changes in ambient air quality conditions. The second step is the identification of relevant studies examining the relationships between air quality and these benefit categories and studies estimating the value of avoiding damages. The most prominent avoided damages are those related to human health risk reductions, effects on crops and plant life, visibility, and materials damage.

It is difficult to identify all the types of benefits that might result from environmental regulation and to value those benefits that are identified, due to the non-market nature of many benefits categories. Since many pollution effects (e.g., adverse health or ecological effects) traditionally have not been traded as market commodities, economists and analysts cannot look to changes in market prices and quantities to estimate the value of these effects. This lack of observable markets may lead to the omission of significant benefits categories from an environmental benefits analysis. It is not possible to quantify the magnitude of this underestimation. The more important of these omitted effect categories are shown in Table VII-6.

Table VII-6. Unquantified Benefit Categories*

	Unquantified Benefit Categories Associated with Ozone and Nitrogen Oxides	*Unquantified Benefit Categories Associated with PM*
Health Categories	Airway responsiveness. Pulmonary inflammation. Increased susceptibility to respiratory infection. Acute inflammation and respiratory cell damage. Chronic respiratory damage/premature aging of lungs. Ultraviolet-B radiation (cost).	Changes in pulmonary function. Morphological changes. Altered host defense mechanisms. Cancer. Other chronic respiratory disease.
Welfare Categories	Ecosystem and vegetation effects in Class I areas (e.g., national parks). Damage to urban ornamentals (e.g.,grass, flowers, shrubs, and trees in urban areas). Fruit and vegetable crops. Reduced yields of tree seedlings, commercial and non-commercial forests. Damage to ecosystems. Materials damage (other than consumer cleaning cost savings). Nitrates in drinking water. Brown clouds.	Materials damage (other than consumer cleaning cost savings). Damage to ecosystems (e.g., acid sulfate deposition). Nitrates in drinking water. Brown clouds.

* Note that there are other pollutants that are reduced in conjunction with the Tier 2 rule that are not considered in this analysis, such as carbon (a pollutant associated with global climate change).

Within each effect category, there may be several possible estimates of health and welfare effects. Each of these possibilities represents a health or welfare "endpoint." The basic structure of the analysis is to create a set of benefit estimates reflecting key assumptions concerning environmental conditions and the responsiveness of human health and the environment to changes in air quality. Total benefits are presented as the sum of non-overlapping endpoints, to avoid double-counting benefits.

We made subjective judgements in our analysis because of a lack of information. To reflect the range of uncertainty regarding key assumptions– such as the appropriate PM threshold– this analysis uses two suites of assumptions. This RIA has adopted the approach of presenting a range of monetized benefits that reflects these uncertainties by selecting alternative values for each of several key assumptions. Taken together, these alternative sets of assumptions define a "high end" and a "low end" estimate for the benefits that have been monetized in this analysis.

Table VII-7 lists the specific health and welfare effects that are included in at least one of the assumptions sets, indicating the specific effect categories that are included in the plausible range of benefits. This table also includes the estimates of mean WTP, or "unit values" used to monetize the benefits for each effect. Table VII-8 highlights the key differences between the assumption sets.

Table VII-7. Quantified and Monetized Primary Health and Welfare Effects

Effect	*Pollutant*	*Value per incident ($1997)* *LOW*	*HIGH*
Health Effects in the Benefits Analysis			
Mortality, long-term exposure - over age 30	$PM_{2.5}$	$2,730,000	$5,894,400
Mortality, short-term exposure	Ozone	$0	$5,894,400
Chronic bronchitis - all ages	PM_{10}	$74,500	$319,280
Hospital admissions - all respiratory, all ages	Ozone & $PM_{2.5}$	$9,672 (Ozone) $9,142 (PM)	$9,672 (Ozone) $9,142 (PM)
Hospital admissions - congestive heart failure	PM_{10}	$11,931	$11,931
Hospital admissions - ischemic heart disease	PM_{10}	$14,854	$14,854
Any of 19 acute respiratory symptoms -adult	Ozone	$22	$22
Acute bronchitis - children	$PM_{2.5}$	$55	$55
Lower respiratory symptoms (LRS) - children	PM_{10}	$15	$15
Upper respiratory symptoms (URS) - children	PM_{10}	$23	$23
Work loss days (WLD) - adult	$PM_{2.5}$	$102	$102
Minor restricted activity days (MRAD) - adult	$PM_{2.5}$	$47	$47
Welfare Effects in the Benefits Analysis			
Agriculture - select commodity crops	Ozone	n/a	n/a
Household soiling (annual value)	PM_{10}	$3.09/household/ $\mu g/m^3$ change in PM_{10}	$3.09/household/$\mu g/m^3$ change in PM_{10}
Nitrogen deposition: (annual value)	NO_x		
Albemarle-Pamilico Sound		$90/kg of nitrogen	$90/kg of nitrogen
Chesapeake Bay		$59/kg of nitrogen	$59/kg of nitrogen
Tampa Bay		$238/kg of nitrogen	$238/kg of nitrogen
Average nine estuaries		$129/kg of nitrogen	$129/kg of nitrogen
Decreased worker productivity	Ozone	$1/worker/10% change in ozone	$1/worker/10% change in ozone
Visibility - residential	PM and gases	not valued	$17/household per deciview
In-region recreational visibility: (annual value)	PM and gases		
California		$6.43/household /deciview	$12.89/household /deciview
Southwest		$8.41/household	$16.82/household

Effect	*Pollutant*	*Value per incident ($1997)* *LOW*	*HIGH*
Southeast		$3.99/household /deciview	$7.98/household /deciview
Out-of-region recreational visibility: California		$4.48/household /deciview	$8.96/household /deciview
Southwest		$6.76/household /deciview	$13.51/household /deciview
Southeast		$2.46/household /deciview	$4.91/household /deciview

Table VII-8. Key Differences Between Low and High Assumption Sets

Assumption	*Low*	*High*
Threshold for PM effect	15 µg/m^3	background
PM Mortality	value of statistical life year lost	value of statistical life
Ozone-related short-term exposure mortality	excluded	included
Agriculture	low crop sensitivity to ozone	high crop sensitivity to ozone
Visibility	no residential visibility valuation	recreational and residential visibility valued
Infant mortality	excluded	included

2. Issues in Estimating Changes in Health Effects

This benefits analysis relies on concentration-response (C-R) functions estimated in published epidemiological studies relating adverse health to ambient air quality. The specific C-R functions used are included in Table VII-9. While a broad range of adverse health effects have been associated with exposure to elevated ozone and PM levels (as noted for example in Table VII-6), in this quantified benefit analysis only a subset of health effects are included. Health effects are excluded from the current analysis for three reasons: (1) the possibility of double counting (such as hospital admissions for specific respiratory diseases); (2) uncertainties in applying effect relationships based on clinical studies (where human subjects are exposed to various levels of air pollution in a carefully controlled and monitored laboratory situation) to the affected population; or (3) a lack of an established C-R relationship.

When a single published study is selected as the basis of the C-R relationship between a

pollutant and a given health effect, or "endpoint," applying the C-R function is straightforward. This is the case for most of the endpoints selected for inclusion in the benefits analysis. A single C-R function may be chosen over other potential functions because the underlying epidemiological study used superior methods, data or techniques, or because the C-R function is more generalized and comprehensive. For example, the study that estimated the effects of PM on hospital admissions for all ages and all respiratory diseases is selected over studies limited to the over age 65 population or specific categories of respiratory diseases.

An exception to the "single study" selection in the benefits analysis is mortality associated with exposure to ozone. Estimates of premature mortality associated with short-term exposure to $PM_{2.5}$ and PM_{10}, are also based on multiple estimates of the relationship between PM and mortality, but are presented as a sensitivity analysis. When several estimated C-R relationships between a pollutant and a given health endpoint have been selected, they are combined or pooled to derive a single estimate of the relationship. A separate technical support document provides details of the procedures used to combine multiple C-R functions (Abt Associates, 1999).

Whether the C-R relationship between a pollutant and a given health endpoint is estimated by a single function from a single study or by a pooled function of C-R functions from several studies, we apply that same C-R relationship everywhere in the benefits analysis. Although the C-R relationship may in fact vary somewhat from one location to another (for example, due to differences in population susceptibilities or differences in the composition of PM), location-specific C-R functions are generally not available. While a single function applied everywhere may result in overestimates of incidence changes in some locations and underestimates of incidence changes in other locations, these location-specific biases will to some extent cancel each other out when the total incidence change is calculated. It is not possible to know the extent or direction of the bias in the total incidence change based on application of a single C-R function everywhere.

The remainder of this Section discusses two key issues involving the use of C-R functions to estimate the benefits of the Tier 2 rule: baseline incidences and health effect thresholds, i.e. levels of pollution below which changes in air quality have no impacts on health.

Table VII-9. PM and Ozone Health Concentration-Response Function Summary Data

Endpoint	*Pollutant*	*Concentration-Response Function*		*Averaging Time*		*Population*[b]	*Pollutant Coefficient*[c]
		Source	*Functional Form*[a]	*Studied*	*Applied*		
Mortality							
Mortality (long-term exposure) - $PM_{2.5}$	$PM_{2.5}$	Pope et al. (1995)	log-linear	annual median	annual median[c]	ages 30+	0.006408
Mortality (short-term exposure)	Ozone	Kinney et al., (1995)	log-linear	daily 1-hour max	daily 1-hour max	all	0.000000
	Ozone	Ito and Thurston (1996)	log-linear	1-day average	1-day average	all	0.000677
	Ozone	Moolgavkar et al. (1995)	log-linear	1-day average	1-day average	all	0.000611
	Ozone	Samet et al. (1997)	log-linear	1-day average	1-day average	all	0.000936
Hospital Admissions							
All respiratory illnesses	$PM_{2.5}$/ PM_{10}	Thurston et al. (1994)	linear	1-day average	1-day average	all	3.45×10^{-8}
Congestive heart failure	PM_{10}	Schwartz & Morris (1995)	log-linear	2-day average	1-day average	age 65+	0.00098
Ischemic heart disease	PM_{10}	Schwartz & Morris (1995)	log-linear	1-day average	1-day average	age 65+	0.00056
All respiratory illnesses	Ozone	Thurston et al. (1992)	linear	daily 1-hour max	daily 1-hour max	all	0.00137

Endpoint	*Pollutant*	*Concentration-Response Function*		*Averaging Time*		*Population*[b]	*Pollutant Coefficient*[c]
		Source	*Functional Form*[a]	*Studied*	*Applied*		
Respiratory Symptoms/Illnesses not requiring hospitalization							
Development of chronic bronchitis	PM_{10}	Schwartz (1993)	logistic	annual mean	annual mean	all	0.012
Acute bronchitis	$PM_{2.5}$	Dockery et al.(1989)	logistic	annual mean	annual mean[d]	ages 10-12	0.0298
Upper respiratory symptoms (URS)	PM_{10}	Pope et al. (1991)	log-linear	1-day average	1-day average	asthmatics, ages 9-11	0.0036
Lower respiratory symptoms (LRS)	PM_{10}	Schwartz et al. (1994)	logistic	1-day average	1-day average	ages 8-12	0.01823
Any of 19 acute respiratory symptoms	Ozone	Krupnick et al. (1990)	logistic	daily 1-hour max	daily 1-hour max	ages 18-65	0.00014
Minor restricted activity days (MRAD)	$PM_{2.5}$	Ostro and Rothschild (1989)	log-linear	2-week average	1-day average	ages 18-65	0.00741
Work loss days (WLD)	$PM_{2.5}$	Ostro (1987)	log-linear	2-week average	1-day average	ages 18-65	0.0046
Decreased worker productivity	Ozone	Crocker & Horst (1981) and EPA (1994)	percent change	1-day average	1-day average	laborers	n/a

[a] The log-linear is the most common concentration-response relationship; in this case, the relationship between a change in pollutant level, ΔPM, and the change in incidence of the health effect, Δy, is: Δy = population* incidence rate*[exp(B*ΔPM)-1].

[b] The population examined in the study and to which this analysis applies the reported concentration-response (C-R) relationship. In general, epidemiological studies analyzed the C-R relationship for a specific age group (e.g., ages 65+) in a specific geographical area. This analysis applies the reported pollutant coefficient to all individuals in the age group nationwide.

[c] A single pollutant coefficient reported for several studies indicates a pooled analysis; see text for discussion of pooling C-R relationships across studies.

a. Baseline Incidences

The epidemiological studies of the association between pollution levels and adverse health effects generally provide a direct estimate of the relationship of air quality changes to the relative risk of a health effect, rather than an estimate of the absolute number of avoided cases. For example, a typical result might be that a ten $\mu g/m^3$ decrease in daily $PM_{2.5}$ levels might decrease hospital admissions by three percent. The baseline incidence of the health effect is necessary to convert this relative change into a number of cases.

Because most PM and ozone studies that estimate C-R functions for mortality considered only non-accidental mortality, we adjusted county-specific baseline mortality rates used in the estimation of PM- and ozone-related mortality to provide a better estimate of county-specific non-accidental mortality. We multiplied each county-specific mortality rate by the ratio of national non-accidental mortality to national total mortality (0.93). We estimated county-specific baseline mortality incidences among individuals aged 30 and over– necessary for $PM_{2.5}$-related long-term exposure mortality, estimated by Pope et al. (1995)– by applying national age-specific death rates to county-specific age distributions, and adjusting the resulting estimated age-specific incidences so that the estimated total incidences (including all ages) equals the actual county-specific total incidences.

County-level incidence rates are not available for other endpoints. The analysis used national incidence whenever possible, because these data are most applicable to a national assessment of benefits. However, for some studies, the only available incidence information come from the studies themselves; in these cases, incidence in the study population is assumed to represent typical incidence at the national level.

b. Thresholds

A very important issue in applied modeling of changes in PM is whether to apply the C-R functions to all predicted changes in ambient concentrations, even small changes occurring at levels approaching “anthropogenic background”. Different assumptions about whether to model thresholds, and if so, at what level, can have a major effect on the resulting benefits estimates. We use two thresholds– a different threshold for the low, primary, and high sets of assumptions– which are set respectively at: 1) 15 $\mu g/m^3$ for all effects except those that have a lowest observed level higher than 15 $\mu g/m^3$; and 2) the background level of the pollutant (i.e., the pollutant level that would occur after removing all anthropogenic emissions).

3. PM- and Ozone-related Health Effects

This Section discusses the methods used to estimate the change in the incidence of PM- and ozone-related health effects due to the Tier 2 rule and the methods used to value this change.

a. Premature Mortality

Both ozone and particulate matter have been associated with increased risk of premature mortality, which is a very important health endpoint in this economic analysis due to the high monetary value associated with risks to life. There are two types of exposure to elevated levels of air pollution that may result in premature mortality. Acute (short-term) exposure (e.g., exposure on a given day) to peak pollutant concentrations may result in excess mortality on the same day or within a few days of the elevated exposure. Chronic (long-term) exposure (e.g., exposure over a period of a year or more) to levels of pollution that are generally higher may result in mortality in excess of what it would be if pollution levels were generally lower. The excess mortality that occurs will not necessarily be associated with any particular episode of elevated air pollution levels. Both types of effects are biologically plausible, and there is an increasing body of consistent corroborating evidence from animal toxicity studies indicating that both types of effects exist.

There are, similarly, two basic types of epidemiological studies of the relationship between mortality and exposure to pollutants. Long-term studies (e.g., Pope et al., 1995) estimate the association between long-term (chronic) exposure to air pollution and the survival of members of a large study population over an extended period of time. Such studies examine the health endpoint of concern in relation to the general long-term level of the pollutant of concern– for example, relating annual mortality to some measure of annual pollutant level. Daily peak concentrations would impact the results only insofar as they affect the measure of long-term (e.g., annual) pollutant concentration. In contrast, short-term studies relate daily levels of the pollutant to daily mortality. By their basic design, daily studies can detect acute effects but cannot detect the effects of long-term exposures. A chronic exposure study design (a prospective cohort study, such as the Pope study) is best able to identify the long-term exposure effects, and may detect some of the short-term exposure effects as well. Because a long-term exposure study may detect some of the same short-term exposure effects detected by short-term studies, including both types of study in a benefit analysis would likely result in some degree of double counting of benefits.

Another major advantage of the long-term study design concerns the issue of the degree of prematurity of mortality associated with air pollution. It is possible that the short-term studies are detecting an association between air pollution and mortality that is primarily occurring among terminally ill people. Critics of the use of short-term studies for policy analysis purposes correctly point out that an added risk factor that results in a terminally ill person dying a few days or weeks earlier than they otherwise would have (known as “short-term harvesting”) is potentially included in the measured air pollutant mortality “signal” detected in such a study. As the short-term study design does not examine individual people (it examines daily mortality rates in large populations, typically a large city population), it is impossible to know anything about the overall health status of the specific population that is detected as dying early. While

some of the detected excess deaths may have resulted in a substantial loss of life (measuring loss of life in terms of lost years of remaining life), others may have lost a relatively short amount of lifespan.

While the long-term study design is preferred, these types of studies are expensive to conduct and consequently there are relatively few well designed long-term studies. For PM, there has only been one high quality study accepted by the Science Advisory Board, and for ozone, no acceptable long-term studies have been published. For this reason, our analysis used short-term ozone mortality studies as the basis for determining ozone-related mortality benefits. The next two Sections provide details on the measurement of changes in incidences of premature mortality associated with changes in PM and ozone arising from implementation of the Tier 2 rule.

Estimating PM-related Premature Mortality

The benefits analysis estimated PM-related mortality using the $PM_{2.5}$ relationship from Pope et al. (1995). This decision reflects the Science Advisory Board's explicit recommendation for modeling the mortality effects of PM in both the completed §812 Retrospective Report to Congress and the ongoing §812 Prospective Study. The Pope et al. study estimates the association between long-term (chronic) exposure to $PM_{2.5}$ and the survival of members of a large study population. This relationship is selected for use in the benefits analysis instead of short-term (daily pollution) studies for a number of reasons.

We selected the Pope et al. (1995) long-term study as providing the best available estimate of the relationship between PM and mortality. It is used alone– rather than considering the total effect to be the sum of estimated short-term and long-term effects– because summing creates the possibility of double-counting a portion of PM-related mortality. We selected the Pope et al. study in preference to other available long-term studies because it uses better statistical methods, has a much larger sample size, the longest exposure interval, and more locations (51 cities) in the United States, than other studies. It is unlikely that the Pope et al. study contains any significant amount of short-term harvesting. First, the health status of each individual tracked in the study is known at the beginning of the study period. Persons with known pre-existing serious illnesses were excluded from the study population. Second, the statistical model used in the Pope study examines the question of survivability throughout the study period (ten years). Deaths that are premature by only a few days or weeks within the ten-year study period (for example, the deaths of terminally ill patients, triggered by a short duration PM episode) are likely to have little impact on the calculation of the average probability of surviving the entire ten year interval. In relation to the "Six-cities" study by Dockery et al. (1993), the Pope et al. study found a smaller increase in excess mortality for a given PM air quality change.

Estimating Ozone-related Premature Mortality

The literature on the possible relationship between exposure to ambient ozone and premature mortality has been evolving rapidly. Of the 28 time-series epidemiology studies identified in the literature that report results on a possible association between daily ozone concentrations and daily mortality (see (see: U.S. EPA, 1997e, Appendix J), 21 were published or presented since 1995. In particular, a series of studies published in 1995 through 1997 (after closure on the ozone Criteria Document) from multiple cities in western Europe has significantly increased the body of studies finding a positive association. Fifteen of the 28 studies report a statistically significant relationship between ozone and mortality, with the more recent studies tending to find statistical significance more often than the earlier studies. The ozone-mortality datasets have also tended to become larger in more recent studies as longer series of air quality monitoring data have become available over time. This suggests that it may take many years of data before the ozone effect can be separated from the daily weather and seasonal patterns with which it tends to be correlated.

In 1997, as a part of the ozone NAAQS promulgation RIA, EPA staff reviewed this recent literature. They identified nine studies that met a defined set of selection criteria, and conducted a meta-analysis of the results of the nine studies (U.S. EPA, 1997e). Our analysis implements the same basic approach to quantifying ozone mortality as the NAAQS, with the exception that a subset of four of the nine studies is used, representing only U.S. based analyses.[xx] In a post-NAAQS RIA review of the methodology for assessing ozone mortality effects, it was determined that the relationships between ambient ozone and mortality in the non-U.S. study locations included in the original NAAQS-related analysis may not be representative of the range of ozone-mortality C-R relationships in the United States. To reduce the potential for applying inappropriate C-R functions of the ozone mortality benefits from the Tier 2 rule, the analysis only included U.S. studies, based on the assumption that demographic and environmental conditions on average would be more similar between the study and policy sites. However, the full body of peer-reviewed ozone mortality studies should be considered when evaluating the weight of evidence regarding the presence of an association between ambient ozone concentrations and premature mortality.

Because of differences in the averaging times used in the underlying studies (some use daily average ozone levels, while others use 1-hour daily maximum values), it is not possible to conduct a meaningful analysis directly on the coefficients of the C-R functions. Instead, the analysis translated each C-R function into a set of predicted mortality incidence changes that would be estimated by that C-R function, given the set of air quality changes. We then combined these studies to estimate the impact of ozone on mortality incidence. The technical support document for this analysis provides additional details of this approach (Abt Associates, 1999)

Infant Mortality

[xx]The U.S. study-only approach has been implemented previously in the NO_x SIP call RIA (U.S. EPA, 1998b).

Woodruff et al. (1997) found a significant association between annual PM_{10} levels and post-neonatal mortality (deaths of infants aged 28 - 51 weeks). This estimate should not overlap with the Pope et al. (1995) estimate because the Pope et al. function is based on a population over the age of 30. The SAB recently advised the §812 Prospective project, however, to not include this in the §812 primary analysis at this time, primarily because the study is of a new endpoint and the results have not been replicated in other studies in the U.S. Consequently, our analysis includes infant mortality in the high set of assumptions.

Valuing Premature Mortality

To value the benefit of reducing premature mortality, we employ two approaches to the calculated change in incidence. One approach, the "value of statistical lives lost" (VSL) approach, uses information from several value-of-life studies to determine a reasonable benefit of preventing mortality. The mean value of avoiding one statistical death is estimated to be $5.9 million in 1997 dollars (or $4.8 million in 1990 dollars as has been used in previous EPA analyses). This represents an intermediate value from a variety of estimates that appear in the economics literature, and is a value that EPA has frequently used in RIAs for other rules. This estimate is the mean of a distribution fitted to the estimates from 26 value-of-life studies identified in the §812 study as "applicable to policy analysis." The approach and set of selected studies mirrors that of Viscusi (1992) (with the addition of two studies), and uses the same criteria used by Viscusi in his review of value-of-life studies. The $5.9 million estimate is consistent with Viscusi's conclusion (updated to 1997$) that "most of the reasonable estimates of the value of life are clustered in the $3.7 to $8.6 million range." Five of the 26 studies are contingent valuation (CV) studies, which directly solicit WTP information from subjects; the rest are wage-risk studies, which base WTP estimates on estimates of the additional compensation demanded in the labor market for riskier jobs. The 26 studies used to form the distribution of the value of a statistical life are listed in Table VII-10.

The second approach for valuing premature mortality is the value of statistical life-years lost" (VSLY) approach, which incorporates assumptions to account for the age-distribution of the affected population. Moore and Viscusi (1998) suggest one approach for determining the value of a statistical life-year lost. They assume that the willingness to pay to save a statistical life is the value of a single year of life times the expected number of years of life remaining for an individual. They suggest that a typical respondent in a mortal risk study may have a life expectancy of an additional 35 years. Using a mean estimate of $4.8 million (1990 dollars), their approach would yield an estimate of $137,000 per life-year lost or saved. If an individual discounts future additional years using a standard discounting procedure. Using a 35 year life expectancy, a $4.8 million value of a statistical life, and a 5 percent discount rate, the implied value of each life-year lost is $293,000. A higher discount rate would produce a greater value per life-year, and a lower discount rate would produce a lower value per life-year. The Moore and Viscusi procedure is identical to this approach, but uses a zero discount rate. In addition to the VSLY, the expected number of life-years saved is necessary to determine the appropriate value for an avoided incidence of premature mortality. Based on adjustments to reflect age-

specific relative premature mortality is determined to be 9.8 years. Using 9.8 years, the value of an avoided incidence of PM-related premature mortality is then $2.2 million (1990$). Thus, for the low-end estimate of premature mortality in this analysis we apply the value of $2.7 million in 1997 dollars per life-year saved, and the high-end estimate applies $5.9 million per life to the full estimate of incidence.

Table VII-10. Summary of Mortality Valuation Estimates[a]

Study	*Type of Estimate*	*Valuation per Statistical Life (millions of 1990 $)*
Kneisner and Leeth (1991) (US)	Labor Market	0.7
Smith and Gilbert (1984)	Labor Market	0.9
Dillingham (1985)	Labor Market	1.1
Butler (1983)	Labor Market	1.4
Miller and Guria (1991)	Contingent Valuation	1.5
Moore and Viscusi (1988)	Labor Market	3.1
Viscusi et al. (1991)	Contingent Valuation	3.3
Gegax et al. (1985)	Contingent Valuation	4.1
Marin and Psacharopoulos (1982)	Labor Market	3.4
Kneisner and Leeth (1991) (Australia)	Labor Market	4.1
Gerking et al. (1988)	Contingent Valuation	4.2
Cousineau et al. (1988)	Labor Market	4.4
Jones-Lee (1989)	Contingent Valuation	4.7
Dillingham (1985)	Labor Market	4.8
Viscusi (1978; 1979)	Labor Market	5.0
R.S. Smith (1976)	Labor Market	5.6
V.K. Smith (1983)	Labor Market	5.8
Olson (1981)	Labor Market	6.4
Viscusi (1981)	Labor Market	8.0
R.S. Smith (1974)	Labor Market	8.8
Moore and Viscusi (1988)	Labor Market	9.0
Kneisner and Leeth (1991) (Japan)	Labor Market	9.3
Herzog and Schlottman (1987)	Labor Market	11.2
Leigh and Folson (1984)	Labor Market	11.9
Leigh (1987)	Labor Market	12.8
Garen (1988)	Labor Market	16.6

[a] Based on Viscusi (1992). The values in Viscusi have been updated to 1997 $, as detailed in (Abt Associates, 1999).

b. Chronic Bronchitis

There are a limited number of studies that have estimated the impact of air pollution on chronic bronchitis. An important hindrance is the lack of long-term health data and the associated air pollution levels. Schwartz (1993) and Abbey et al.(1993; 1995) provide the evidence that long-term PM exposure gives rise to the development of chronic bronchitis in the U.S. Following the NO_x SIP call analysis (U.S. EPA, 1998b), our analysis uses the Schwartz study to develop a C-R function linking PM to chronic bronchitis.

It should be noted that Schwartz used data on the *prevalence* of chronic bronchitis, not its *incidence*. To use Schwartz's study and still estimate the change in incidence, there are at least two possible approaches. The first is to simply assume that it is appropriate to use the baseline *incidence* of chronic bronchitis in a C-R function with the estimated coefficient from Schwartz's study, to directly estimate the change in incidence. The second is to estimate the percentage change in the prevalence rate for chronic bronchitis using the estimated coefficient from Schwartz's study in a C-R function, and then to assume that this percentage change applies to a baseline incidence rate obtained from another source. (That is, if the prevalence declines by 25 percent with a drop in PM, then baseline incidence drops by 25 percent with the same drop in PM.) Following work in the retrospective analysis of the Clean Air Act (U.S. EPA 1997a, pg. D-24), our analysis uses the former approach, and estimates the change in incidence using an annual incidence rate of 0.6 percent.

Valuing Chronic Bronchitis

PM-related chronic bronchitis is the only measured morbidity endpoint that may be expected to last from the initial onset of the illness throughout the rest of the individual's life. WTP to avoid chronic bronchitis would therefore be expected to incorporate the present discounted value of a potentially long stream of costs (e.g., medical expenditures and lost earnings) and pain and suffering associated with the illness. Two studies, Viscusi et al. (1991) and Krupnick and Cropper (1992), provide estimates of WTP to avoid a case of chronic bronchitis.

The Viscusi et al. and the Krupnick and Cropper studies were experimental studies intended to examine new methodologies for eliciting values for morbidity endpoints. Although these studies were not specifically designed for policy analysis, we believe the studies provide reasonable estimates of the WTP for chronic bronchitis. As with other contingent valuation studies, the reliability of the WTP estimates depends on the methods used to obtain the WTP values. Some specific attributes of the studies may raise some questions regarding their reliability. An alternative approach that can be use is the cost of illness (COI) approach, which considers only the expenditures on the illness as a valuation method. This approach, however, underestimates the true value of a change in incidence because it does not consider other components of the valuation such as the amount an individual would be willing to pay to avoid the illness even if they did not have medical expenses to consider. As such, it can serve as a

lower bound of the value for chronic bronchitis. Therefore, this analysis values chronic bronchitis by using the COI approach in the low-end estimate and the WTP approach for the high-end estimate.

The COI approach for valuing chronic bronchitis uses average annual lost earnings and average annual medical expenditures reported in Krupnick and Cropper (1990). Using a 5 percent discount rate and assuming that (1) lost earnings continue to age 65, (2) medical expenditures are incurred until death, and (3) life expectancy is unchanged by chronic bronchitis, the present discounted value of the stream of medical expenditures and lost earnings associated with an average case of chronic bronchitis is estimated to be about $94,500 for a 30 year old, $about $71,200 for a 40 year old, about $73,000 for a 50 year old, and about $50,300 for a 60 year old. The midpoint of the COI estimates across the range of ages is $72,400 per case, which is used to value the low-end estimate of benefits for reduce incidence of chronic bronchitis.

For the WTP approach, we use two studies. The study by Viscusi et al. uses a sample that is larger and more representative of the general population than the study by Krupnick and Cropper (which selects people who have a relative with the disease). Thus, the valuation for the high-end estimate is based on the distribution of WTP responses from Viscusi et al. (1991). The WTP to avoid a case of pollution-related chronic bronchitis is derived by starting with the WTP to avoid a severe case of chronic bronchitis, as described by Viscusi et al. (1991)[yy], and adjusting it downward to reflect (1) the decrease in severity of a case of pollution-related CB relative to the severe case described in the Viscusi et al. study, and (2) the elasticity of WTP with respect to severity reported in the Krupnick and Cropper (Krupnick et al., 1992) study. The technical support document describes the adjustment procedure in more detail (Abt Associates, 1999). The mean value of the adjusted distribution is $319,280. This is the WTP for chronic bronchitis we used in our benefits analysis.

As expected, the WTP estimate is greater than the full COI estimate in part because it reflects the willingness to pay to avoid the pain and suffering associated with the illness. Thus, the COI approach has a known downward bias because it does not include a measure of an individual's willingness to pay some amount to avoid the illness even if no medical expenses and no loss of earnings occurred. The WTP estimate of $319,280 is from 3.4 times the COI estimate for 30 year olds to 6.3 times the estimate for 60 year olds.

[yy]As previously mentioned, the Schwartz (1993) study defines a case of chronic bronchitis for the purpose of estimating a concentration-response function. This function only examines the relationship of chronic bronchitis and PM without differentiating between severity of cases. Therefore, an adjustment for severity is necessary to value the benefits of reduced incidences.

c. Hospital Admissions

Both ozone and particulate matter have been associated with increased risk of premature mortality. Each is discussed below.

Estimating Ozone-related Hospital Admissions

Our analysis estimates ozone-related hospital admissions for "all respiratory diseases," using a C-R function based on the work of Thurston et al. (1992). Thurston et al. examined hospital admissions for all ages in the population. Because of the comprehensiveness of the Thurston et al. study, it is selected over other available studies that are restricted to limited age ranges (e.g., the population aged 65 years and older), and/or specific diagnoses (e.g., hospital admissions for pneumonia). The age- and disease-specific effect categories are subsets of the all-age, all-respiratory disease hospital admission category. Therefore, the benefits of avoided hospital admissions for respiratory illnesses for all ages should be larger than the benefits for more restricted categories. However, that is not true for the estimated benefits, based on the available studies. The estimated relationship produces fewer benefits than either of the two available alternatives: all respiratory disease admissions for the population over 65; or the sum of pneumonia and chronic obstructive pulmonary disease (COPD) admissions for the population over 65. Clearly adding the results for these study types would involve a serious amount of double counting. Therefore, selecting the Thurston et al. study may underestimate the total benefits of hospital admissions.

Estimating PM-related Hospital Admissions

The benefits analysis includes three PM-related hospital admissions, due to all respiratory illnesses (Thurston et al., 1994), congestive heart failure (Schwartz and Morris, 1995), and ischemic heart disease (Schwartz and Morris, 1995). As with ozone-induced hospital admissions, the benefits analysis relies on a study of all respiratory hospital admissions for all age groups, rather than studies examining the population over 65.

Valuing Hospital Admissions

An individual's WTP to avoid a hospital admission will include, at a minimum, the amount of money they pay for medical expenses (i.e., what they pay towards the hospital charge and the associated physician charge) and the loss in earnings. In addition, however, an individual is likely to be willing to pay some amount to avoid the pain and suffering associated with the illness itself. That is, even if they incurred no medical expenses and no loss in earnings, most individuals would still be willing to pay something to avoid the illness.

Because medical expenditures are to a significant extent shared by society, via medical insurance, Medicare, etc., the medical expenditures actually incurred by the individual are likely to be less than the total medical cost to society. The total value to society of an individual's

avoidance of hospital admission, then, might be thought of as having two components: (1) the cost of illness (COI) to society, including the total medical costs plus the value of the lost productivity, as well as (2) the individual's WTP to avoid the illness itself.

In the absence of estimates of social WTP to avoid hospital admissions for specific illnesses (components 1 plus 2 above), estimates of total COI (component 1) are typically used as conservative (lower bound) estimates. Because these estimates do not include the value of avoiding the illness itself (component 2), they are biased downward. Some analyses adjust COI estimates upward by multiplying by an estimate of the ratio of WTP to COI, to better approximate total WTP. Other analyses have avoided making this adjustment because of the possibility of over adjusting -- that is, possibly replacing a known downward bias with an upward bias. The previous RIAs for PM and ozone, as well as the revised RIA for ozone and PM NAAQS, did adjust the COI estimate upward. The COI values used in this benefits analysis will not be adjusted to better reflect the total WTP. This is consistent with the guidance offered by the §812 Science Advisory Board (SAB) committee.

The COI estimates used in our analysis consist of three components: estimated physician charges (based on the average length of a hospital stay for the illness), the estimated opportunity cost of time spent in the hospital, and estimated hospital charges.

Our analysis assumes that physician charges associated with hospital care for asthma and chronic obstructive pulmonary disease (COPD) (two endpoints not estimated for this analysis) provide reasonably good estimates of average physician charges associated with hospital stays for the illness categories considered here. Abt Associates (1992) estimated that physician charges for the first day of hospital care for asthma (in 1988) or COPD (in 1989) averaged $135 (in 1997 $); physician charges for subsequent days of hospital care averaged $50. Estimated physician charges for a hospital stay of n days for any of the illness categories discussed below, then, would be $135 + $50(n-1).

The opportunity cost of a day spent in the hospital is estimated, for people in the workforce, as the value of the lost daily wage. This is estimated at $102. The study on PM and work loss days from which this value is derived (Ostro, 1987), however, considers only individuals 18 to 65 years old, while two of the hospital admission studies used in this analysis ("all respiratory, all ages", Thurston et al., 1994; and Thurston et al., 1992), considers all ages for both ozone and PM. It should be noted that, because the value of a PM-related work loss day (WLD) is elsewhere added into the total benefits analysis as a separate health endpoint, including it as a component of the WTP to avoid a PM-related hospital admission associated would be double counting. Additionally, because there is a not a separate work loss function for ozone, the lost productivity is included in the cost of an ozone hospital admission, but not for PM.

To derive estimates of the opportunity cost of a day spent in the hospital for respiratory illness based on Thurston et al. (1994) or Thurston et al. (1992), which considered individuals of

all ages, we assumed that half of the PM- or ozone-related hospital admissions are among individuals who are not employed, including the young and the elderly.[zz] We therefore estimated the expected opportunity cost of a day spent in the hospital for an individual randomly selected from among those admitted to the hospital for PM- or ozone-related respiratory illnesses to be (0.5)($102) +(0.5)($51) = $76.50. However, because the value of work loss days for those in the labor force is a separate component of the total benefit for PM, only the second component of opportunity cost enters the PM-related "all respiratory" hospital admissions benefit, which is, then, (0.5)($51) = $25.50.

To estimate the opportunity cost of a day spent in the hospital for an individual aged 65 or older (necessary for the ischemic heart disease and congestive heart failure hospital admission functions for individuals 65 years and over), we assumed that such an individual is not in the workforce. Although the value of a WLD may be an inappropriate way to estimate the opportunity cost of a day spent in the hospital for someone who is not employed (including the young and the elderly), this opportunity cost is positive and should not be ignored. As a rough approximation, we assumed that, for the young, the elderly, and any other unemployed individuals, the opportunity cost of a day spent in the hospital is one-half what it is for individuals in the workforce, or $51.

Finally, for all hospital admissions included in this analysis, we based estimates of hospital charges on discharge statistics provided by Elixhauser et al. (1993). The resulting Cost of Illness values for hospital admissions are shown in Table VII-11.

[zz]This is approximately the same as the ratio of employed to total population in the United States. In 1994, for example, this ratio was (123 million)/(260 million), or 47 percent.

Table VII-11. Derivation of Cost of Illness (COI) and Total WTP Estimates for Hospital Admissions Endpoints (1997$[a])

Hospital Admissions For:	*Hospital Charge (1)*	*Physician Charge (2)*	*Opportunity Cost*			*Total Cost of Illness (COI) (1) + (2) + (3)* *(Standard Deviation)*
			Opportunity Cost per day	*Avg Length of Stay (days)*	*Total Opportunity Cost (3)*	
Ischemic Heart Disease, age $ 65 (ICD codes 410-414)	$13,996	$438	$50.96	7	$357	$14,791 ($126)
Congestive Heart Failure, age $ 65 (ICD code 428)	$10,854	$539	$50.96	9	$459	$11,852 ($166)
PM-Related "all respiratory illnesses," all ages (ICD codes 466, 480-482, 485, 490-493)	$8,414	$488	$25.48	8	$204	$9,106 ($115)
Ozone-Related "all respiratory illnesses," all ages (ICD codes 466, 480-486, 490-493)	$8,607	$438	$76.44	7	$535	$9,580 ($93)

[a] Note: Two different escalation factors were used in the adjustment to 1997$. Hospital and physician charges both used escalation factors based upon the CPI-U for medical care. The opportunity cost adjustment used an escalation factor base upon the CPI-U for "all items." The standard deviation in the Total Cost of Illness column is based upon a weighted average of each of the three COI components.

d. Acute Bronchitis

Dockery et al. (1989) examined the relationship between PM and other pollutants on the reported rates of chronic cough, bronchitis and chest illness, in a study of 5,422 children aged ten to twelve. Bronchitis and chronic cough were both found to be significantly related to PM concentrations.

Estimating WTP to avoid a case of acute bronchitis is difficult for several reasons. First, WTP to avoid acute bronchitis itself has not been estimated. Estimation of WTP to avoid this health endpoint therefore must be based on estimates of WTP to avoid symptoms that occur with this illness. Second, a case of acute bronchitis may last more than one day, whereas it is a day of avoided symptoms that is typically valued. Finally, the C-R function used in the benefit analysis for acute bronchitis was estimated for children, whereas WTP estimates for those symptoms associated with acute bronchitis were obtained from adults.

With these caveats in mind, we estimate WTP to avoid a case of acute bronchitis as the midpoint between a low estimate and a high estimate. The low estimate ($16.32) is the sum of the midrange values recommended by IEc (1994) for two symptoms believed to be associated with acute bronchitis: coughing ($7.72) and chest tightness ($8.60). The high estimate was taken to be twice the value of a minor respiratory restricted activity day ($47.12), or $94.24. The midpoint between the low and high estimates is $55.26.

e. PM-related Upper Respiratory Symptoms

The benefits analysis used the C-R function for PM-related Upper Respiratory Symptoms (URS) from Pope et al. (1991). Pope et al. describe URS as consisting of one or more of the following symptoms: runny or stuffy nose; wet cough; and burning, aching, or red eyes. The children in the Pope et al. study were asked to record respiratory symptoms in a daily diary, and the daily occurrences of URS and LRS, as defined above, were related to daily PM_{10} concentrations. Estimates of WTP to avoid a day of symptoms are therefore appropriate measures of benefit.

Willingness to pay to avoid a day of URS is based on symptom-specific WTPs to avoid those symptoms identified by Pope et al. as part of the URS complex of symptoms. Three contingent valuation (CV) studies have estimated WTP to avoid various morbidity symptoms that are either within the URS symptom complex defined by Pope et al. (1991) or are similar to those symptoms identified by Pope et al. In each CV study, participants were asked their WTP to avoid a day of each of several symptoms. The three individual symptoms that were identified as most closely matching those listed by Pope et al. for URS are cough, head/sinus congestion, and eye irritation. A day of URS could consist of any one of seven possible “symptom complexes” consisting of at least one of these symptoms. It is assumed that each of the seven

types of URS is equally likely. The mean WTP to avoid a day of URS is therefore the average of the mean WTPs to avoid each type of URS, or $22.96. This is the point estimate for the dollar value for PM-related URS used in the benefit analysis. Finally, it is worth emphasizing that what is being valued here is URS *as defined by Pope et al.* While other definitions of URS are certainly possible, we used this definition of URS in the benefits analysis because it is the incidence of this specific definition of URS that has been related to PM exposure by Pope et al.(1991).

f. PM-related Lower Respiratory Symptoms

Schwartz et al. (1994) estimated the relationship between Lower Respiratory Symptoms (LRS) and PM-10 concentrations. The method for deriving a point estimate of mean WTP to avoid a day of LRS is the same as for URS. Schwartz et al. define LRS as at least two of the following symptoms: cough, chest pain, phlegm, and wheeze. The symptoms for which WTP estimates are available that reasonably match those listed by Schwartz et al. for LRS are cough (C), chest tightness (CT), coughing up phlegm (CP), and wheeze (W). A day of LRS, as defined by Schwartz et al., could consist of any one of the 11 combinations of at least two of these four symptoms.

We assumed that each of the eleven types of LRS is equally likely. The mean WTP to avoid a day of LRS as defined by Schwartz et al. (1994) is therefore the average of the mean WTPs to avoid each type of LRS, or $14.51. This is the point estimate used in the benefit analysis for the dollar value for LRS as defined by Schwartz et al. The WTP estimates are based on studies which considered the value of a *day* of avoided symptoms, whereas the Schwartz et al. study used as its measure a *case* of LRS. Because a case of LRS usually lasts at least one day, and often more, WTP to avoid a day of LRS should be a conservative estimate of WTP to avoid a case of LRS.

Finally, as with URS, it is worth emphasizing that what is being valued here is LRS *as defined by Schwartz et al. (1994).* While other definitions of LRS are certainly possible, this definition of LRS is used in this benefit analysis because it is the incidence of this specific definition of LRS that has been related to PM exposure by Schwartz et al.

The point estimates derived for mean WTP to avoid a day of URS and a case of LRS are based on the assumption that WTPs are additive. For example, if WTP to avoid a day of cough is $8.60, and WTP to avoid a day of shortness of breath is $6.14, then WTP to avoid a day of both cough and shortness of breath is $14.74. If there are no synergistic effects among symptoms, then it is likely that the marginal utility of avoiding symptoms decreases with the number of symptoms being avoided. If this is the case, adding WTPs would tend to overestimate WTP for avoidance of multiple symptoms. However, there may be synergistic effects– that is, the discomfort from two or more simultaneous symptoms may exceed the sum of the discomforts associated with each of the individual symptoms. If this is the case, adding WTPs would tend to

underestimate WTP for avoidance of multiple symptoms. It is also possible that people may experience additional symptoms for which WTPs are not available, again leading to an underestimate of the correct WTP. However, for small numbers of symptoms, the assumption of additivity of WTPs is unlikely to result in substantive bias.

There are three sources of uncertainty in the valuation of both URS and LRS: (1) an occurrence of URS or of LRS may be comprised of one or more of a variety of symptoms (i.e., URS and LRS are each potentially a "complex of symptoms"), so that what is being valued may vary from one occurrence to another; (2) for a given symptom, there is uncertainty about the mean WTP to avoid the symptom; and (3) the WTP to avoid an occurrence of multiple symptoms may be greater or less than the sum of the WTPs to avoid the individual symptoms.

g. Ozone-related Any of 19 Respiratory Symptoms

The presence of "any of 19 acute respiratory symptoms" is a somewhat subjective health effect used by Krupnick et al. (1990). Moreover, not all 19 symptoms are listed in the Krupnick et al. study. It is therefore not clear exactly what symptoms were included in the study. Even if all 19 symptoms were known, it is unlikely that WTP estimates could be obtained for all of the symptoms. Finally, even if all 19 symptoms were known and WTP estimates could be obtained for all 19 symptoms, the assumption of additivity of WTPs becomes tenuous with such a large number of symptoms. The likelihood that all 19 symptoms would occur simultaneously, moreover, is very small.

Acute respiratory symptoms must be either upper respiratory symptoms or lower respiratory symptoms. In the absence of further knowledge about which of the two types of symptoms is more likely to occur among the "any of 19 acute respiratory symptoms," we assumed that they occur with equal probability. Because this health endpoint may also consist of combinations of symptoms, it was also assumed that there is some (smaller) probability that upper and lower respiratory symptoms occur together.

To value avoidance of a day of "the presence of any of 19 acute respiratory symptoms" we therefore assumed that this health endpoint consists either of URS, or LRS, or both. We also assumed that it is as likely to be URS as LRS and that it is half as likely to be both together. That is, it was assumed that "the presence of any of 19 acute respiratory symptoms" is a day of URS with 40 percent probability, a day of LRS with 40 percent probability, and a day of both URS and LRS with 20 percent probability. Using the point estimates of WTP to avoid a day of URS and LRS derived above, the point estimate of WTP to avoid a day of "the presence of any of 19 acute respiratory symptoms" is:

$$(0.40)(\$22.96) + (0.40)(\$14.51) + (0.20)(\$22.96 + \$14.51) = \$22.48$$

Because this health endpoint is only vaguely defined, and because of the lack of information on

the relative frequencies of the different combinations of acute respiratory symptoms that might qualify as "any of 19 acute respiratory symptoms," the unit dollar value derived for this health endpoint must be considered only a rough approximation.

h. Work Loss Days

Ostro (1987) estimated the impact of PM on the incidence of work-loss days (WLD) in a national sample of the adult working population, ages 18 to 65, living in metropolitan areas. Separate coefficients were developed for each year in the analysis (1976-1981); we then combined these coefficients for use in this analysis.

Willingness to pay to avoid the loss of one day of work was estimated by dividing the median weekly wage for 1990 (U.S. Bureau of the Census, 1992) by five (to get the median daily wage). This values the loss of a day of work at the median wage for the day lost. Valuing the loss of a day's work at the wages lost is consistent with economic theory, which assumes that an individual is paid exactly the value of his labor.

The use of the median rather than the mean, however, requires some comment. If all individuals in society were equally likely to be affected by air pollution to the extent that they lose a day of work because of it, then the appropriate measure of the value of a work loss day would be the mean daily wage. It is highly likely, however, that the loss of work days due to pollution exposure does not occur with equal probability among all individuals, but instead is more likely to occur among lower income individuals than among high income individuals. It is probable, for example, that individuals who are vulnerable enough to the negative effects of air pollution to lose a day of work as a result of exposure tend to be those with generally poorer health care. Individuals with poorer health care have, on average, lower incomes. To estimate the average lost wages of individuals who lose a day of work because of exposure to PM pollution, then, would require a weighted average of all daily wages, with higher weights on the low end of the wage scale and lower weights on the high end of the wage scale. Because the appropriate weights are not known, however, the median wage was used rather than the mean wage. The median is more likely to approximate the correct value than the mean because means are highly susceptible to the influence of large values in the tail of a distribution (in this case, the small percentage of very large incomes in the United States), whereas the median is not susceptible to these large values. The median daily wage in 1990 was $101.92 (adjusted to 1997 $). This is the value that was used to represent work loss days (WLD).

i. Minor Restricted Activity Days

Ostro and Rothschild (1989) estimated the impact of $PM_{2.5}$ on the incidence of minor restricted activity days (MRAD) in a national sample of the adult working population, ages 18 to 65, living in metropolitan areas. We developed separate coefficients for each year in the analysis

(1976-1981), which were then combined for use in this analysis.

No studies are reported to have estimated WTP to avoid a minor restricted activity day (MRAD). However, IEc (1993) has derived an estimate of WTP to avoid a minor respiratory restricted activity day (MRRAD), using WTP estimates from Tolley et al. (1986) for avoiding a three-symptom combination of coughing, throat congestion, and sinusitis. This estimate of WTP to avoid a MRRAD, so defined, is $47.12. Although Ostro and Rothschild (1989) estimated the relationship between $PM_{2.5}$ and MRADs, rather than MRRADs (a component of MRADs), it is likely that most of the MRADs associated with exposure to $PM_{2.5}$ are in fact MRRADs. For the purpose of valuing this health endpoint, then, we assumed that MRADs associated with PM exposure may be more specifically defined as MRRADs, and therefore used the estimate of mean WTP to avoid a MRRAD.

Any estimate of mean WTP to avoid a MRRAD (or any other type of restricted activity day other than WLD) will be somewhat arbitrary because the endpoint itself is not precisely defined. Many different combinations of symptoms could presumably result in some minor or less minor restriction in activity. Krupnick and Kopp (1988) argued that mild symptoms will not be sufficient to result in a MRRAD, so that WTP to avoid a MRRAD should exceed WTP to avoid any single mild symptom. A single severe symptom or a combination of symptoms could, however, be sufficient to restrict activity. Therefore WTP to avoid a MRRAD should, these authors argue, not necessarily exceed WTP to avoid a single severe symptom or a combination of symptoms. The “severity” of a symptom, however, is similarly not precisely defined; moreover, one level of severity of a symptom could induce restriction of activity for one individual while not doing so for another. The same is true for any particular combination of symptoms.

Given that there is inherently a substantial degree of arbitrariness in any point estimate of WTP to avoid a MRRAD (or other kinds of restricted activity days), the reasonable bounds on such an estimate must be considered. By definition, a MRRAD does not result in loss of work. WTP to avoid a MRRAD should therefore be less than WTP to avoid a WLD. At the other extreme, WTP to avoid a MRRAD should exceed WTP to avoid a single mild symptom. The highest IEc midrange estimate of WTP to avoid a single symptom is $19.30, for eye irritation. The point estimate of WTP to avoid a WLD in the benefit analysis is $101.92. If all the single symptoms evaluated by the studies are not severe, then the estimate of WTP to avoid a MRRAD should be somewhere between $19.30 and $101.92. Because the IEc estimate of $47.12 falls within this range (and acknowledging the degree of arbitrariness associated with any estimate within this range), we used the IEc estimate as the point estimate of mean WTP to avoid a MRRAD.

j. Worker Productivity

The benefits analysis based the valuation used to monetize benefits associated with

increased worker productivity resulting from improved ozone air quality on information reported in Crocker and Horst (1981) and summarized in EPA (1994). Crocker and Horst (1981) examined the impacts of ozone exposure on the productivity of outdoor citrus workers. The study measured productivity impacts as the change in income associated with a change in ozone exposure, given as the elasticity of income with respect to ozone concentration (-0.1427). The reported elasticity translates a ten percent reduction in ozone to a 1.4 percent increase in income. Given the average daily income for outdoor workers engaged in strenuous activity reported by the 1990 U.S. Census, $89.64 per day (adjusted to 1997 $), a ten percent reduction in ozone yields approximately $1 in increased daily wages.

4. Ozone- and PM-Related Welfare Effects

In addition to the effects on human health described above, emission reductions attributed to the Tier 2 rule will also produce welfare (i.e., non-health) benefits. Welfare effects cover a potentially broad range of adverse effects, including adverse impacts on plants, animals, structural materials, visibility, and ecosystem functions. Like health effects, in order to be included in a quantified monetary benefits analysis, all of the analytical links between changes in emissions and the monetary value of the effects must be available. While the required analytical components are available for certain welfare endpoints, our analysis omits many other likely or possible welfare categories. The availability of information on each analytical step limits the total coverage of the welfare effects. All of the welfare benefits that are quantified and included in the benefits analysis were included in the NO_x SIP call. Table VII-12 lists the welfare categories that are included in the benefits analysis; the technical support document for this RIA provides further detail on these endpoints (Abt Associates, 1999). Each of these categories will be discussed separately below.

Table VII-12. Quantified Welfare Effects Included in the Benefits Analysis

Welfare Effect	*Pollutant*	*Study*
Agriculture - commodity crops	Ozone	Taylor (1993)
Nitrogen deposition in estuarine and coastal waters	NO_x	EPA (1998a)
Visibility-recreational	PM and gases	Chestnut et al. (1997)
Visibility-residential	PM and gases	McClelland et al. (1991)
Household soiling	PM	ESEERCO (1994)

a. Commodity Agricultural Crops

The economic value associated with varying levels of yield loss for ozone-sensitive commodity crops is analyzed using the AGSIM© agricultural benefits model (Taylor et al.,

1993). AGSIM© is an econometric-simulation model that is based on a large set of statistically estimated demand and supply equations for agricultural commodities produced in the United States. The model is capable of analyzing the effects of changes in policies (in this case, the implementation of the Tier 2 rule) that affect commodity crop yields or production costs. The technical support document for this RIA provides further details on AGSIM© (Abt Associates, 1999).

The measure of benefits calculated by the model is the net change in consumers' and producers' surplus from baseline ozone concentrations to the ozone concentrations resulting from attainment of particular standards. Using the baseline and post-control equilibria, the model calculates the change in net consumers' and producers' surplus on a crop-by-crop basis[aaa]. Dollar values are aggregated across crops for each standard. The total dollar value represents a measure of the change in social welfare associated with the Tier 2 rule. Although the model calculates benefits under three alternative welfare measures (perfect competition, price supports, and modified agricultural policy), results presented here are based on the "perfect competition" measure to reflect recent changes in agricultural subsidy programs. Under the recently revised 1996 Farm Bill , most eligible farmers have enrolled in the program to phase out government crop price supports for the AGSIM©-relevant crops: wheat, corn, sorghum, and cotton.

For the purpose of our analysis, the model analyzed the six most economically significant crops: corn, cotton, peanuts, sorghum, soybean, and winter wheat.[bbb] The model employs biological exposure-response information derived from controlled experiments conducted by the National Crop Loss Assessment Network (NCLAN) (1996).

b. Nitrogen Deposition

Excess nutrient loads, especially that of nitrogen, cause a variety of adverse consequences to the health of estuarine and coastal waters. These effects include toxic and/or noxious algal blooms such as brown and red tides, low (hypoxic) or zero (anoxic) concentrations of dissolved oxygen in bottom waters, the loss of submerged aquatic vegetation due to the light-filtering effect of thick algal mats, and fundamental shifts in phytoplankton community structure. Direct C-R functions relating deposited nitrogen and reductions in estuarine benefits are not available. The preferred willingness-to-pay based measure of benefits depends on the availability of these C-R functions and on estimates of the value of environmental responses. Because neither appropriate C-R functions nor sufficient information to estimate the marginal

[aaa] Agricultural benefits differ from other health and welfare endpoints in the length of the assumed ozone season. For agriculture, the ozone season is assumed to extend from April to September. This assumption is made to ensure proper calculation of the ozone statistic used in the exposure-response functions. The only crop affected by changes in ozone during April is winter wheat.

[bbb] The total value for these crops in 1997 was $57 billion.

value of changes in water quality exist at present, this analysis used an avoided cost approach instead of willingness-to-pay to generate estuary-related benefits. The use of the avoided cost approach to establish the value of a reduction in nitrogen deposition is problematic, because there is not a direct link between implementation of the air pollution regulation and the abandonment of a separate costly regulatory program by some other agency, (i.e. a state environmental agency). However, there are currently no readily available alternatives to this approach.[ccc]

The avoided costs to surrounding communities of reduced nitrogen loadings were calculated for three case study estuaries.[ddd] These costs are used to estimate the avoided costs for ten East Coast estuaries, and two Gulf Coast case study estuaries for which reduced nitrogen loadings were modeled.[eee] The avoided cost estimates for the ten East Coast case study estuaries, which represent approximately half of the estuarine watershed area in square miles along the East Coast, are then used to extrapolate avoided costs to all East Coast estuaries. The three case study estuaries are chosen because they have agreed upon nitrogen reduction goals and the necessary nitrogen control cost data. The remaining estuaries in this analysis are chosen based on their potential representativeness and our ability to estimate the direct and indirect nitrogen load from atmospheric deposition.

Our analysis values atmospheric nitrogen reductions on the basis of avoided costs associated with agreed upon controls of nonpoint water pollution sources. We estimated benefits using a weighted-average, locally-based cost for nitrogen removal from water pollution (U.S. EPA, 1998a). Valuation reflects water pollution control cost avoidance based on the weighted average cost/pound of current non-point source water pollution controls for nitrogen in the three case study estuaries. Taking the weighted cost/pound of these available controls assumes States will combine low cost and high cost controls, which could inflate avoided cost estimates.

Reductions in nitrogen deposition from the Tier 2 rule should impact estuaries all along the eastern seaboard and the Gulf Coast. Nitrogen reduction programs are currently targeting many of the estuaries in these areas due to current impairment of estuarine water quality by excess nutrients. Some of the largest of these estuaries, including the Chesapeake Bay, have established goals for nitrogen reduction and target dates by which these goals should be

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[ccc] Avoided cost is only a proxy for benefits, and should be viewed as inferior to willingness-to-pay based measures. Current research is underway to develop other approaches for valuing estuarine benefits, including contingent valuation and hedonic property studies. However, this research is still sparse, and does not contain sufficient information on the marginal willingness-to-pay for changes in concentrations of nitrogen (or changes in water quality or water resources as a result of changes in nitrogen concentrations).

[ddd] The case study estuaries are Albemarle-Pamlico Sounds, Chesapeake Bay, and Tampa Bay.

[eee] The ten East Coast estuaries are Albemarle-Pamlico Sounds, Cape Cod Bay, Chesapeake Bay, Delaware Bay, Delaware Inland Bays, Gardiners Bay, Hudson River/Raritan Bay, Long Island Sound, Massachusetts Bays, and Narragansett Bays. The Gulf Coast estuaries are Sarasota Bay and Tampa Bay.

achieved. Using the best and most easily implemented existing technologies, many of the estuaries will not be able to achieve the stated goals by the target dates. Meeting these additional reductions will require development of new technologies, implementation of costly existing technologies (such as stormwater controls), or use of technologies with significant implementation difficulties, such as agricultural best management practices (BMPs). Reductions in nitrogen deposition from the atmosphere will directly reduce the need for these additional costly controls. Thus, while the Tier 2 rule does not totally eliminate the need for nutrient management programs already in place, it may substitute for some of the incremental costs and programs (such as an agricultural BMP program) necessary to meet the nutrient reduction goals for each estuary.

The fixed capital costs for non-point controls in the case study estuaries ranged from $0.75 to $55.59 per pound for agricultural and other rural best management practices and from $42.98 to $175.16 per pound for urban nonpoint source controls (stormwater controls, reservoir management, onsite disposal system changes, onsite BMPs).[fff] Using these as a base, we calculated the total fixed capital cost per pound (weighted on the basis of fractional relationship of nitrogen load controlled for the estuary goal) for each of the case-study estuaries and applied in the valuation of their avoided nitrogen load controlled. The weighted capital costs per pound for the case-study estuaries are $40.95 for Albemarle-Pamlico Sounds, $26.79 for Chesapeake Bay, and $108.36 for Tampa Bay[ggg]. For the purposes of our analysis, EPA assumes that estuaries that have not yet established nutrient reduction goals will utilize the same types of nutrient management programs as projected for the case study estuaries. For the other nine estuaries, an average capital cost per pound of nitrogen (from the three case-estuaries) of $58.70/lb is calculated and applied; it is unclear whether this cost understates or overstates the costs associated with reductions in these other estuaries. The other nine estuaries generally represent smaller, more urban estuaries (like Tampa Bay), which typically have fewer technical and financial options available to control nitrogen loadings from nonpoint sources. This may result in higher control costs more similar to the Tampa Bay case. On the other hand, these estuaries may have opportunities to achieve additional point source controls at a lower costs. Also, increased public awareness of nutrification issues and technological innovation may, in the future, result in States finding lower cost solutions to nitrogen removal.

The benefits analysis assumed that the ten included East Coast estuaries are highly or moderately nutrient sensitive, and they represent approximately 45.46 percent of all estuarine watershed area along the East Coast.[hhh] Because NOAA data indicate that approximately 92.6

[fff] The figures in the original work have been updated to 1997 $ using an all-good CPI index.

[ggg] The value for Tampa Bay is not a true weighted cost per pound, but a midpoint of a range of $71.89 to $144.47 developed by Apogee Research for the control possibilities (mostly urban BMPs) in the Tampa Bay estuary.

[hhh] There are 43 East Coast estuaries of which ten were in the sample, and 31 Gulf of Mexico estuaries of which two are in the sample.

percent of the watershed and surface area of East Coast estuaries are highly or moderately nutrient sensitive, it is reasonable to expect that East Coast estuaries not included in this analysis would also benefit from reduced deposition of atmospheric nitrogen. Therefore, we scaled-up total benefits from the ten representative East Coast estuaries to include the remainder of the nutrient sensitive estuaries along the East Coast on the basis of estuary watershed plus water surface area. Since the ten estuaries are assumed to be nutrient sensitive and account for 48 percent of total eastern estuarine area, we scaled-up estimates by multiplying the estimate for the ten East Coast estuaries by 2.037 (equal to 92.6 percent divided by 45.46 percent). We then added this figure to the benefits estimated for the two Gulf Coast estuaries for a total benefits estimate for nitrogen deposition.

We then annualized all capital cost estimates based on a seven percent discount rate and a typical implementation horizon for control strategies. Based on information from the three case study estuaries, this typically ranges from five to ten years. EPA has used the midpoint of 7.5 years for annualization, which yields an annualization factor of 0.1759. Non-capital installation costs and annual operating and maintenance costs are not included in these annual cost estimates. Depending upon the control strategy, these costs can be significant. Reports on the Albemarle-Pamlico Sounds indicate, for instance, that planning costs associated with control measures comprises approximately 15 percent of capital costs. Information received from the Association of National Estuary Programs indicates that operating and maintenance costs are about 30 percent of capital costs, and that permitting, monitoring, and inspections costs are about one to two percent of capital costs. For these reasons, the annual cost estimates may be understated.

c. Household Soiling Damage

Welfare benefits also accrue from avoided air pollution damage, both aesthetic and structural, to architectural materials and to culturally important articles. At this time, data limitations preclude the ability to quantify benefits for all materials whose deterioration may be promoted and accelerated by air pollution exposure. However, our analysis addresses one small effect in this category, the soiling of households by particulate matter.

Assumptions regarding the air quality indicator are necessary to evaluate the C-R function. PM_{10} and $PM_{2.5}$ are both components of TSP. However, it is not clear which components of TSP cause household soiling damage. The Criteria Document cites some evidence that smaller particles may be primarily responsible, in which case these estimates are conservative.

Several studies have provided estimates of the cost to households of PM soiling. The study that is cited by ESEERCO (1994) as one of the most sophisticated and is relied upon by EPA in its 1988 Regulatory Impact Analysis for SO_2 is Manuel et al. (1982). Using a household production function approach and household expenditure data from the 1972-73 Bureau of Labor

Statistics Consumer Expenditure Survey for over twenty cities in the United States, Manuel et al. estimate the annual cost of cleaning per $\mu g/m^3$ PM per household as $1.55 ($0.59 per person times 2.63 persons per household). This estimate is low compared with others (e.g., estimates provided by Cummings et al. (1981) and Watson and Jaksch (1982) are about eight times and five times greater, respectively). The ESEERCO report notes, however, that the Manuel et al. estimate is probably downward biased because it does not include the time cost of do-it-yourselfers. Estimating that these costs may comprise at least half the cost of PM-related cleaning costs, they double the Manuel et al. estimate to obtain a point estimate of $3.09 (reported by ESEERCO in 1992 dollars as $2.70).

d. Visibility

Visibility effects reported earlier in this chapter are described in terms of changes in deciview, a unitless measure useful for comparing the effects of air quality on visibility. This measure is used in the WTP function for visibility and is directly related to two other common visibility measures: visual range (measured in km) and light extinction (measured in km^{-1}). Modeled changes in visibility are measured in terms of changes in light extinction, which are then transformed into deciviews. A change of one deciview represents a change of approximately 10 percent in the light extinction budget, "which is a small but perceptible scenic change under many circumstances." (Sisler, 1996) A change of less than 10 percent in the light extinction budget represents a measurable improvement in visibility, but may not be perceptible to the eye in many cases. All of the average regional changes in visibility are substantially less than one deciview (i.e. less than 10 percent of the light extinction budget), and thus less than perceptible. However, this does not mean that these changes are not real or significant. Our assumption is then that individuals can place values on changes in visibility that may not be perceptible. This is quite plausible if individuals are aware that many regulations lead to small improvements in visibility which when considered together amount to perceptible changes in visibility.

The analysis derives the residential visibility valuation estimate from the results of an visibility study (McClelland et al., 1991). We derive a household WTP value by dividing the value reported in McClelland et al. by the corresponding hypothesized change in deciview, yielding an estimate of $17 per unit change in deciview. Due to the somewhat dated methods used in the McClelland study and inconsistencies of the study with current best practices for conducting contingent valuation studies, the reliability of the results of the McClelland is uncertain. EPA recognizes these uncertainties, but believes a non-zero value exists for residential visibility improvements. Without alternative studies to verify the reliability of the WTP estimate from McClelland, the low-end estimate in this analysis does not value residential visibility while the high-end estimate uses the $17 per unit change in deciview obtained from the study. This value is applied to all households – including any households living in or around national parks– in any area estimated to experience a change in visibility.

A separate valuation component is needed for valuing improvements in visibility in national parks and other areas (collectively known as "Class I areas"). Chestnut (1997) developed a method for estimating the value to the U.S. public of visibility improvements in Class I visibility areas. The approach was based on the results of a 1990 Cooperative Agreement project jointly funded by the EPA and the National Park Service, "Preservation Values For Visibility Protection at the National Parks." Based on that contingent valuation study of visibility improvements, Chestnut calculates a household WTP for visibility improvements in Class I-area National Parks, capturing both use and non-use recreational values, and accounts for geographic variations in the willingness to pay. The PM and ozone NAAQS RIA (U.S. EPA, 1997b) analysis used this method. Similar to the McClelland study, the reliability of the results of the Chestnut study are uncertain because of inconsistency with certain elements of best practices for conducting contingent valuation. Contingent valuation is a rapidly developing field and new methodologies for study design are continually evolving. As such, studies developed during the late 1980's and early 1990's may differ in some elements of study design from more recent studies. EPA recognizes that there are some important aspects of the Chestnut study that are still useful for providing valuations associated with recreational visibility improvements. In the author's judgement, the WTP value derived in the Chestnut study "*may be indicative of an accuracy no better than ± 50 percent* (Chestnut and Rowe, 1990)." Due to these uncertainties, the low-end estimate presents a conservative estimate of WTP for recreational visibility improvements that reflects the lower-bound of the variation (-50 percent).

More specifically, the Preservation Values study examined the demand for visibility in Class I-area National Parks in three broad regions of the country, California, Southwest, and Southeast. Because the Tier 2 rule has an impact on ambient pollution in all states – even in California, due to drift from neighboring states – all three regions are relevant to the visibility analysis. For a given region, the Preservation Values study asked respondents in Arizona, California, Missouri, New York and Virginia for their willingness to pay to protect visibility at National Parks in that region. Table VII-13 lists the parks included in the study in the study regions, as well as the parks in other regions specifically mentioned in the Preservation Values study. These other parks are used in estimating the visibility benefits in the "transfer regions", as described below.

Table VII-13. Class I Areas Included in Visibility Study By Region

Visibility Region	*National Parks*
California & Nevada	**Yosemite**, Sequoia/Kings Canyon, Redwoods, Pinnacles, Lava Beds, Death Valley, Lassen Volcanic, Joshua Tree, Point Reyes
Southwest	**Grand Canyon**, Mesa Verde, Arches, Bandelier, Capitol Reef, Carlsbad Caverns, Bryce Canyon, Chiricahua, Zion, Saguaro, Canyonlands, Petrified Forest, Rocky Mountain
Southeast	**Shenandoah**, Great Smoky Mountains, Mammoth Cave, Everglades
Transfer Region	*National Parks*
Northwest (transfer from California & Nevada)	Crater Lake, Mount Rainier, North Cascades, Olympic
North Central	**Yellowstone/Grand Tetons**, Badlands, Craters of the Moon, Glacier, Theodore Roosevelt, Wind Cave
Northeast	Acadia, Big Bend, Guadalupe Mountains, Isle Royale, Voyageurs

Note: The "indicator" park (where identified) is shown in bold for each regions. In each case the indicator park is a well-known park in that region. Source: Chestnut (1997).

Photos from each region's "indicator park" were provided as part of the survey instrument. After a number of preparatory questions, respondents reached the WTP section of the survey. Respondents were first instructed that their answer to the WTP question applied only to the region in their survey, and that they did not have to worry about other regions of the country. After furnishing their WTP, respondents were asked what portion of their stated total value was for visibility at the indicator park alone. To avoid including benefits outside of the region, the reported answers were appropriately adjusted. All of these safeguards make it less likely that there will be overlap between urban (i.e., "residential") and National Park (i.e., "recreational") visibility benefits.[iii]

When estimating the benefits attributable to visibility improvement at specific Class I recreational parks, adjustments can be made to account for the location of parks, whether the people valuing the park live "in-region" or "out-of-region," and whether or not the park is an "indicator park." These issues are discussed below.

First, because the regional distribution of national parks throughout the U.S. is so varied, the estimated WTP coefficient per change in deciview changes in value depending upon the location of the Class I area. Based on the National Parks Visibility Valuation Study (Chestnut

[iii]There are a number of Class I areas in each region that are *not* National Parks (e.g., Florida's Okefenokee Wilderness Area), and are thus not included in the estimated value for visibility. We do not attempt to estimate WTP for these other areas, and simply note that they are omitted.

and Rowe, 1990), Chestnut (1997, p. 10) estimated coefficients for the three study visibility regions: California, Southwest, and Southeast. To account for national parks in the rest of the contiguous U.S., however, the same coefficients are transferred to value visibility changes in parks located in adjacent regions, termed here as "transfer regions." Table VII-14 displays the "in-region" and "out-of-region" coefficients used in each of the different visibility regions.

Table VII-14. Estimated Coefficients Used in the Valuation of WTP for Improved Visibility

*Study Visibility Regions and Transfer Visibility Regions**	*Estimated β for Out-of-Region Households*	*Estimated β for In-Region Households*
California & Northwest	$8.96	$12.89
Southwest & Centralwest	$13.51	$16.82
Southeast & Northeast	$4.91	$7.98

* Transfer regions are groups of states adjacent to the study region from which WTP values are assigned.

The in-region coefficient estimates the WTP of residents within a given visibility region for visibility improvements at all parks located within that same region. The out-of-region coefficient estimates the WTP of residents living outside a given visibility region for visibility improvements at all parks located within that region. The results of the survey suggest that in-region residents are likely to value visibility improvements at their parks more than out-of-region residents. This is consistent with expectations, as in-region households are more likely to visit, know about, and care for these parks.

Because the WTP coefficients are for visibility improvements at more than one park within a given visibility region, the WTP values must be apportioned between parks within a given visibility region. Our analysis assumes that WTP for visibility is related to a park's number of visitors. This is clearly a very crude approximation, since the WTP that we are attempting to estimate includes both use and non-use values, and a visitation rate is a better measure of use value and is not clearly linked to non-use values. On the other hand, short of conducting a survey for individual parks, it is difficult to estimate the relative importance of visibility at each park, and using a visitation rate to weight seems more appropriate than taking a simple average or using some other weighting metric, such as the size of the park.

For each study visibility region, we sum 1997 visitor-days at each Class I park. We then divide this total visitation figure into a WTP coefficient (in- or out-of-region, as appropriate) to create a WTP per visitor-days for the entire study region. Multiplying this new value by each park's own number of 1997 visitor-days yields an apportioned per-park WTP coefficient for each park present in the study visibility region. Thus, we apply a visibility valuation function from a

study region to an extrapolated, transfer region.

For aggregate benefits, the low-end estimate does not value residential visibility and uses the lower-bound estimate for recreational visibility for each region. In the high set of valuation assumptions, total visibility benefits consist of residential visibility benefits, as well as in- and out-of-region recreational visibility benefits (using the WTP estimates reported by Chestnut without adjustments to reflect the upper-bound of variation).

e. Ozone- and PM-related Welfare Effect Benefits Estimation

Table VII-15 presents estimates of the monetary benefits arising from each of the welfare endpoints associated with the air quality changes attributed to the Tier 2 rule.

Table VII-15. Welfare Endpoint Monetary Benefits

Endpoint	*Pollutant*	*Monetary Benefits (millions 1997$)*	
		Low	*High*
Agricultural crop damage	Ozone	-1	301
Nitrogen deposition	NO_x	200	200
Household soiling damage	PM	60.1	60.1
Visibility			
Out-of-region recreational	PM and gases	266.33	266.33
In-region recreational	PM and gases	64.10	64.10
Residential	PM and gases	not valued	371.02

5. Total Aggregated Benefits

In our analysis, we aggregated dollar benefits associated with each of the effects examined, such as hospital admissions, into a total benefits estimate assuming that none of the included health and welfare effects overlap. The point estimate of the total benefits associated with the health and welfare effects in each set (low and high) is just the sum of the separate effects estimates. 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 effect) is added to the previous estimate of total dollar benefits, the estimated total dollar benefits increases. The uncertainty surrounding the estimate of total dollar benefits, however, also

increases.

A significant portion of the uncertainty in the benefit estimate derives from uncertainty about the true value of the coefficient in the C-R functions and the true dollar value of the effects. The analysis relies on estimates of these parameters, but the true values being estimated are unknown. This type of uncertainty can often be probabilistically quantified. For example, the uncertainty about pollutant coefficients is typically quantified by reported standard errors of the estimates of the coefficients in the C-R functions estimated by epidemiological studies. The Technical Support Document for this analysis quantifies the uncertainty associated with each health and welfare endpoint. Another important source of uncertainty derives from the discrete set of assumptions used to select endpoints and concentration-response functions and to determine inputs to the concentration-response functions. This type of uncertainty can be quantified through the use of sensitivity analyses, but is not easily conveyed in probabilistic terms.

6. Sensitivity Analyses

A portion of the uncertainty associated with benefits analysis involves discrete choices between assumptions. We can not easily assign non-arbitrary probabilities to the alternative assumptions, and instead we use a reasonable range of assumptions. Our analysis uses two sets of assumptions that incorporate the following key assumptions:

(1) the choice of the PM threshold (15 $\mu g/m^3$,or background);
(2) the value placed on reduced mortality associated with PM (the value of a statistical life, or the value of statistical life adjusted to reflect age-distributions of the affected population);
(3) the value placed on reduced incidence of chronic bronchitis;
(4) whether PM is associated with infant mortality;
(5) whether ozone is associated with the mortality of someone at any age;
(6) whether plantings of commodity crop cultivars are sensitive or insensitive to ozone; and
(7) the value placed on visibility benefits (both residential and recreational visibility).

Table VII-16 presents the estimates for the impacts and the associated economic value for each set of assumptions. The results shown in the table demonstrate that selected alternative assumptions drastically changes the total benefits that can be assumed for this rule. Actual benefits are likely to be between the Low and High estimates provided.

Table VII-16. Avoided Incidence and Monetized Benefits Associated with the Tier 2 Rule for a Range of Assumption Sets

	Avoided Incidence (cases/year)		*Monetary Benefits (millions 1997$)*	
Endpoint	*Low*[a]	*High*[c]	*Low*	*High*
PM				
Mortality (long-term exp. - ages 30+)	832	2,416	2,275	14,256
Mortality (long-term exp. - infants)	–	10	–	56
Chronic bronchitis	3,885	3,914	281	1,354
Hosp. Admissions - all respiratory (all ages)	504	836	4.6	7.6
Hosp. Admissions - congestive heart failure	127	138	1.5	1.7
Hosp. Admissions - ischemic heart disease	146	159	2.2	2.4
Acute bronchitis	984	4,072	0.1	0.2
Lower respiratory symptoms (LRS)	19,782	37,437	0.3	0.5
Upper respiratory symptoms (URS)	3,093	3,387	0.1	0.1
Work loss days (WLD)	233,000	415,000	23.8	42.3
Minor restricted activity days (MRAD)	1,856,000	3,370,000	87.7	159.3
Household soiling damage	–	–	60.1	60.1
Ozone				
Mortality (short-term; four U.S. studies)	–	388	–	2,312
Hospital admissions - all respiratory (all ages)	549	736	5.3	7.1
Any of 19 acute symptoms	54,101	71,545	1.3	1.7
Decreased worker productivity	–	–	43.0	60.4
Agricultural crop damage	–	–	-1	301
Visibility	–	–	330	701
Nitrogen Deposition	–	–	200	200
Total (PM + ozone + visibility + N deposition)	–	–	3,315	19,525

[a] The low assumption set assumes effects from PM do not occur below concentrations of 15 $\mu g/m^3$, that all mortality and chronic bronchitis effects occur within the same year of the PM reduction (see section 7.a for a discussion of this uncertainty), utilizes the value of statistical life year lost approach, ozone-related mortality and PM-related infant mortality are not included in the benefits estimate, chronic bronchitis valued with the cost of illness approach, plantings of commodity crop cultivars are assumed to be insensitive to ozone, and does not value residential visibility benefits.

[c] The high assumption set assumes a PM threshold of background, utilizes the value of a statistical life approach, both ozone-related mortality and PM-related mortality are included in the estimation of benefits, chronic bronchitis valued with a willingness-to-pay approach, plantings of commodity crop cultivars are assumed to be sensitive to ozone, and full accounting for recreational and residential visibility benefits.

7. Limitations of the Analysis

Given incomplete information, this national benefits analysis yields approximate results because of the uncertainty associated with any estimate. Potentially important sources of uncertainty exist and many of these are summarized in Table VII-17. These uncertainties can cause the total benefits estimate to be understated or overstated. Where possible, we state the direction of the bias presented by the uncertainty. However, in most cases the effect of the uncertainty on total benefits is unknown (i.e., it could increase or decrease benefits depending on specific conditions). The remainder of this Section provides a discussion of four broad areas of uncertainty.

Table VII-17. Sources of Uncertainty in the Benefit Analysis

1. Uncertainties Associated With Concentration-Response Functions
-The value of the ozone- or PM-coefficient in each C-R function. -Application of a single C-R function to pollutant changes and populations in all locations. -Similarity of future year C-R relationships to current C-R relationships. -Correct functional form of each C-R relationship. (e.g., It is uncertain whether there are thresholds and, if so, what they are.) -Extrapolation of C-R relationships beyond the range of ozone or PM concentrations observed in the study.
2. Uncertainties Associated With Ozone and PM Concentrations
-Estimating future-year baseline and hourly ozone and daily PM concentrations. -Estimating the change in ozone and PM resulting from the control policy.
3. Uncertainties Associated with PM Mortality Risk
-No scientific basis supporting a plausible biological mechanism. -Potential causal agents within the complex mixture of PM responsible for the reported adverse health effects have not been identified. -While there were a great number of studies associated with PM_{10}, there were a limited number of studies that directly measured $PM_{2.5}$. -The extent to which adverse health effects are associated with low level exposures that occur many times in the year versus peak exposures. -Estimated health effects levels associated with $PM_{2.5}$ exposure were small. -Possible confounding in the epidemiological studies of $PM_{2.5}$, effects with other factors (e.g., other air pollutants, weather, indoor/outdoor air, etc.). -The extent to which effects reported in the long-term studies are associated with historically higher levels of PM rather than the levels occurring during the period of study. -Reliability of the limited ambient $PM_{2.5}$ monitoring data in reflecting actual $PM_{2.5}$ exposures.
4. Uncertainties Associated With Possible Lagged Effects
-What portion of the PM-related long-term exposure mortality effects associated with changes in annual PM levels would occur in a single year, and what portion might occur in subsequent years. Ignoring lags may lead to an overestimate of benefits.
5. Uncertainties Associated With Baseline Incidence Rates
-Some baseline incidence rates are not location-specific (e.g., those taken from studies) and may therefore not accurately represent the actual location-specific rates. -Current baseline incidence rates may not well approximate what baseline incidence rates will be in the year 2007. -Projected population and demographics -- used to derive incidences – may not well approximate future-year population and demographics.
6. Uncertainties Associated With Economic Valuation
-Unit dollar values associated with health and welfare endpoints are only estimates of mean WTP and therefore have uncertainty surrounding them. -Mean WTP (in constant dollars) for each type of risk reduction may differ from current estimates due to differences in income or other factors.
7. Uncertainties Associated With Aggregation of Monetized Benefits
-Health and welfare benefits estimates are limited to the available C-R functions. Thus, unquantified benefit categories

will cause total benefits to be under

a. PM Mortality Risk and Health Effects

Table VII-20 summarizes a number of the uncertainties associated with estimating mortality risk associated with particulate matter (PM). Most of these uncertainties can serve to increase or decrease the estimated benefits relative to a hypothetical "true" prediction. Some uncertainties may inflate estimates, while others - such as exclusion of effects categories - can result in understatement. The fundamental concentration-response relationships used to estimate benefits are derived from epidemiological studies of community health. Based on these studies and other available information, the EPA Criteria Document concluded that the observed associations between particulate matter and mortality and other serious health effects were "likely causal." The Criteria Document also noted that, as yet, the scientific information did not provide a basis for determining what biological mechanisms might account for such effects. To the extent that some chance remains that no causal mechanisms are found for some PM components or for the PM mix taken as a whole, the benefit estimates derived from the epidemiological studies would be overstated.

Similarly, the evaluation of the epidemiological evidence included an extensive assessment of a number of potential pollutant and weather confounders or effects modifiers. The Criteria Document concluded that these factors could not fully account for the observed PM/effects associations, but it is possible that some portion of the quantitative relationships are affected by the presence of other pollutants. While multiple pollutant effects may be additive, it is also possible that the PM related effects association may be overstated for some studies, which might inflate the benefits estimates derived from such studies.

In addition, following the recommendation of the Advisory Council on Clean Air Compliance analyses (an SAB advisory committee established to review methodology for the 812 study), the PM mortality benefit estimates have been derived from a single study that likely encompasses both short-and long-term mortality effects (Pope et al. 1995). Similarly, the Agency has used a single study (Schwartz 1993) in its estimates of the benefits of reduced cases of chronic bronchitis. The approach used in both cases assumes that the benefits of the PM reductions will occur within a year of the reductions. Because some fraction of the estimated mortality or chronic bronchitis effects may well be associated with multi-year exposures, the benefits of a given reduction in concentrations in one year will not all be realized in that year. To date, however, the available studies have not developed any estimates of the relative proportion of near term as compared to the potential "lagged" consequences of PM reductions (HEES, 1999).

Some analysts believe, however, that this analysis should provide an estimate that reflects the potential effect of considering such lagged effects in presenting the range of estimated benefits. For example, if one were to assume that realization of the full health benefits from

reductions in particulate matter resulting from this rule might take up to 5 years, the estimated monetized benefits for reductions in premature mortality and chronic bronchitis would be reduced by $204 million at the low end of the range of total benefits (see Table VII-18 below).

Table VII-18. PM Health Effects and Benefits (No Lag and Lag of up to Five Years)

Health Effects	Benefits (No Lag) (millions 1997$)	Benefits (Lag of up to 5 years)[jjj] (millions 1997$)
Chronic Bronchitis	$281	$259
Mortality	$2,278	$2,096
Total	$2,559	$2,355

As discussed above, SAB has concluded that selection of a value for such a lag at this time would be arbitrary and inclusion of pollutant-related time lags in mortality is premature (HEES, 1999). For this reason, we have not incorporated lags into this analysis. The Agency is committed to working with the SAB and others during the development of the final rule to look at how to address this issue in the benefits range for both the Tier 2 final rule and RIA and in future regulatory analyses.

b. Unquantifiable Benefits

In considering the monetized benefits estimates, the reader should be aware that many limitations for conducting these analyses are mentioned throughout this RIA. One significant limitation of both the health and welfare benefits analyses is the inability to quantify many PM and ozone-induced adverse effects listed in Table VII-6. In general, if it were possible to include the unquantified benefits categories in the total monetized benefits, the benefits estimates presented in this RIA would increase. Specific examples of unquantified benefits explored in more detail below include other human health effects, urban ornamental plants, aesthetic injury to forests, nitrogen in drinking water, and brown clouds.

The benefits of reductions in a number of ozone- and PM-induced health effects have not been quantified due to the paucity of C-R and/or economic valuation data. These effects include: reduced pulmonary function, morphological changes, altered host defense mechanisms, cancer, other chronic respiratory diseases, infant mortality, airway responsiveness, increased susceptibility to respiratory infection, pulmonary inflammation, acute inflammation and

[jjj]This approach assumes that 25 percent of the reductions in health effects reduction are realized in year 1, 25 percent in year 2, 16.67 percent in year 3, 16.67 in year 4 and 16.67 in year 5. This is an illustrative example only and does not represent any known lag structure for these health effects.

respiratory cell damage, and premature aging of the lungs.

In addition to the above non-monetized health benefits, there are a number of non-monetized welfare benefits including: reduced adverse effects on vegetation, forests, and other natural ecosystems. The CAA and other statutes, through requirements to protect natural and ecological systems, indicate that these are scarce and highly valued resources. Lack of comprehensive information, insufficient valuation tools, and significant uncertainties therefore result in understated welfare benefits estimates in this RIA. However, a number of expert biologists, ecologists, and economists (Costanza et al., 1997) argue that the benefits of protecting natural resources are enormous and increasing as ecosystems become more stressed and scarce in the future. Additionally, agricultural, forest and ecological scientists (Heck and Cowling, 1997) believe that vegetation appears to be more sensitive to ozone than are humans and consequently, that damage is occurring to vegetation and natural resources at concentrations below the ozone NAAQS. Experts also believe that the effect of ozone on plants is both cumulative and long-term. The specific non-monetized benefits from reductions in ambient ozone concentrations would accrue from: decreased foliar injury; averted growth reduction of trees in natural forests; maintained integrity of forest ecosystems (including habitat for native animal species); and the aesthetics and utility of urban ornamentals (e.g., grass, flowers, shrubs and trees). Other welfare categories for which there is incomplete information to estimate the economic value of reduced adverse effects include: materials damage; and reduced sulfate deposition to aquatic and terrestrial ecosystems.

Other Human Health Effects

Human exposure to PM and ozone is known to cause health effects such as: impaired airway responsiveness, increased susceptibility to respiratory infection, acute inflammation and respiratory cell damage, premature aging of the lungs and chronic respiratory damage. An improvement in ambient PM and ozone air quality is expected to reduce the number of incidences within each effect category that the U.S. population would experience. Although these health effects are known to be PM or ozone-induced, C-R data is not available for quantifying the benefits associated with reducing these effects. The inability to quantify these effects leads to an underestimation of the monetized benefits presented in this analysis.

Urban Ornamentals

Urban ornamentals represent an additional vegetation category likely to experience some degree of 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 economic benefits analysis has been conducted. It is estimated that more than $20 billion (1990 dollars) are spent annually on landscaping using ornamentals (Abt Associates, 1995), both by private property owners/tenants and by governmental units responsible for public areas, making this 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.

Commercial Forests

Any attempt to estimate economic benefits for commercial forests associated with reductions in ozone arising from implementation of the Tier 2 rule is constrained by a lack of exposure-response functions for the commercially important mature trees. Although exposure-response functions have been developed for seedlings for a number of important tree species, these seedling functions cannot be extrapolated to mature trees based on current knowledge. Recognizing this limitation, a study (de Steiger et al., 1990; Pye et al., 1988) involving expert judgment about the effect of ozone levels on percent growth change has been used to develop estimates of ozone-related economic losses for commercial forest products. Our analysis, however, did not quantify benefits from improved production within commercial forests.

Aesthetic Injury to Forests

Ozone is a regionally dispersed air pollutant that has been shown conclusively to cause discernible injury to forest trees (Fox and Mickler, 1996). One of the welfare benefits 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 that ambient ozone levels cause visible injury to foliage and impair the growth of some sensitive plant species (U.S. EPA, 1996c, p. 5-521). However, present analytic tools and resources preclude EPA from quantifying the benefits of improved forest aesthetics.

Nitrates in Drinking Water

Nitrates in drinking water are currently regulated by a maximum contaminant level (MCL) of 10 mg/L on the basis of the risk to infants of methemoglobinemia, a condition which adversely affects the blood's oxygen carrying capacity. In an analysis of pre-1991 data, Raucher et al.(1993) found that approximately 2 million people were consuming public drinking water supplies which exceed the MCL. Supplementing these findings, the National Research Council concluded that 42 percent of the public drinking water users in the U.S. (approximately 105 million people) are either not exposed to nitrates or are exposed to concentrations below 1.3 mg/L (National Research Council 1995).

In a recent epidemiological study by the National Cancer Institute, a statistically significant relationship between nitrates in drinking water and incidence of non-Hodgkin's lymphoma were reported (Ward et al., 1996). Though it is generally acknowledged that traditional water pollution sources such as agricultural runoff are mostly responsible for violations of the MCL, other more diffuse sources of nitrate to drinking water supplies, such as that from atmospheric deposition, may also become an important health concern should the

cancer link to nitrates be found valid upon further study.

Other Unquantified Benefits Categories

There are other welfare benefits categories for which there is incomplete information to permit a quantitative assessment for this analysis. For some endpoints, gaps exist in the scientific literature or key analytical components and thus do not support an estimation of incidence. In other cases, there is insufficient economic information to allow estimation of the economic value of adverse effects. Potentially significant, but unquantified welfare benefits categories include: existence and user values related to the protection of Class I areas (e.g., Shenendoah National Park), damage to tree seedlings of more than 10 sensitive species (e.g., black cherry, aspen, ponderosa pine), non-commercial forests, ecosystems, materials damage, and reduced sulfate deposition to aquatic and terrestrial ecosystems. Although scientific and economic data are not available to allow quantification of the effect of ozone in these categories, the expectation is that, if quantified, each of these categories would lead to an increase in the monetized benefits presented in this RIA.

c. Potential Disbenefits

In this discussion of unquantified benefits, a discussion of potential disbenefits must also be mentioned. Several of these disbenefit categories are related to nitrogen deposition, while one category is related to the issue of ultraviolet light. Because EPA is not able to quantify these disbenefit categories, total benefits will be overstated.

Passive Fertilization

Several disbenefit categories are related to nitrogen deposition. Nutrients deposited on crops from atmospheric sources are often referred to as passive fertilization. Nitrogen is a fundamental nutrient for primary production in both managed and un-managed ecosystems. Most productive agricultural systems require external sources of nitrogen in order to satisfy nutrient requirements. Nitrogen uptake by crops varies, but typical requirements for wheat and corn are approximately 150 kg/ha/yr and 300 kg/ha/yr, respectively (NAPAP, 1990). These rates compare to estimated rates of passive nitrogen fertilization in the range of 0 to 5.5 kg/ha/yr (NAPAP, 1991). So, for these crops, deposited nitrogen could account for as much as two to four percent of nitrogen needs. Holding all other factors constant, farmers' use of purchased fertilizers or manure may increase as deposited nitrogen is reduced. EPA has not estimated the potential value of this possible increase in the use of purchased fertilizers, but it is likely that the overall value is very small relative to the value of other health and welfare endpoints presented in this analysis. First, reductions in NO_x emissions affect only a fraction of total nitrogen deposition. Approximately 70 to 80 percent of nitrogen deposition is in the form of nitrates (and thus can be traced to NO_x emissions) while most of the remainder is due to ammonia emissions (Dennis, 1997). The annual average change in nitrogen deposition attributable to the Tier 2 rule

is about 11 percent of baseline levels, suggesting a relatively small potential change in passive fertilization. Second, some sources of nitrogen, such as animal manure, are available at no cost or at a much lower cost than purchased nitrogen. In addition, in certain areas nitrogen is currently applied at rates which exceed crop uptake rates, usually due to an overabundance of available nutrients from animal waste. Small reductions in passive fertilization in these areas is not likely to have any consequence to fertilizer application. The combination of these factors suggests that the cost associated with compensating for reductions in passive fertilization is relatively minor.

Information on the effects of changes in passive nitrogen deposition on forests and other terrestrial ecosystems is very limited. The multiplicity of factors affecting forests, including other potential stressors such as ozone, and limiting factors such as moisture and other nutrients, confound assessments of marginal changes in any one stressor or nutrient in forest ecosystems. However, reductions in deposition of nitrogen could have negative effects on forest and vegetation growth in ecosystems where nitrogen is a limiting factor (U.S. EPA, 1993).

On the other hand, there is evidence that forest ecosystems in some areas of the United States are nitrogen saturated (U.S. EPA, 1993). Once saturation is reached, adverse effects of additional nitrogen begin to occur such as soil acidification which can lead to leaching of nutrients needed for plant growth and mobilization of harmful elements such as aluminum. Increased soil acidification is also linked to higher amounts of acidic runoff to streams and lakes and leaching of harmful elements into aquatic ecosystems.

Ultraviolet Light

A reduction of tropospheric ozone is likely to increase the penetration of ultraviolet light, specifically UV-b, to ground level. UV-b is an issue of concern because depletion of the stratospheric ozone layer (i.e., ozone in the upper atmosphere) due to chlorofluorocarbons and other ozone-depleting chemicals is associated with increased skin cancer and cataract rates. Currently, EPA is not able to adequately quantify these effects for the purpose of valuing benefits for this policy.

Other EPA programs exist to address the risks posed by changes in UV-b associated with changes in total column ozone. As presented in the Stratospheric Ozone RIA (U.S. EPA, 1992), stratospheric ozone levels are expected to significantly improve over the next century as the major ozone depleting substances are phased out globally. This expected improvement in stratospheric ozone levels is estimated to reduce the number of non-melanoma skin cancers by millions of cases in the U.S. by 2075.

d. Projected Income Growth

Our analysis does not attempt to adjust benefits estimates to reflect expected growth in

real income. Economic theory argues, however, that WTP for most goods (such as environmental protection) will increase if real incomes increase. The degree to which WTP may increase for the specific health and welfare benefits provided by the Tier 2 rule cannot be estimated due to insufficient income elasticity information.

D. Cost

Since the benefits assessment has been performed on the basis of a fully turned over fleet of tier 2 vehicles, consistent costs were developed by using the same basis. Costs to be compared to the monetized value of the benefits were therefore developed for a fleet the size of the year 2010 fleet. For this purpose we used the long term cost once the capital costs have been recovered and the manufacturing learning curve reductions have been realized, since this most closely represents the makeup of a fully turned-over fleet.

This analysis also made adjustments in the costs to account for the fact that there is a time difference between when some of the costs are expended and when the benefits are realized. The vehicle costs are expended when the vehicle is sold, while the fuel related costs and the benefits are distributed over the life of the vehicle.

We resolved this difference by using costs distributed over time such that there is a constant cost per ton of emissions reduction and such that the net present value of these distributed costs corresponds to the net present value of the actual costs. A constant ratio of cost to emission reduction over the life of the vehicle would also reflect itself in the ratio of the net present value of the costs and net present value of the emission reductions. This, of course, is how EPA determined the cost effectiveness estimates for the proposed rule. Thus, the simplest way to develop this distributed cost number is simply to multiply the cost effectiveness ratio (dollars per ton) times the emission reduction estimates for the benefits assessment.

The resulting adjusted costs are somewhat greater than the actual annual cost of the program, reflecting the time value adjustment. Thus, both because of the assumption of a fully turned over fleet and because of the time value adjustment, the costs presented in this section do not represent actual annual costs of the Tier 2/gasoline sulfur program for 2010. Rather, they represent an approximation of the steady-state cost per ton that would likely prevail in 2015 and beyond. The benefit cost ratio for the earlier years of the program would be expected to be lower than that based on these costs, since the fleet-adjusted costs are larger in the early years of the program while the benefits are smaller.

Since the long term costs are not representative of the per vehicle costs in the early phases of the program, we also estimated an adjusted cost based on the near term cost effectiveness value. Using the near term cost effectiveness value of $2134/per ton, the adjusted cost would be $4.3 billion. While no actual in-use fleet could consist entirely of vehicles experiencing this near term cost, this value does present an upper bound on the cost figure.

The resulting adjusted cost values are given in Table VII-19.

Table VII - 19. Adjusted Cost for Comparison to Benefits

Cost Basis	*Cost per ton ratio*	*Tons of NOx + NMHC*	*Adjusted Cost (billions of dollars)*
Long term	1748	2,003,761	3.5

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Chapter VIII: Regulatory Flexibility

This chapter presents our Initial Regulatory Flexibility Analysis (IRFA) which evaluates the impacts of the proposed Tier 2 and gasoline sulfur standards on small businesses. This analysis has the following objectives: 1) to specify an appropriate definition for "small business" for entities subject to the final rule, 2) to characterize small businesses in the petroleum refining and motor vehicle manufacturing industries (described in more detail below in Table VIII-1), 3) to assess the impact of the proposed standards on these businesses, and 4) to evaluate the relief provided by regulatory alternatives.

A. Requirements of the Regulatory Flexibility Act

When proposing and promulgating rules subject to notice and comment under the Clean Air Act, we are generally required under the Regulatory Flexibility Act (RFA) to conduct a regulatory flexibility analysis unless we certify that the requirements of a regulation will not cause a significant impact on a substantial number of small entities. The key elements of the IRFA include:

- the number of affected small entities;
- the projected reporting, record keeping, and other compliance requirements of the proposed rule, including the classes of small entities that would be affected and the type of professional skills necessary for preparation of the report or record;
- other federal rules that may duplicate, overlap, or conflict with the proposed rule; and,
- any significant alternatives to the proposed rule that accomplish the stated objectives of applicable statutes and which minimize significant economic impacts of the proposed rule on small entities.

The Regulatory Flexibility was amended by the Small Business Regulatory Enforcement Fairness Act of 1996 (SBREFA), to ensure that concerns regarding small entities are adequately considered during the development of new regulations that affect them.

In developing the NPRM, we concluded that the proposed Tier 2 and gasoline sulfur standards would likely have a significant impact on a substantial number of small entities. To comply with the requirements of the RFA, we were required to quantify these economic impacts. The methodology used to calculate the per-refinery costs for desulfurizing gasoline is located above in Chapter 5.B.; the cost for an average small refiner to comply with the 30 ppm standard is described below in section C.

Based on the results of our economic analyses, we convened a Small Business Advocacy Review Panel (the Panel), as required by SBREFA. The purpose of the Panel was to collect the

advice and recommendations of small entity representatives (SERs) that would be affected by the proposed Tier 2 and gasoline sulfur standards. The report of the Panel has been placed in the rulemaking record.[1]

B. Description of Affected Entities

A Tier 2 program establishing stringent vehicle emission standards and requiring reductions in gasoline sulfur content would primarily affect manufacturers of LDVs, LDTs, HDGVs, and oil refiners that produce gasoline. Most companies in these industries do not meet the small business definitions provided in the U.S. Small Business Administration (SBA) regulations (13 CFR Part 121). However, we have identified several companies within these industries that are small businesses as defined by SBA. These businesses may be subject to the Tier 2 vehicle and gasoline sulfur standards and could be significantly impacted by the new standards. Table VIII-1, below, describes the affected industries, including the small business size standards SBA has established for each type of economic activity under the Standard Industrial Classification (SIC) and North American Industrial Classification systems.

Table VIII-1. Industries Containing Small Businesses Potentially Affected by Today's Proposed Rule

Industry	*NAICS[1] Codes*	*SIC[2] Codes*	*Defined by SBA as a Small Business If:[3]*
Petroleum Refiners	324110	2911	< 1500 employees
Petroleum Marketers and Distributors	422710 422720	5171 5172	< 100 employees
Independent Commercial Importers of Vehicles and Vehicle Components	811112 811198 541514	7533 7549 8742	< $5 million annual sales
Alternative Fuel Vehicle Converters	336311 541690	3592 8931	< 500 employees
	336312	3714	< 750 employees
	422720	5172	< 100 employees
	454312 811198 541514	5984 7549 8742	< $5 million annual sales
Motor Vehicle Manufacturers	336111 336112 336120	3711	< 1000 employees

1) North American Industry Classification System
2) Standard Industrial Classification system
3) According to SBA's regulations (13 CFR 121), businesses with no more than the listed number of employees or dollars in annual receipts are considered "small entities" for purposes of a regulatory flexibility analysis.

1. Small Refiners

Of the approximately 160 petroleum refineries that currently produce gasoline in the U.S., about 15 meet SBA's definition of a small business. SBA's SIC code for petroleum refining is 2911. According to this code, a petroleum refining company must have fewer than 1500 employees to qualify as a SBA small business. In the event that we propose gasoline sulfur control, some small refiners could have greater difficulty than larger refiners in complying with the standard(s), due to such factors as limited operational flexibility, lack of access to alternate crude oil feedstocks, limited availability of new sulfur reduction equipment, or difficulty in raising capital to finance projects.

2. Small Petroleum Marketers

While refiners would be the primary affected parties in a gasoline sulfur control program, some marketers of gasoline, many of which are small by SBA definitions, may be directly subject to the rule and could be adversely impacted by it. This impact appears to be limited to new or expanded requirements for reporting the sulfur content of gasoline samples.

SBA defines small businesses in this category (SIC codes 5171 and 5172) as those with fewer than 100 employees. There are several hundred small gasoline marketers participating at various points in the national gasoline distribution system.

3. Small Certifiers of Covered Vehicles

In addition to the major vehicle manufacturers, three distinct categories of businesses relating to LDV, LDTs, and HDGVs exist that would be covered by Tier 2 emission standards. Some companies in each of these categories are small businesses according to SBA regulations.

Small Independent Commercial Importers

Independent Commercial Importers are companies that hold a Certificate (or Certificates) of Conformity which permits them to alter imported vehicles to meet U.S. emission standards. As with alternative fuel vehicle converters described below, these businesses could face greater technical challenges if emission standards are tightened. We have identified five businesses in this category that are currently active and that appear to be small entities under SBA regulations.

Alternative Fuel Vehicle Converters

Under certain circumstances, our current policy permits the conversion of gasoline or diesel vehicles to operate on an alternative fuel without applying for and receiving the EPA Certificate of Conformity (also known as the “certification” process) that is required of conventional manufacturers. However, certification can provide certain benefits to a converter, and a few businesses have completed certification or have expressed interest in certifying alternative fueled vehicle models. Beginning in model year 2000, converters must seek a certificate for all of their vehicle models, although there will be some aspects of the certification process that will be simplified for small volume manufacturers (SVMs), including these converters. To the extent that companies are involved in this business when Tier 2 emission standards become effective, they would be subject to such standards and could face greater technical challenges in achieving the new standards with the vehicles they convert.

Small Volume Vehicle Manufacturers

We permit vehicle manufacturers selling 10,000 or fewer vehicles per year to be

designated as SVMs. This status allows vehicle models to be certified under a slightly simpler certification process. More stringent Tier 2 standards could be relatively more difficult for small manufacturers to achieve than larger manufacturers to the extent that research and development resources are more limited. Less than five current SVMs meet the SBA guidelines for vehicle manufacturers of 1000 or fewer employees.

C. Projected Costs of the Proposed Gasoline Sulfur Standards

The costs for an average-size small refinery (19,000 bbls gasoline/day) to produce gasoline with a sulfur level of 30 ppm are described below in Table VIII-2. A more detailed discussion of our refinery cost analysis, in general, can be found above in Chapter 5.

Table VIII-2. Costs for a 19,000 bbls gasoline/day Refinery to Produce 30 ppm Gasoline

Location	*Per-Gallon Cost (cents/gallon)*	*Operating Cost ($million/year)*	*Capital Cost ($million/year)*
PADD III	2.9	8	16
PADD IV	3.4	9	22

Costs for a small refinery located in PADD II to produce 30 ppm gasoline would fall between the costs for a refinery in PADD III and a refinery in PADD IV.

In comparison, the average annual sales of small refiners in the U.S. were approximately $385 million for 1997 based on data obtained from Dun & Bradstreet.

D. The Types and Number of Small Entities to Which the Proposed Rule Would Apply

The types and number of small entities to which the proposed rule would apply are described in Table VIII-3, below.

Table VIII-3. Types and Number of Small Entities to Which the Proposed Tier 2/Gasoline Sulfur Rule Would Apply

Type of Small Entity	*Number of Companies Affected by Today's Rule*
Small Refiners	Approximately 17
Small Gasoline Marketers	Several Hundred
Small Certifiers of Covered Vehicles	Approximately 15

Using our 1990 refinery baseline data, established for the purposes of the RFG and anti-dumping programs, we have estimated that small refiners produce approximately 3.5 percent of all gasoline in the U.S. Furthermore, of the 17 refineries that we have identified as meeting SBA's definition of small business, nine already have gasoline sulfur levels less than 90 ppm. Therefore, approximately eight small refineries (out of 160 refineries in the U.S.) will need to significantly reduce their gasoline sulfur levels to comply with the proposed gasoline sulfur standards.

We are also aware that there are several hundred gasoline distributors/marketers in the U.S. The proposed rule may include a new requirement for them to add sulfur content to the set of gasoline quality parameters they currently report or record. However, this requirement should not be burdensome since sulfur content is generally measured along with other parameters and the results would simply need to be recorded and reported.

E. Projected Reporting, Recordkeeping, and Other Compliance Requirements of the Proposed Rule

We are proposing to require that refiners and importers keep and make available to us certain records which demonstrate compliance with the sulfur program requirements. These records include information about each batch of gasoline produced or imported, including batch volume, sulfur test results and calculations used to determine compliance. We believe that the proposed recordkeeping requirements for refiners and importers are necessary to allow independent auditors and our inspectors to determine if the gasoline produced or imported, in fact, met the applicable sulfur standards when it left the refinery or import facility. A similar record retention requirement is included in the RFG and anti-dumping regulations.

Because the information required to be reported under today's rule in many cases is not included in the RFG and anti-dumping compliance reports, and because we believe it would be difficult to adapt the present RFG and anti-dumping reports to include the information required

under today's proposed rule, we are proposing to require refiners and importers to submit a separate annual sulfur compliance report along with the refiner's or importer's RFG and/or anti-dumping compliance reports. The sulfur report form would be relatively short and would require only the minimum information necessary to demonstrate compliance with the applicable sulfur standards. Parties would be required to include the refiner and refinery facility registration numbers or importer registration number issued under the RFG regulations, the total volume of gasoline (RFG and conventional gasoline) produced at the refinery (or refineries, if aggregated prior to 2006) or imported by the importer during the averaging period, and the annual average sulfur content of the gasoline produced or imported. Small refiners who have EPA-approved individual baselines also be required to include the sulfur standards applicable to the refinery.

F. Other Relevant Federal Rules Which May Duplicate, Overlap, or Conflict with the Proposed Rule

The Tier 2 emission standards and gasoline sulfur control regulations that we are proposing are similar in many respects to existing regulations; in some cases, these regulations are replacing earlier requirements with more stringent requirements for refiners and vehicle manufacturers. However, the Panel is not aware of any area where the new regulations would duplicate, overlap, or conflict with the existing federal, state, or local regulations.

G. Regulatory Alternatives

The Panel considered a wide range of options and regulatory alternatives for providing small businesses with flexibility in complying with potential Tier 2 vehicle emission and gasoline sulfur standards. As a part of the process, the Panel requested and received comment on several early ideas for compliance flexibility that were suggested by the SERs and Panel members. Taking into consideration the comments received on these ideas as well as additional business and technical information gathered about the affected small entities, the Panel recommended that we solicit comment on several of them. As described below, the Panel recommended some of these concepts individually and, in the case of small refiners, recommended a comprehensive option that incorporates several ideas. The Panel took considerable time in addressing the concerns of the small refiners, who indicated their belief that their businesses may have to close if relief is not considered for their industry. Taken together, the Panel believed that these options would provide meaningful relief to small businesses in each of the industry sectors potentially affected by a Tier 2/gasoline sulfur control program while protecting the environmental goals of the program.

1. Small Refiners

The Panel recommended that small refiners be provided a four- to six-year period during

which less stringent gasoline sulfur requirements would apply. Each refinery's gasoline sulfur limit would be based on its individual average sulfur level as reported in its most recent batch report (submitted under the reformulated gasoline program, e.g., for 1997) available at the time of the proposed rule. This four- to six-year period of relief would begin at the time that final standards become effective for the refining industry as a whole. Following this period of relief, small refiners would be required to meet the industry-wide standard, although temporary hardship relief would be available on a case-by-case basis. The Panel believed that the additional time that this approach would provide would 1) allow larger refiners to demonstrate new sulfur-reduction technologies, 2) permit the costs of advanced technology units to drop as the volume of their sales increases, 3) free-up industry engineering and construction resources, and 4) provide additional time for small refiners to raise capital for infrastructure changes.

Although during the Panel process we had not yet decided on an approach for a proposed sulfur control program, several small refiner options were discussed which made assumptions about the program that might be in place. Among the program designs that we were considering during the Panel process, the "worst case" scenario for small refiners was a national, year-round sulfur requirement of 30 ppm on average with an 80 ppm per-gallon cap beginning in 2004. The following discussion of the specific small refiner relief provisions assumed the existence of the "worst case" scenario and a scenario where the gasoline sulfur standards would be higher than 30 and 80 ppm. The Panel emphasized that we had not yet made decisions regarding the level and scope of sulfur controls that we were intending to propose.

a. Interim Sulfur Standards

In the Panel's recommended approach, small refiners covered by this special provision would be assigned interim sulfur standards based on their individual refinery gasoline sulfur levels today, according to Table VIII-4 below.

Table VIII-4. Federal Gasoline Sulfur Program with Sulfur Standards of 30 ppm on Average and an 80 ppm Per-Gallon Cap

Average Refinery Sulfur Level (ppm)	*Interim Sulfur Standards (average/cap, ppm) **
0 to 30	30/80
31 to 80	80 (Cap only)
81 to 200	Average: Maintain current average level Cap: Factor of 2.0 above the average
201 and above	Average: One-half current average level, 200 ppm minimum and 300 ppm maximum Cap: Factor of 1.5 above average level

* Note that if the federal program were to include a phase-in of sulfur standards, and if a refiner's current average sulfur level was below the phase-in level, the phase-in level would become the refiner's compliance level for the period of the phase-in.

More generally, if standards higher than 30/80 ppm were promulgated, the recommended interim standards for small refiners would be at the levels described in Table VIII-5, below.

Table VIII-5. Federal Gasoline Sulfur Program with Sulfur Standards Above 30 ppm on Average and an 80 ppm Per-Gallon Cap

Average Refinery Sulfur Level (ppm)	*Interim Sulfur Standards (average/cap, ppm)**
0-200	Average: Maintain federal standard or current average level Cap: Factor of 2 times the average
201-400	Average: 200 ppm or federal standard Cap: Factor of 1.5 times the average
401-600	Average: One-half of current average level Cap: Factor of 1.5 times the average
601 and above	300/450

* Note that if the federal program were to include a phase-in of sulfur standards, and if a refiner's current average sulfur level was below the phase-in level, the phase-in level would become the refiner's compliance level for the period of the phase-in.

i. Duration of Interim Standards

In addition to recommending that we propose a duration of four to six years during which the interim standards would apply, beginning from the effective date of the sulfur standard, the

Panel also recommends that we specifically request comment on an alternative duration of 10 years.

b. Hardship Relief

i. Small Refiners

The Panel believed that it would be impossible to predict what the nature of the refining industry would be in the latter part of the next decade, when small refiners will need to comply with the final gasoline sulfur standard(s). Given this uncertainty, the Panel recommended that we propose provisions for small refiners that would allow us on a case-by-case basis to extend some form of relief from the standards for an additional period of time in cases of severe hardship. The Panel recommended that we design such a proposed hardship relief provision to include, at a minimum, the following characteristics:

- Criteria for granting of hardship relief that are sufficiently specific to help assure fairness among recipients of such relief while allowing a degree of flexibility for EPA to address special problems that may face individual refiners. Such criteria should be designed to require a demonstration that the refiner faces extreme economic consequences absent the relief and has exhausted other channels that could limit the consequences. EPA should consider including in proposed hardship relief provisions criteria such as, demonstrated inability on the part of the small refiner to develop sufficient capital, the temporary unavailability of new lower-cost sulfur removal technology, or the temporary unavailability of engineering or construction resources necessary for the design and installation of the new equipment.

- A provision for a small refiner to propose an appropriate time period for this additional relief. The Panel believes that the refiner should be expected to carefully document the need for a specific period of additional relief. The Panel also believes that such a period should be a minimum of two years so that the refiner can demonstrate a degree of stability into the future when seeking capital or credit.

The Panel was hopeful that the time provided by the interim standards for small refiners (perhaps added to any time provided by a phase-in of the industry-wide program) would allow for industry technology prove-out and cost reductions and for individual refiner planning such that hardship relief would be seldom or never needed. The Panel was also satisfied that current OMS management is committed to providing hardship relief if and when the need is demonstrated and we encourage future OMS management to be similarly open to small refiners facing dire economic impacts due to gasoline sulfur reduction standards.

Finally while the Panel recommended a refinery-based compliance option for small refiners, as discussed above, OMB noted that the Panel received comments from small refiners and small gasoline distributors supporting a geographically-limited sulfur program proposed by API and NPRA. In light of these comments, OMB recommended that we evaluate the API/NPRA proposal.

ii. Small Marketers of Gasoline

The Panel believed that adding gasoline sulfur to the fuel parameters already being sampled and tested by gasoline marketers will likely result in little, if any, additional burden. The gasoline marketer SERs that commented to the Panel did not address this issue. The Panel did not recommend any special provisions for gasoline marketers. (These parties raised concerns about indirect effects of a sulfur control program on marketers, especially if some refiners go out of business and reduce the number of gasoline suppliers. However, the focus of the RFA and SBREFA is on direct effects of a potential rule on small entities, which in this case do not appear to be problematic.)

2. Small Certifiers of Covered Vehicles

The Panel recommended that EPA solicit comment on several ideas suggested by small companies that certify LDVs, LDTs, and HDGVs, as discussed further below. However, several other concerns that these businesses raised to the Panel do not appear to be affected by potential new Tier 2 emission standards but rather involve existing regulations. While the Panel did not believe that these “non-Tier 2" issues would be appropriately addressed in a Tier 2 rulemaking, the Panel encouraged EPA to meet with small certifiers designated as ICIs to discuss those issues.

The Panel recommended that EPA solicit comment on the following potential regulatory options:

1) For small certifiers that convert imported vehicles to U.S. standards or that convert vehicles to operate on alternative fuels, provide a delay in required compliance of two years after Tier 2 standards apply to the model (engine family) involved.

2) If the Tier 2 program involves a phase-in of standards, allow small certifiers to comply at the end of such a phase-in.

3) If the Tier 2 program does not involve a phase-in of standards, delay compliance for small certifiers until 2007 (or three years after the program begins industry-wide).

4) Establish a credit program as a part of the Tier 2 program, and provide incentives for large manufacturers to make credits available to small certifiers. In addition, develop a

program to provide credits to small certifiers for taking older vehicles off the road (scrappage).

5) Design a case-by-case hardship relief provision that would delay required compliance for small certifiers that demonstrate that they would face a severe economic impact from meeting the Tier 2 standards.

Chapter VIII. References

1. Report of the Small Business Advocacy Panel on Tier 2 Light-Duty Vehicle and Light-Duty Truck Emission Standards, Heavy-Duty Gasoline Engine Standards, and Gasoline Sulfur Standards, October 1998.

Appendix A: 47-State and Four-Cities Analyses

Double-click on the icon below to open Appendix A:

Acrobat Document

Appendix B: Evidence Supporting the Irreversibility of Sulfur's Emission Impact

Fuel sulfur impacts vehicle emissions in two basic ways. One is an immediate impact, which occurs within a few miles of driving. The other is a more lasting impact, ranging from 20 or more miles to potentially permanent. This lasting effect of sulfur on emissions is termed irreversibility, referring to the fact that the emission impact of high sulfur fuel does not reverse when low sulfur fuel is used.

The immediate impact of sulfur on emissions is summarized in an EPA technical report.[1] There, it was shown that operation on typical conventional gasoline containing 330 ppm sulfur increases exhaust VOC and NOx emissions from LEV and Tier 2 vehicles (on average) by 40 percent and 150 percent, respectively, relative to their emissions with certification fuel containing roughly 30 ppm sulfur. All of the data supporting these impacts were generated with very short exposures to high sulfur gasoline, essentially a few miles of preconditioning and a few miles of actual emission testing. When the vehicles were tested using low sulfur fuel after being operated on high sulfur fuel, special preconditioning was performed to ensure that any residual effect of the high sulfur fuel was removed. This preconditioning would not normally occur through normal vehicle operation, so the emission impacts described in Section III only strictly apply to situations where the vehicle operated on fuel with a single sulfur level over its entire life.

In this section, we are concerned with the impact of sulfur under more realistic conditions. In particular, we are interested in vehicles' emission response following exposure to low sulfur fuel after exposure to high sulfur fuel. We are also concerned with the potential that long term exposure to high sulfur fuel may increase emissions to a greater degree than the short term exposures simulated in most emission testing.

This section is divided into five parts. The first section describes the sensitivity of vehicle exhaust emissions to gasoline sulfur content. The second discusses the theory of how sulfur affects catalytic activity and the conditions conducive for its removal (sulfur reversibility/irreversibility). The third describes the vehicle testing programs which have attempted to measure the reversibility of the sulfur impact. This part also compares the relative impact of long term sulfur exposure versus short term exposure. The fourth presents criteria for evaluating the wide range of sulfur reversibility data which are available. Finally, the fifth describes EPA's projections of the degree of sulfur reversibility for various vehicle types (e.g., Tier 1 vehicle, LEVs, and Tier 2 vehicles).

A. Exhaust Emission Sensitivity to Sulfur Content

The sulfur in gasoline increases exhaust emissions of HC, CO, and NOx by decreasing the efficiency of the three-way catalyst used in current and advanced emission control systems.

For the purpose of this document, we will refer to this phenomenon as "sulfur sensitivity." Sulfur sensitivity has been demonstrated through numerous laboratory and vehicle fleet studies. These studies have demonstrated that significant reductions in HC, CO, and in particular, NOx emissions can be realized by reducing fuel sulfur levels. Sulfur sensitivity for Tier 0 and Tier 1 vehicles is marginal, with NOx emissions decreasing between 11 percent to 16 percent when sulfur is reduced from 330 ppm to 40 ppm. Sulfur sensitivity for LEV and ULEV vehicles, however, is much more significant. When sulfur is increased from 40 ppm to 330 ppm, we project that emissions increase by the following percentages:

Vehicle Type	NMHC	NOx
LEV and ULEV LDV	40%	134%
LEV and ULEV LDT	24%	42%

These percentages apply to "normal emitting" vehicles, which generally are those in-use vehicles with emissions at or below twice their applicable emission standards. Higher emitting vehicles are projected to be less sensitive to sulfur, because the catalyst is not operating at peak efficiency in-use and should therefore be less affected on a percentage basis by higher sulfur levels.

We anticipate that Tier 2 vehicles will be at least as sensitive to sulfur as LEV and ULEV LDVs and possibly even more so, due to the greater stringency of the proposed Tier 2 emission standards, especially for NOx. At present, however, we have only projected that Tier 2 vehicles will be just as sensitive as LEV and ULEV LDVs and not more so.

More detailed discussions of sulfur sensitivity can be found in the "EPA Staff Paper on Gasoline Sulfur Issues,"[2] published May 1, 1998, and the EPA report which developed sulfur sensitivity estimates for a range of vehicle classes for incorporation in the draft version of EPA's fleet-wide emissions model, MOBILE6. This report is titled "Fuel Sulfur Effects on Exhaust Emissions"[3] and is dated January 5, 1999.

Sulfur sensitivity has been shown to be variable and to depend upon both catalyst formulation and vehicle operating conditions, which are discussed in detail in both reports. Another variable, which was not discussed in either report, is the effect of real world vehicle aging with sulfur. Sulfur sensitivity is temperature dependent. Sulfur adheres to the catalyst surface more thoroughly at lower catalyst temperatures (approximately 450EC to 500EC) than higher temperatures. Several vehicle manufacturers have suggested that the sulfur sensitivity results from the numerous fleet studies actually underestimate the sensitivity of sulfur on exhaust emissions, because the test cycles (FTP or LA4 cycles) used to saturate the catalyst with sulfur result in catalyst temperatures that are too high. Specifically, the argument is that most vehicles achieve catalyst temperatures over the FTP that exceed 450EC, thus not allowing complete adsorption of sulfur to the catalyst surface, whereas real-world vehicle operation in metropolitan non-attainment areas quite frequently result in catalyst temperatures at or below 450EC.

We have a sulfur test program currently underway to assess the validity of this concern. Although testing is still ongoing, very preliminary results from a single vehicle seems to support the fact that emissions are even more sensitive to sulfur when the catalyst is saturated with sulfur via on-road operation. We plan to have the results of this test program available prior to the development of technical analyses for the final rule. If the remainder of the testing supports the early results and manufacturer's contentions, real world levels of sulfur sensitivity would be even greater than the levels discussed above, further supporting the need for sulfur reduction in gasoline.

A second concern about the current estimates of sulfur sensitivity is that all of the vehicles in the test programs used to develop to above projections of sulfur sensitivities were only exposed to high sulfur fuel for a few miles of driving prior to emission testing. In addition to adsorbing onto the surface of the catalyst, sulfur can also penetrate into the precious metal layer, especially into palladium, and into the oxygen storage material. This penetration may not have fully occurred during the very few miles of operation prior to emission testing on high sulfur fuel. In an API sulfur reversibility test program discussed further below in this appendix, vehicles' sulfur sensitivity were measured after both short-term exposure to high sulfur fuel and after 1,000-2,000 miles of driving with high sulfur fuel. For the five vehicles tested, NMHC emission sensitivity was the same with both short-term and longer-term exposure to high sulfur fuel. However, NOx emission sensitivity was 25-50% higher after longer-term exposure to high sulfur fuel when compared to short-term exposure. Thus, the above sulfur sensitivities could significantly underestimate the impact of sulfur on NOx emissions for LEVs, ULEVs and Tier 2 vehicles. We plan to investigate this issue further in the future.

B. Theory Supporting the Reversibility and Irreversibility of Sulfur's Emission Impact

Sulfur impacts emissions from modern vehicles primarily by reducing the efficiency of the three-way catalyst. Molecules of sulfur (either in the form of sulfur dioxide or hydrogen sulfide) adsorb on the catalyst surface and basically take up space so that molecules of HC, CO and NOx cannot adsorb and react to form water, nitrogen, oxygen and carbon dioxide. With palladium catalysts, it appears that sulfur also penetrates into the metal itself, forming a reservoir of sulfur within the catalyst. Sulfur dioxide also penetrates into the oxygen storage medium of the catalyst and reduces the ability of the catalyst to manage the level of oxygen on the catalyst surface. This oxygen management function is a key component of the 98 percent plus efficiencies of today's three-way catalysts, particularly for controlling NOx emissions.

EPA summarized the basic chemical and thermodynamic mechanisms involved in sulfur's two types of interference in it staff paper on gasoline sulfur in May of 1998.[4] This paper also summarized the conditions required to remove sulfur from the catalyst once the vehicle had been exposed to high sulfur fuel. The results of a number of studies showed that generally high temperatures (in excess of 700° F) are required to remove sulfur from both the surface of the catalyst and from the washcoat matrix. In addition to high temperature, a rich exhaust (absence

of oxygen coupled with presence of HC and CO, or a low air-fuel ratio) or an alternating sequence of rich and lean (presence of more oxygen in the exhaust than is needed to oxidize the HC and CO present, or a high air fuel ratio) exhaust was often needed to fully regenerate the catalyst. Larger degrees of lean and rich exhaust appear to be much more conducive to sulfur removal than small changes in air fuel ratio. When these rich or alternating rich-lean conditions were not present, even higher temperatures were required to remove the sulfur from the catalyst, when such removal was successful. However, when the combination of temperature and variation in the air-fuel ratio is sufficient, the sulfur accumulated from operation on high sulfur fuel appears to be essentially eliminated and the emission impact of the high sulfur fuel is fully reversed.

If sulfur reversibility was the only criteria involved in catalyst design, auto manufacturers could place their catalysts right up against the engine and design the onboard computer to vary the air fuel ratio from rich to lean sufficiently to regenerate the catalyst after any temporary exposure to high sulfur fuel. Engine exhaust temperatures are generally high enough at the exhaust manifold during typical driving to facilitate sulfur removal. The onboard computer is certainly capable of varying the air-fuel ratio significantly. However, other critical catalyst design criteria prevent such the use of such simple measures. First, excessive temperatures can thermally damage the catalyst and reduce its efficiency. Second, simultaneously high conversion efficiencies of HC, CO and NOx require very tight air fuel ratio control (minimal swings to either rich or lean conditions).

Regarding catalyst temperature, auto manufacturers must balance a number of conflicting criteria. One important criterion for catalyst design is that it light-off quickly. Most of the HC and CO emissions from LEV vehicles, and significant amounts of NOx emissions, occur prior to catalyst light-off. Achieving this has affected the type and amount of materials used in the catalyst and resulted in moving the catalyst closer to the engine. Many manufacturers have switched to catalysts containing palladium, which generally can withstand higher temperatures than platinum and rhodium catalysts. At the same time, catalyst manufacturers have improved the design of their platinum and rhodium catalysts so that they can withstand higher temperatures, as well. Moving the catalyst closer to the engine also increases catalyst temperature during warmed-up operation, other factors being equal. Despite improvements in the thermal durability of catalysts, sufficiently high temperatures can still cause a significant loss of catalyst efficiency.

Engine load also affects exhaust and catalyst temperature. The engine load for a given vehicle is a function of vehicle speed, rate of acceleration, vehicle weight and road grade, with higher levels of all of these factors leading to higher engine loads and catalyst temperatures. Vehicles which carry the most widely varying loads and which are driven the most aggressively will generally experience the most variation in their catalyst temperature. Manufacturers must design their catalysts to both light-off quickly and stay warm under light loads while not sustaining thermal damage under heavy loads. Light trucks and sporty vehicles probably present the most difficult challenges in this regard. For example, light trucks are most often driven with one person and minimal cargo. However, they also are used to carry numerous passengers or

carry or pull heavy cargo up steep hills. The catalyst must be designed to withstand the higher temperatures of these heavier loads.

One additional factor affecting catalyst temperature is the upcoming implementation of EPA and California SFTP standards. The SFTP standards address emissions generated while the vehicle is driving aggressively (high speeds and high rates of acceleration) and while the air conditioning is turned on, both of which generate higher engine loads than exist during EPA's FTP test cycle. Manufacturers have historically designed their engines to run rich under high loads. The excess fuel decreases exhaust and catalyst temperature relative to an engine running at stoichiometry (just the right amount of air to burn the fuel). The SFTP standards will require that manufacturers reduce much of this high-load enrichment in order to reduce HC and CO emissions during these high loads. Therefore, all other factors being equal, exhaust and catalyst temperatures under extreme conditions will increase after implementation of the SFTP standards, which begin their phase-in in the 2001 model year. Thus, the SFTP standards incrementally increase the difficulty of quickly lighting-off the catalyst while still protecting it from thermal damage during extreme driving conditions. While these extreme conditions must be considered in the catalyst design process, their frequency in-use is not sufficient to rely upon for sulfur removal. For example, some vehicle owners own and tow trailers up steep hills, while others do not. Therefore, while the SFTP standards may increase temperatures under some conditions, they will not necessarily increase sulfur removal capability for the general vehicle population.

Requiring manufacturers to increase the temperature of their catalysts under light loads to improve sulfur reversibility would therefore increase temperatures under heavy loads even further. EPA has not assessed the feasibility of manufacturers increasing warmed-up catalyst temperatures beyond that required by the current standards, as well as the proposed Tier 2 standards, without additional degradation in catalyst efficiency. However, based on the Johnson-Matthey data presented in the next section, even very high temperatures of 900° F are not necessarily sufficient to fully reverse the sulfur impact if extensive use of high sulfur fuel has occurred. Regular operation at such temperatures places the catalyst at risk of thermal damage from even occasional excursions above this level, which can regularly occur from the types of high load operation described above, as well as occasional spark plug misfire. Since the vast majority of the HC, CO and NOx emission control occurring under both the current standards and the proposed Tier 2 standards relies on the proper operation of the catalyst over the life of the vehicle, increasing catalyst temperatures to enhance sulfur reversibility risks essentially all of the benefits of EPA's exhaust emission control program (both current and proposed),. Therefore, it would be imprudent to require vehicle manufacturers to design catalysts that operate at temperatures high enough to improve the reversibility of sulfur effects and also meet the proposed Tier 2 standards in-use.

Moving to the variation in air-fuel ratio, manufacturers have significantly enhanced their engines' and computers' abilities over the past few years specifically to avoid large swings in rich and lean operations. This ability to maintain tight control of the air-fuel ratio has increased catalyst efficiency significantly in the process. Designing the vehicle to have alternating rich-lean operation may improve the reversibility of sulfur effects, but would reduce catalyst

efficiency and potentially prevent the achievement of both current and proposed Tier 2 exhaust emissions standards. As was the case with increasing catalyst temperature, it would be counter-productive to reverse this progress in overall emission control just to enhance the sulfur reversibility of catalyst systems.

Thus, the two changes in emission control design, hotter catalyst temperatures and variable air-fuel ratios both run counter to other design criteria aimed at achieving stringent emission standards in-use. Therefore, EPA believes that sulfur reversibility should be evaluated with the catalyst temperatures and air-fuel ratio control of today's cleanest vehicles, considering the impact of the future SFTP standards. The next section will do this by evaluating the available sulfur reversibility data on such vehicles.

C. Results of Sulfur Reversibility Test Programs

EPA has received data from three test programs which evaluate the reversibility of sulfur's impact on vehicle emissions. These three programs are summarized in the following three sections. A fourth section summarizes other test data received, as well as describing some EPA testing which is underway.

1. Coordinating Research Council (CRC) Sulfur Reversibility Program

The CRC sulfur reversibility program evaluated six 1997 LEV LDV models that were part of their original sulfur sensitivity program. The following table lists the six vehicles used in the program.

Table B-1. CRC Test Vehicles

Vehicle	*Number of Cylinders*	*Engine Displacement*
Ford Taurus	6	3.0L
Ford Escort	4	2.0L
Honda Civic	4	1.6L
Toyota Camry	4	2.2L
Nissan Sentra	4	1.6L
Suzuki Metro	4	1.3L

All six vehicles were equipped with 100K mile bench aged catalysts and oxygen sensors.

Testing was performed in two phases - I and II. Phase I consisted of three FTP tests (with a single LA4 cycle run in between) with an initial baseline fuel containing 30 ppm sulfur. Three additional FTP tests (again with the single LA4 preconditioning) were run using fuel containing 600 ppm sulfur. In order to evaluate the reversibility of the effects of the higher 600 ppm sulfur from the catalyst surface of the six vehicles, all of the vehicles ran eight FTP tests using an LA4 test just prior to each FTP as a sulfur "purge" cycle. The LA4 cycle was chosen as a purge cycle because of its general representativeness of city driving. Reversibility was defined as the ratio of 1) the difference between the average of emissions with high sulfur fuel and the average of emissions from the subsequent eight tests using low sulfur fuel to 2) the difference between the average of the high sulfur results with the average of the initial baseline low sulfur results. Total mileage accumulation during purge testing was roughly 250 miles. In other words, after 250 miles of operation, emission performance stabilized and no further purging of sulfur from the catalyst surface occurred.

Phase II consisted of three FTP tests with fuel containing 600 ppm sulfur followed by two FTP tests with 30 ppm sulfur fuel with an LA4 purge cycle prior to each FTP. Six FTP tests were then performed with a US06 cycle prior to each FTP as a sulfur purge cycle. The US06 cycle was chosen as a purge cycle to simulate aggressive high speed and load operation that would encourage higher catalyst temperatures and rich A/F operation. Reversibility was determined in the same manner as in phase I (same initial 30 ppm sulfur baseline). Total mileage accumulation turned out to be roughly 200 miles.

The following table lists the results of the CRC sulfur reversibility test program.

Table B-2. Sulfur Reversibility: CRC Test Program (%)

		NMHC		***NOx***	
		Purge Cycle		*Purge Cycle*	
Vehicle Manufac	Models	LA4	US06	LA4	US06
Ford	Taurus	69.0	83.0	70.0	95.0
Ford	Escort	137.0	122.0	95.0	100.0
Honda	Civic	94.0	99.0	96.0	97.0
Nissan	Sentra	99.0	111.0	85.0	88.0
Toyota	Camry	112.0	98.0	50.0	102.0
Suzuki	Metro	170.0	165.0	86.0	87.0
Fleet Estimate		**97.0**	**108.0**	**84.0**	**95.0**

The fleet estimate used for the CRC data was determined by averaging the baseline low sulfur results, the high sulfur results and the final low sulfur results for all vehicles and determining reversibility as discussed above. These results indicate that on average, NMHC emissions are very reversible, regardless of purge cycle used (LA4 or US06). The Ford Taurus, however, showed only a moderate level of reversibility for NMHC, especially with the LA4 purge cycle (69 percent). The results for NOx indicate that with the LA4 purge cycle, the average level of reversibility is 84 percent with the Toyota Camry having reversibility as low as 50 percent. When using the US06 purge cycle, NOx emissions were far more reversible with an average reversibility of 95 percent. The Nissan Sentra and Suzuki Metro showed almost the exact same level of reversibility with both purge cycles.

2. American Petroleum Institute Sulfur Reversibility Program

The API program[kkk] evaluated a total of seven vehicles, four were 1998 LEV LDVs, one was a 1998 ULEV LDV, and the other two were Tier 1 vehicles (LDV and LDT1). All of the vehicles had been driven for 6,000-10,000 miles, except for the S10 pickup, which had 50,000

[kkk] API has completed a third-party review of the results of their test program (as well as the CRC test program). See "Reversibility of Gasoline Sulfur Effects on Low Emissions Vehicles," T.J. Truex and L.S. Caretto for API, April 7, 1999.

miles on it. API replaced the catalysts of all of the vehicles. Reversibility of the sulfur effect was measured for all of these vehicles with their new catalysts thermally aged to the equivalent of 4,000 miles (i.e., low mileage catalysts) and after only a very short exposure to high sulfur fuel. Four of these vehicles were also tested with 1,000 miles of road aging on high sulfur fuel (540 ppm) prior to reversibility testing.

The sulfur reversibility of two vehicles was also tested after short term exposure to high sulfur fuel with their catalysts thermally aged to represent 100,000 miles of driving. (However, the oxygen sensors were not aged.) Finally, one vehicle was tested after 2,000 miles of driving using high sulfur fuel with its catalysts thermally aged to represent 100,000 miles of driving.

All of the vehicles were tested in a sequence similar to the one used by CRC. The program started with testing using low sulfur fuel (40 ppm). This was followed by testing with a high sulfur fuel (540 ppm). Then, the fuel was switched back to the low sulfur fuel and the vehicle operated over either an LA4 or US06 cycle, which was used as a sulfur purge cycle. Following this purge cycle, emissions were again measured with the FTP.

One major difference between the API and CRC programs was that API generally only performed two tests at each sulfur level, including the purge cycle phase. Thus, statistically speaking, the API program is weaker than the CRC program. Examination of individual emission test results shows significant variability occurred.

Table B-3 lists the vehicle tested in the API program.

Table B-3. API Test Vehicles

Vehicle	*Number of Cylinders*	*Engine Displacement*
1998 Ford Taurus (LEV)	6	3.0L
1998 Honda Accord (ULEV)	6	2.3L
1998 Toyota Avalon (LEV)	6	3.0L
1998 Nissan Altima (LEV)	4	2.4L
1998 Ford Grand Marquis (LEV)	8	4.6L
1998 Ford Town Car (Tier1)	8	4.6L
1997 Chevrolet S-10 (Tier1)	6	4.3L

API screened specific vehicles for this test program by performing emission testing over both the FTP and the US06 cycle. API believed that these vehicles were nearly in compliance with future SFTP standards and therefore representative of 2000 and later emission control

technology. This will be discussed further below.

Table B-4 shows the sulfur reversibility emission results for all of the vehicles when tested with low mileage (4,000 mile) catalysts.

Table B-4. Sulfur Reversibility: API Test Program
Low Mileage Catalysts, Short-Term Exposure to High Sulfur Fuel (%)

		NMHC		***NOx***	
		Purge Cycle		*Purge Cycle*	
Vehicle Manufac	Models	LA4	US06	LA4	US06
Ford	98 Taurus	100.0	n/a *	96.2	n/a
Honda	98 Accord (ULEV)	23.1	100.0	78.3	97.8
Toyota	98 Avalon	71.4	42.9	52.1	106.3
Nissan	98 Altima	800	n/a*	125.0	n/a
Ford	98 Gr. Mar	103.2	80.6	84.5	71.8
Ford	98 Town Car (Tier1)	46.3	60.0	95.0	104.4
Chevrolet	97 S-10 (Tier1)	66.7	154.2	70.3	117.4
Fleet Estimate		**67.9**	**45.9**	**83.3**	**92.3**

* Vehicle not tested with US06 purge cycle.

The most obvious difference between the reversibilities measured by API and those found by CRC is that API's average NMHC reversibility rate when using the LA4 as a purge cycle is 68 percent, while CRC's average NMHC reversibility rate shows nearly ful reversible at 97 percent. The measured NOx reversibilities (with the LA4 purge cycle) were almost identical in the two programs, 83 percent for API compared to 84 percent for CRC.

API found much higher reversibility using the US06 cycle as a purge cycle for NOx (92.3 percent). However, the opposite was true for NMHC (45.9 percent). This 45.9 percent reversibility is considerably lower than that found in the CRC program, where NMHC emissions were essentially fully reversible after purging with the US06 cycle.

Another difference between the API and CRC test results is the great deal of disparity between the reversibilities measured for individual vehicles in the API program. Some vehicles were highly reversible while others were not. The CRC results appear to be more consistent

from vehicle-to-vehicle. This could be a result of the fact that CRC performed eight purge/FTP combinations with low sulfur fuel after exposure to high sulfur fuel, compared to API, which only performed two purge/FTP combinations. The CRC data showed that emissions after the switch back to low sulfur fuel fluctuated up and down before reaching a more consistent level during the eight tests. It is also possible that API simply experienced greater test-to-test variability, or that the vehicles in the API program simply differed more in their inherent reversibility.

Table B-5 shows measured reversibility for vehicles with low mileage catalysts that were operated on high sulfur fuel (540 ppm) for 1,000 miles on the road. Four vehicles were evaluated in this manner. The Taurus was tested with the LA4 purge cycle, but not the US06, while the Accord, Avalon, and Grand Marquis all were tested with the US06 purge cycle but not the LA4. As with the low mileage catalyst data, there is a significant amount of disparity between vehicles, especially for NMHC reversibility with the US06 cycle. Reversibility of NOx emissions with the US06 cycle, however, are consistent and indicate that the sulfur effect is almost fully reversible with the US06 cycle. The Taurus with only short term exposure to high sulfur fuel was 100 percent reversible with the LA4 purge cycle for NMHC, but only 67.9 percent reversible with the LA4 cycle after road aging. Reversibility of NOX emissions from the Taurus was nearly complete for both short term and longer term exposure to high sulfur fuel.

Table B-5. Sulfur Reversibility: API Test Program
Low Mileage Catalysts, 1,000 Mile Exposure to High Sulfur Fuel (%)

	1,000 Mile Exposure				***Short-Term Exposure***			
	NMHC		***NOx***		***NMHC***		***NOx***	
	Purge Cycle		*Purge Cycle*		*Purge Cycle*		*Purge cycle*	
Models	LA4	US06	LA4	US06	LA4	US06	LA4	US06
98 Taurus	67.5	102.5	97.6	169.0	100.0	n/a *	96.2	n/a
98 Accord (ULEV)	n/a	100.0	n/a	94.5	23.1	100.0	78.3	97.8
98 Avalon	n/a	75.0	n/a	101.4	71.4	42.9	52.1	106.3
98 Grand Marquis	n/a	45.5	n/a	101.9	103.2	80.6	84.5	71.8
Fleet Estimate	**67.5**	**88.0**	**97.6**	**106.5**	**94.0**	**69.0**	**77.7**	**88.4**

Table B-7 shows measured reversibility for vehicles with catalysts bench aged to represent 100,000 mile of driving. Only two vehicles were tested with this configuration - the Taurus and the Altima. Due to problems with the fuel tank on the original Altima used in the program, a second Altima was procured and tested with a 100K catalyst system. Reversibility of

the Altima's emissions was measured after both short-term exposure to high sulfur fuel, as well as after 2,000 miles of highway driving with high sulfur fuel. This was the only vehicle in the API program that had both a 100,000 mile catalyst and extended road aging with high sulfur fuel. It was also the only vehicle with 2,000 miles of driving with high sulfur fuel instead of 1,000 like the other four vehicles with more extended use with high sulfur fuel.

Table B-6. Sulfur Reversibility: API with 100K Aged Catalysts Test Program (%)

	NMHC		***NOx***	
	Purge Cycle		*Purge Cycle*	
Models	LA4	US06	LA4	US06
Short-term Exposure to High Sulfur Fuel				
98 Taurus	207.0	107.0	88.7	85.4
98 Altima	84.9	102.7	78.9	89.2
Fleet estimate	**120.0**	**104.0**	**87.3**	**87.3**
2,000 Mile Exposure to High Sulfur Fuel				
98 Altima	n/a	115.1	n/a	93.9

The Taurus showed very similar levels of NMHC emission reversibility (after the LA4 purge cycle) with both low mileage and high mileage catalysts (essentially fully reversible in both cases). NOx emission reversibility dropped from 96.2 percent with the low mileage catalyst to 88.7 percent with the 100,000 mile catalyst. NOx emission reversibility did not improve after purging with US06 cycles.

The first Altima tested, which had a 4000 mile catalyst, was fully reversibility for both NMHC and NOx emissions with the LA4 purge cycle. The second Altima, which had a 100,000 mile catalyst showed less reversibility, only 84.9 percent for NMHC emissions and 78.9 percent for NOx emissions. Both NMHC and NOx emission reversibility improved with purging with the US06 cycle, though NOx emissions were still not fully reversible.

The second Altima showed similar NMHC and NOx reversibility with both short-term and long-term exposure to high sulfur fuel with the US06 purge cycle. The second Altima was not tested with the LA4 purge cycle.

While the focus of the API test program was reversibility, the fact both short and longer term exposures to high sulfur fuel were evaluated also allows the comparison of sulfur sensitivity under these two conditions. Table B-7 presents the FTP emissions on both low and high sulfur

fuel, the latter after both very short term exposure to high sulfur levels and 1,000-2,000 miles of driving on high sulfur fuel. All five vehicles so tested showed greater NOx emission increases after exposure to high sulfur fuel for 1,000-2,000 miles than occurred after short term exposure. NMHC emissions, on the other hand, showed essentially the same sensitivity to sulfur after either short or longer term exposure. The increased NOx emission sensitivity with extended mileage is a concern, as the sulfur sensitivity being projected for current and future vehicles was derived from testing which included only short term exposure to high sulfur fuel. The API data indicates that the effect of sulfur on NOx emissions may be 30-50 percent greater than is currently being projected. EPA plans to investigate this further in the future.

Table B-7. Sulfur Sensitivity: API Test Program
Low Mileage Catalysts, Short-Term Exposure to High Sulfur Fuel (g/mi)

	NMHC			***NOx***		
FTP Test Sulfur Level	*30 ppm*	*540 ppm*	*540 ppm*	*30 ppm*	*540 ppm*	*540 ppm*
Sulfur Exposure	---	Short-term	1,000 Mile	----	Short-term	1,000 Mile
Vehicle	Low Mileage Catalysts					
Taurus	0.033	0.051	0.073	0.075	0.101	0.117
Accord	0.029	0.036	0.041	0.100	0.164	0.245
Avalon	0.040	0.058	0.060	0.068	0.130	0.143
Gr. Marq.	0.044	0.075	0.055	0.040	0.143	0.152
Average	0.037	0.055	0.057	0.071	0.135	0.164
	100,000 Mile Catalysts					
Altima	0.041	0.059	0.057	0.061	0.112	0.132

3. Johnson Matthey Sulfur Reversibility Program

Johnson Matthey (JM), a catalyst manufacturer, conducted a test program to evaluate if long term exposure to high sulfur fuel damaged catalysts, whether the damage was reversible when the system was run on low sulfur fuel, and to determine whether exposure of catalysts to higher temperatures with low sulfur fuel reversed the damage. Four catalyst designs: Palladium (Pd), Pd/Rhodium (Rh), Platinum (Pt)/Rh, and Pt/Pd/Rh, were bench aged for 45 hours approximately equal to 50K miles. There were two sets of catalysts. Set A was aged using 87 ppm sulfur, while set B was aged using 735 ppm. Set A was always used as the baseline test.

Set B was used to measure high sulfur results (735 ppm) and the consequent low sulfur results. A single vehicle was used for all of the testing - a 1990 Tier 0 Mitsubishi Galant. Each catalyst was installed on the vehicle and then evaluated. Each catalyst was located in a front underbody position. Sulfur purging with the US06 cycle was not evaluated, only the LA4 purge cycle.

After evaluating reversibility performance of each catalyst to exposure of low sulfur fuel, JM attempted to demonstrate the effect prolonged exposure to high catalyst temperatures would have on sulfur reversibility, since most of the scientific literature has suggested that exposing the catalyst system to temperatures over 700° C should facilitate reversibility. Each catalyst was run over a steady-state sulfur recovery cycle which involved an A/F ratio (AFR) oscillation of stoichiometry +/- 0.5 AFR @ 0.10 Hz (5 seconds rich/5 seconds lean) and a catalyst bed temperature of 700° C. This procedure was followed by a cycle at 800° C and then a final cycle at 900° C. What JM found was that according to their results, sulfur is highly irreversible even when the catalyst is exposed for five straight hours to temperatures of 700° C, 800° C, and 900° C.

Table B-8 lists the results of JM's sulfur reversibility program. The fleet estimate is also a simple arithmetic average of the data. It should be noted that all of the catalysts had very poor reversibility when only switching back to low sulfur fuel. As the catalysts were then exposed to increasing temperature, the results became mixed - some catalysts improving, while others deteriorated. For NMHC, the Pt/Rh catalyst appears to be the only catalyst that showed more reversibility in response to increased temperatures. Curiously, most of the catalysts seemed to respond best to the 700° C and 800° C temperatures and poorly to the highest temperature (900° C). For NOx, the results were even poorer. For example, the Pd/Rh catalyst never experienced a NOx sulfur reversibility rate above 18 percent. In fact, most of the time it had negative reversibility rates, meaning once the catalyst was re-exposed to low sulfur fuel after having been operated on high sulfur fuel, the low sulfur emission results were higher than the high sulfur results.

Table B-8. Sulfur Reversibility: Johnson Matthey Test Program (LA4 Purge Cycle) (%)

Catalyst	*NMHC*				*NOx*			
	Sulfur Purging Temperature							
	None	700° C	800° C	900° C	None	700° C	800° C	900° C
Pd	50.0	50.0	66.0	17.0	44.0	75.0	88.0	69.0
Pd/Rh	30.0	30.0	20.0	10.0	-5.0	18.0	-50.0	-33.0
Pt/Rh	50.0	92.0	92.0	83.0	32.0	32.0	32.0	32.0
Pt/Pd/Rh	38.0	85.0	46.0	54.0	47.0	65.0	-35.0	47.0
Fleet Estimate	42.0	64.3	56.0	41.0	29.5	47.5	8.8	28.8

4. Other Testing

Honda has suggested that in order for complete sulfur adsorption onto the catalyst surface, catalyst temperatures must be below 500° C. Honda believes that the cycles that have been used in the various sulfur test programs to adhere the sulfur to the catalyst surface have been inadequate. They believe catalyst temperatures over the FTP or LA4 test have generally been exceeding 500° C at some point or another during the cycle. They proposed a conditioning cycle that consisted of an extended 35 mph cruise making sure the catalyst temperature does not exceed 450° C - 500° C. Full sulfur adsorption is determined by monitoring feedgas SO_2 and exhaust SO_2 until they are the same. Honda found that when using their conditioning cycle, NMHC emissions were 20 percent more irreversible than when using the FTP or LA4 for sulfur conditioning. NOx emissions were 19 percent more irreversible.

As a result of Honda's information, the 1K road aging results from the API program, and the apparent effect of sulfur aging on the JM results, we have undertaken our own EPA sulfur reversibility evaluation program. The primary focus of our program is to determine the effect road aging has on sulfur adsorption to the catalyst and the subsequent removal or reversal of the sulfur. At this time, testing is still underway and we are just about to start the road aging. Although this data will not be available for the NPRM, it will be completed in time for the final rule.

D. Criteria for Evaluating Sulfur Reversibility Data

Projecting the degree of sulfur irreversibility for various vehicles types under representative in-use conditions is difficult due to inadequacies in essentially all of the available data. As mentioned in the previous section, the sulfur reversibility testing would ideally have

used vehicles designed to meet a range of FTP and SFTP standards, thermally aged catalyst systems prior to testing, exposed these systems to high sulfur fuel for a few thousand miles of typical driving, and used representative driving cycles to purge sulfur between emission tests.

While many of the vehicles tested had thermally aged catalyst systems, none were designed to meet SFTP standards. API tested the vehicles in their test program over the US06 cycle to assess the degree to which they might already be in compliance with future SFTP standards. The results showed that two out of the eight (including the second Altima) vehicles were below the 0.14 g/mi US06 NMHC+NOx standard for LEVs and ULEVs, while half of the vehicles were below the 8.0 g/mi US06 CO standard. However, only one vehicle met the NMHC+NOx standard with any significant margin of safety. Thus, this screening data does not support the contention that these vehicles were essentially in compliance with the SFTP standards. Also, API did not measure emissions over the SC03 cycle, which simulates emissions with the air conditioning system turned on and which is also a part of the SFTP requirement. Thus, there is no evidence that these vehicles were designed to meet non-US06 related SFTP requirements.

In addition to US06 emission data, API also measured each vehicle's air-fuel ratio on a second-by- second basis over both the FTP and US06 cycles. The standard deviation of the air-fuel ratio over the FTP averaged 0.35, while that over the US06 cycle averaged 1.03. Thus, variability in air-fuel mixture control was nearly three time as great over the US06 cycle as over the FTP. Tight air-fuel mixture control is essential to maintaining low engine-out emissions and high catalyst over the entire emission test and during in-use driving. The first step a manufacturer will take in order to comply with the SFTP requirements will be to modify the engine calibration to achieve the best level of air-fuel mixture control possible. The fact that these vehicles showed much greater variability over the US06 cycle indicates that manufacturers had not yet begun the process of making these vehicles SFTP-compliant. Previous studies have shown that wide swings in air-fuel ratio reduce the impact of sulfur on catalyst efficiency and emissions relative to minor swings in air-fuel ratio. Thus, this criterion appears to be of critical importance in projecting the reversibility of SFTP-compliant LEVs and Tier 2 vehicles.

Moving to exposure to high sulfur fuel, while a few vehicles were operated on high sulfur fuel for a thousand miles or more, only two vehicles had catalysts which were thermally aged to more than a few thousand miles. Also, the driving cycles used to purge sulfur after switching from high to low sulfur fuel were not any of the driving cycles developed to be fully "representative" of recent driving patterns. The result of these shortcomings is that considerable technical judgment has to be used to project the degree of sulfur irreversibility which would occur for both current and future vehicles.

EPA established a number of criteria for evaluating the available data in order to project likely levels of in-use sulfur reversibility. The first criterion is to focus exclusively on testing of vehicles with thermally aged catalysts. We believe that this is essential, because catalysts prior to thermal aging contain far more surface area and oxygen storage capacity than is needed to meet low emission levels. It is possible for sulfur to deactivate a considerable portion of the surface

area and oxygen storage with minor impacts on overall catalyst performance. This would not be representative of the impact of sulfur on real-world emissions over most of the vehicle's life.

The second criterion is to give priority to testing where the catalyst has been exposed to high sulfur for a considerable period of time. Long term exposure would be the predominant mode of exposure under a regional sulfur program such as that proposed by API. With the high sulfur region being potentially quite large geographically, most vehicles entering it are likely to be there awhile. Simply crossing the region that would have 300 ppm average sulfur levels under the regional program proposed by API represents roughly 1000 or more miles.

Under any sulfur control program, sulfur levels will vary from batch to batch of gasoline produced by refineries. For example, under the proposal, sulfur could easily vary from less than 10 ppm to 80 ppm in-use after 2008. Under this scenario, exposure to high sulfur fuel could be one tankful at a time, or could continue for several tankfuls, depending on the production patterns at refineries and the purchasing patterns of individuals. Still, even one tankful of fuel typically lasts 300 miles or more. This is far more than the 10-20 miles of exposure to high sulfur fuel which occurred in most of the testing summarized in the previous section.

Development of the subsequent criteria are more complex, because the issues of SFTP compliance and representative driving cycles are not as easily addressed. None of the vehicles tested were certified to either the Tier 1 or LEV SFTP emission standards. While some of the vehicles may have SFTP emissions close to or even below the applicable SFTP standards, it is still likely that manufacturers would change their engine calibrations to enhance compliance with these emission standards in-use. This is confirmed by the API measurements of air-fuel ratio over the FTP and US06 cycles. Thus, none of the test vehicles can be assured of having SFTP-compliant engine calibrations.

Likewise, only the LA4 and US06 driving cycles were used in the test programs performed to date. The LA4 cycle was derived from driving patterns in Los Angeles in the early 1970's. However, due to physical limitations in the dynamometers in use at the time, all accelerations greater than 3.3 mph per second were reduced to this level. This, plus the fact that driving has become more aggressive over the past 25 years makes the LA4 cycle less aggressive on average than today's typical driving. However, the LA4 cycle does include driving as fast as 58 mph, so it is also not representative of light, city driving.

The US06 cycle is made up of real-world driving segments.[lll] However, the concentration of aggressive driving is much higher than occurs in the real world. Therefore, the length of time that the catalyst is exposed to both high temperatures and rich conditions is much higher than would occur in the real world. This could easily remove more sulfur than would be removed in-

[lll] All but one of the segments were taken from EPA's REP05 cycle, which represents the aggressive portion of in-use driving. The remaining segment was taken from ARB's HL07 cycle, which was intended to represent aggressive in-use driving in California.

use even during aggressive driving.

As mentioned in Section B, meeting the SFTP standards will requiring the tightening of air-fuel mixture control and reduce the amount of rich operation in-use during aggressive driving. Both of these changes directionally reduce sulfur removal. This primarily affects the sulfur reversibility testing after preconditioning with the US06 cycle. In particular, it casts considerable doubt in the applicability of measured reversibilities using the US06 purge cycle to SFTP-compliant vehicles. Therefore, the measured levels of sulfur reversibility after operation on US06 cycles will not be used to project the in-use levels of sulfur reversibility for SFTP-compliant vehicles.

For pre-SFTP vehicles, the US06 cycle still likely over-estimates the amount of sulfur reversibility which would occur in-use, due to its unrepresentative concentration of high temperatures and rich operation. Thus, the measured levels of sulfur reversibility after operation on both LA4 and US06 cycles will be used to project the in-use levels of sulfur reversibility for pre-SFTP vehicles.

In summary, the projections developed in the following section will:

1. Only use data from vehicles with aged catalyst systems,
2. Emphasize data from vehicles whose catalysts experienced substantial use with high sulfur fuel,
3. For projections regarding SFTP-compliant vehicles, only use data where the sulfur was purged using the LA4 cycle, and
4. For projections regarding pre-SFTP vehicles, use data where the sulfur was purged using either the LA4 or US06 cycle.

E. Projected Levels of Sulfur Irreversibility In-Use

Applying the first criterion developed in Section D. results in the retention of the CRC and JM data (Tables B-2 and B-8), as that testing was performed on vehicles with thermally aged catalysts. It also allows the use of the API data contained in Table B-6. However, the remaining API data apply to vehicles with low mileage catalysts, which are not sufficiently representative of in-use operation. Therefore, EPA's current conclusions about reversibility of sulfur effects do not rely on the API data except that in Table B-6.

Of these data, only the JM data and the second Altima tested by API also involved extensive use of high sulfur fuel prior to the measurement of reversibility. JM simulated the use of high sulfur fuel through oven aging, so it may not be fully representative as actual vehicle driving on the road. However, oven aging to simulate on-road thermal degradation is well established, so the same for sulfur aging should be equally acceptable.

API actually drove the second Altima on the road for 2,000 miles with high sulfur fuel.

However, the type of driving actually performed is not known, raising some uncertainty about its representativeness. More importantly, API only measured reversibility with this vehicle after operating the vehicle with low sulfur fuel over the US06 cycle. This took advantage of the vehicle's widely varying air-fuel ratio over this test cycle and likely purged more sulfur off of the catalyst than would occur with an SFTP-compliant vehicle. JM, on the other hand, simulated the type of air-fuel ratio control which would be indicative of an SFTP-compliant vehicle with it oven aging and purging. Thus, overall, the JM data should receive the greatest weight in this analysis. Table B-9 summarizes the results of these three test programs.

Table B-9. Sulfur Reversibility: Summary of Relevant Test Programs (%)

	NMHC		***NOx***	
	Purge Cycle		*Purge Cycle*	
Models	LA4	US06	LA4	US06
CRC (6 vehicles)	97%	Complete	84%	95%
JM (4 catalysts)	4-64%	41-64%	30-48%	9-48%
API (2-3 vehicles)	Compete	Complete	87%	89%

The JM results are shown as a range, as it is difficult at this time to average the results at the various sulfur purging temperatures. However, the JM data were placed into the two purge cycle categories by assuming that the test results with no oven-based sulfur purging and the purging at 700° C were similar to LA4 driving, while the results with oven purging at 700-900° C were similar to US06 driving. Another relevant factor is that the results of the API testing are the most erratic, primarily due to the relatively small number of replicate tests.

As can be seen, there is considerable variation in the measured levels of sulfur reversibility in the above test data. In particular, the JM data show much less reversibility and should be given the most weight because it was the only test program thus far to include catalysts aged both thermally and with high sulfur fuel. Therefore, the overall projection of reversibility primarily hinges on the relative weight given to the JM data. In any event, there will be considerable uncertainty in any summary projection developed from these results, because of the limitations in the test methods described above.

For pre-SFTP vehicles, we decided to utilize reversibility measurements using both the LA4 and US06 driving cycles. Since the CRC and API vehicles are pre-SFTP vehicles, these two test programs were given considerable weight along with those of JM. For these vehicles, we project that NMHC emissions are fully reversible, while NOx emissions are only 85 percent reversible. For SFTP-compliant vehicles, we decided above to utilize reversibility measurements using only the LA4 driving cycle. We also gave additional weight to the JM data, as the vehicles

tested in the CRC and API programs were not SFTP-compliant. While the JM test vehicle was also not SFTP-compliant, the purging of the sulfur from the catalyst was conducted in a way that was more consistent with that of an SFTP-compliant vehicle. Given this, we project that both NMHC and NOx emissions from SFTP-compliant vehicles, will be 50 percent reversible. Based on the average results of the three test programs, we could have projected a higher reversibility for NMHC emissions and a lower reversibility for NOx emissions. However, examining the results for the individual vehicles and catalysts and given the fact that none of the vehicles tested were SFTP-compliant, we decided to project a single level of reversibility for both pollutants.

Appendix B. References

1. "Development of Light-Duty Emission Inventory Estimates in the Notice of Proposed Rulemaking for Tier 2 and Sulfur Standards," U.S. EPA, February 1999.

2. "EPA Staff Paper on Gasoline Sulfur Issues," U.S. EPA, May 1998, EPA420-R-98-005.

3. EPA Report Number M6.FUL.001

4. "EPA Staff Paper on Gasoline Sulfur Issues," U.S. EPA, May 1998, EPA420-R-98-005.

Appendix C: One-Hour and Eight-Hour County Design Values

The tables contained in this appendix are as follows:

Table C-1. Areas formally designated as nonattainment areas for ozone under the 1-hour NAAQS, outside California, as of August 10, 1998.

Table C-2. Metropolitan areas and rural counties with 1995-1997 measured design values exceeding the 1-hour standard.

Table C-3. Metropolitan areas and rural counties with 1995-1997 measured design values exceeding the 8-hour standard.

Table C-4. Metropolitan areas and rural counties with 1995-1997 measured design values within 15% of the 8-hour standard.

Table C-5. Metropolitan areas and rural counties with design values projected to exceed the 1-hour standard in 2007 with ROTR controls but without Tier 2/Sulfur controls.

Table C-6. Metropolitan areas and rural counties with design values projected to exceed the 8-hour standard in 2007 with ROTR controls but without Tier 2/Sulfur controls.

Table C-7. Metropolitan areas and rural counties with design values projected to be less than the 8-hour standard but within 15% or it in 2007 with ROTR controls but without Tier 2/Sulfur controls.

Table C-8. Metropolitan areas and rural counties with design values projected to exceed the 8-hour standard in 2007 with ROTR and Tier 2/Sulfur controls.

Table C-9. Metropolitan areas and rural counties with design values projected to exceed the 8-hour standard in 2010 with ROTR controls but without Tier 2/Sulfur controls.

Table C-10. Metropolitan areas and rural counties with design values projected to exceed the 8-hour standard in 2010 with ROTR controls and Tier 2/Sulfur controls.

Table C-11. One-hour county design values (ppb) and population.

Table C-12. Eight-hour county design values (ppb) and population.

Table C-13. Metropolitan areas and rural counties with design values that exceeded the 1-hour standard prior to ROTR controls, and were projected to meet but remain within 15% of the 1-hour standard after ROTR controls.

Table C-1. Areas formally designated as nonattainment areas for ozone under the 1-hour NAAQS, outside California, as of August 10, 1998.[1]

Areas Listed Alphabetically	Classification	1990 Population (1000)	Located in a CMSA or MSA?
Atlanta, GA	Serious	2,654	msa
Baltimore, MD	Severe-15	2,348	msa
Baton Rouge, LA	Serious	559	msa
Beaumont-Port Arthur, TX	Moderate	361	msa
Birmingham, AL	Marginal	751	msa
Boston-Lawrence-Worcester (E. MA), MA-NH	Serious	5,505	cmsa
Chicago-Gary-Lake County, IL-IN	Severe-17	7,886	cmsa
Cincinnati-Hamilton, OH-KY	Moderate	1,705	cmsa
Dallas-Fort Worth, TX	Serious	3,560	cmsa
Door Co, WI	Marginal	26	neither
El Paso, TX	Serious	592	msa
Greater Connecticut	Serious	2,470	cmsa
Houston-Galveston-Brazoria, TX	Severe-17	3,731	cmsa
Kent & Queen Anne's Co.s, MD	Marginal	52	part
Lancaster, PA	Marginal	423	msa
Louisville, KY-IN	Moderate	834	msa
Manitowoc Co, WI	Moderate	80	neither
Milwaukee-Racine, WI	Severe-17	1,735	cmsa
Muskegon, MI	Moderate	159	msa
New York-N. New Jersey-Long Island, NY-NJ-C	Severe-17	17,651	cmsa
Philadelphia-Wilmington-Trenton, PA-NJ-DE-M	Severe-15	6,010	cmsa
Phoenix, AZ	Serious	2,092	msa
Pittsburgh-Beaver Valley, PA	Moderate	2,468	cmsa
Portland, ME	Moderate	441	msa
Portsmouth-Dover-Rochester, NH	Serious	183	msa
Providence (All RI), RI	Serious	1,003	cmsa
Springfield (Western MA), MA	Serious	812	msa
St Louis, MO-IL	Moderate	2,390	msa
Sunland Park, NM (New Area 1995)	Marginal	8	msa
Washington, DC-MD-VA	Serious	3,924	msa

Table C-2. Metropolitan areas and rural counties with 1995-1997 measured design values exceeding the 1-hour standard.

Name of metropolitan area or rural county	Design Value (ppb)	1990 Population
Manitowoc WI	126	80,421
Door WI	127	25,690
Jefferson TN	125	33,016
Mason MI	125	25,537
Kent MD	129	17,842
Sagadahoc ME	125	33,535
Iberville LA	139	31,049
La Porte IN	146	107,066
Atlanta, GA MSA	145	2,959,500
Barnstable-Yarmouth, MA MSA	131	134,954
Baton Rouge, LA MSA	131	528,261
Beaumont-Port Arthur, TX MSA	139	361,218
Birmingham, AL MSA	132	839,942
Boston-Worcester-Lawrence, MA-NH-ME-CT CMSA	138	5,455,403
Chicago-Gary-Kenosha, IL-IN-WI CMSA	129	8,239,820
Cincinnati-Hamilton, OH-KY-IN CMSA	125	1,817,569
Dallas-Fort Worth, TX CMSA	139	4,037,282
Grand Rapids-Muskegon-Holland, MI MSA	137	937,891
Hartford, CT MSA	144	1,157,585
Houma, LA MSA	127	182,842
Houston-Galveston-Brazoria, TX CMSA	189	3,731,029
Kansas City, MO-KS MSA	128	1,582,874
Lancaster, PA MSA	125	422,822
Longview-Marshall, TX MSA	139	193,801
Louisville, KY-IN MSA	125	949,012
Memphis, TN-AR-MS MSA	131	1,007,306
Milwaukee-Racine, WI CMSA	127	1,607,183
New York-Northern New Jersey-Long Island, NY-NJ-CT-PA CMSA	157	19,549,649
Philadelphia-Wilmington-Atlantic City, PA-NJ-DE-MD CMSA	152	5,893,019
Pittsburgh, PA MSA	133	2,394,811
Providence-Fall River-Warwick, RI-MA MSA	133	1,134,350
St. Louis, MO-IL MSA	131	2,492,348
Springfield, MA MSA	132	587,884
Washington-Baltimore, DC-MD-VA-WV CMSA	145	6,726,395

Table C-3. Metropolitan areas and rural counties with 1995-1997 measured design values exceeding the 8-hour standard.

Name of metropolitan area or rural county	Design Value (ppb)	1990 Population
Manitowoc WI	95	80,421
Kewaunee WI	93	18,878
Door WI	92	25,690
Madison VA	86	11,949
Jefferson TN	96	33,016
Chester SC	87	32,170
Franklin PA	86	121,082
Preble OH	86	40,113
Logan OH	86	42,310
Knox OH	91	47,473
Clinton OH	97	35,415
Northampton NC	86	20,798
Haywood NC	85	46,942
Granville NC	94	38,345
Caswell NC	89	20,693
Jefferson NY	88	110,943
Essex NY	86	37,152
Ste. Genevieve MO	87	16,037
Mason MI	98	25,537
Cass MI	94	49,477
Benzie MI	88	12,200
Kent MD	96	17,842
Sagadahoc ME	95	33,535
Knox ME	87	36,310
Iberville LA	96	31,049
Livingston KY	86	9,062
Hancock KY	89	7,864
La Porte IN	104	107,066
Sussex DE	93	113,229
Clay AL	86	13,252
Allentown-Bethlehem-Easton, PA MSA	95	595,081
Altoona, PA MSA	90	130,542
Atlanta, GA MSA	110	2,959,500
Augusta-Aiken, GA-SC MSA	87	415,220
Barnstable-Yarmouth, MA MSA	100	134,954
Baton Rouge, LA MSA	95	528,261
Beaumont-Port Arthur, TX MSA	93	361,218
Benton Harbor, MI MSA	98	161,378
Biloxi-Gulfport-Pascagoula, MS MSA	86	312,368

Table C-3. Metropolitan areas and rural counties with 1995-1997 measured design values exceeding the 8-hour standard.

Name of metropolitan area or rural county	Design Value (ppb)	1990 Population
Birmingham, AL MSA	95	839,942
Boston-Worcester-Lawrence, MA-NH-ME-CT CMSA	97	5,455,403
Buffalo-Niagara Falls, NY MSA	85	1,189,340
Canton-Massillon, OH MSA	88	394,106
Charlotte-Gastonia-Rock Hill, NC-SC MSA	97	1,162,140
Chattanooga, TN-GA MSA	90	424,347
Chicago-Gary-Kenosha, IL-IN-WI CMSA	96	8,239,820
Cincinnati-Hamilton, OH-KY-IN CMSA	99	1,817,569
Cleveland-Akron, OH CMSA	99	2,859,644
Columbus, OH MSA	92	1,345,450
Dallas-Fort Worth, TX CMSA	104	4,037,282
Dayton-Springfield, OH MSA	93	951,270
Detroit-Ann Arbor-Flint, MI CMSA	92	5,187,171
Dover, DE MSA	94	110,993
Elkhart-Goshen, IN MSA	90	156,198
Erie, PA MSA	87	275,572
Evansville-Henderson, IN-KY MSA	93	278,990
Fayetteville, NC MSA	87	274,713
Fort Wayne, IN MSA	90	456,281
Grand Rapids-Muskegon-Holland, MI MSA	99	937,891
Greensboro--Winston-Salem--High Point, NC MSA	89	1,050,304
Greenville, NC MSA	88	108,480
Greenville-Spartanburg-Anderson, SC MSA	88	830,539
Harrisburg-Lebanon-Carlisle, PA MSA	88	587,986
Hartford, CT MSA	101	1,157,585
Houma, LA MSA	85	182,842
Houston-Galveston-Brazoria, TX CMSA	117	3,731,029
Huntington-Ashland, WV-KY-OH MSA	88	312,529
Indianapolis, IN MSA	97	1,380,491
Jamestown, NY MSA	85	141,895
Janesville-Beloit, WI MSA	85	139,510
Johnson City-Kingsport-Bristol, TN-VA MSA	88	436,047
Johnstown, PA MSA	88	241,280
Kalamazoo-Battle Creek, MI MSA	87	429,453
Kansas City, MO-KS MSA	94	1,582,874
Knoxville, TN MSA	95	585,960
Lake Charles, LA MSA	85	168,134
Lancaster, PA MSA	96	422,822
Lexington, KY MSA	85	405,936
Lima, OH MSA	89	154,340

Table C-3. Metropolitan areas and rural counties with 1995-1997 measured design values exceeding the 8-hour standard.

Name of metropolitan area or rural county	Design Value (ppb)	1990 Population
Longview-Marshall, TX MSA	91	193,801
Louisville, KY-IN MSA	92	949,012
Memphis, TN-AR-MS MSA	95	1,007,306
Milwaukee-Racine, WI CMSA	98	1,607,183
Nashville, TN MSA	99	985,026
New York-Northern New Jersey-Long Island, NY-NJ-CT-PA CMSA	108	19,549,649
Norfolk-Virginia Beach-Newport News, VA-NC MSA	87	1,444,710
Owensboro, KY MSA	87	87,189
Parkersburg-Marietta, WV-OH MSA	89	149,169
Philadelphia-Wilmington-Atlantic City, PA-NJ-DE-MD CMSA	110	5,893,019
Pittsburgh, PA MSA	105	2,394,811
Portland, ME MSA	94	221,095
Providence-Fall River-Warwick, RI-MA MSA	96	1,134,350
Raleigh-Durham-Chapel Hill, NC MSA	89	858,485
Reading, PA MSA	92	336,523
Richmond-Petersburg, VA MSA	90	865,640
St. Louis, MO-IL MSA	100	2,492,348
San Antonio, TX MSA	87	1,324,749
Scranton--Wilkes-Barre--Hazleton, PA MSA	90	638,524
Sharon, PA MSA	92	121,003
Sheboygan, WI MSA	92	103,877
South Bend, IN MSA	91	247,052
Springfield, MA MSA	97	587,884
Steubenville-Weirton, OH-WV MSA	85	142,523
Terre Haute, IN MSA	88	147,585
Toledo, OH MSA	89	614,128
Tulsa, OK MSA	88	708,954
Tyler, TX MSA	89	151,309
Washington-Baltimore, DC-MD-VA-WV CMSA	107	6,726,395
Wheeling, WV-OH MSA	86	159,301
York, PA MSA	87	339,574
Youngstown-Warren, OH MSA	93	600,895

Table C-4. Metropolitan areas and rural counties with 1995-1997 measured design values within 15% of the 8-hour standard.

Name	Design Value (ppb)	Pop'n.
Simpson KY	83	15,145
Yancey NC	84	15,419
Wythe VA	78	25,466
Pike KY	74	72,583
Rockingham NC	84	86,064
McLean KY	83	9,628
Person NC	84	30,180
Putnam TN	80	51,373
Monroe MO	84	9,104
Walworth WI	83	75,000
Sharkey MS	80	7,066
Macoupin IL	83	47,679
Ulster NY	82	165,304
St Mary LA	81	58,086
Hardin KY	81	89,240
Henry VA	82	56,942
Union SC	81	30,337
Humphreys TN	77	15,795
Graves KY	74	33,550
Lee MS	75	65,581
Pointe Coupee LA	83	22,540
Haywood TN	82	19,437
Lawrence PA	84	96,246
Frederick VA	84	45,723
Huron MI	82	34,951
Edmonson KY	82	10,357
Jefferson WI	80	67,783
Effingham IL	81	31,704
Grant LA	75	17,526
Hamilton NY	75	5,279
Fond Du Lac WI	79	90,083
Caroline VA	84	19,217
Darlington SC	78	61,851
Camden NC	83	5,904
Dodge WI	78	76,559
Greenbrier WV	83	34,693
Columbia WI	81	45,088
Bell KY	76	31,506
Barnwell SC	81	20,293

Table C-4. Metropolitan areas and rural counties with 1995-1997 measured design values within 15% of the 8-hour standard.

Name	Design Value (ppb)	Pop'n.
Hancock ME	83	46,948
Coos NH	77	34,828
Cheshire NH	74	70,121
Bennington VT	79	35,845
Adams MS	77	35,356
Albany-Schenectady-Troy, NY MSA	81	861,623
Appleton-Oshkosh-Neenah, WI MSA	81	315,121
Asheville, NC MSA	75	191,772
Austin-San Marcos, TX MSA	81	846,227
Bangor, ME MSA	73	91,629
Champaign-Urbana, IL MSA	81	173,025
Charleston-North Charleston, SC MSA	76	506,877
Charleston, WV MSA	81	250,454
Clarksville-Hopkinsville, TN-KY MSA	80	169,439
Columbia, SC MSA	83	453,932
Columbus, GA-AL MSA	83	260,862
Corpus Christi, TX MSA	83	349,894
Davenport-Moline-Rock Island, IA-IL MSA	78	350,855
Decatur, AL MSA	81	131,556
Decatur, IL MSA	83	117,206
Elmira, NY MSA	73	95,195
Green Bay, WI MSA	82	194,594
Hickory-Morganton-Lenoir, NC MSA	79	292,405
Huntsville, AL MSA	84	293,047
Jackson, MS MSA	77	395,396
Jacksonville, FL MSA	81	906,727
Lafayette, LA MSA	84	345,053
Lakeland-Winter Haven, FL MSA	74	405,382
Lansing-East Lansing, MI MSA	83	432,684
Little Rock-North Little Rock, AR MSA	81	513,026
Madison, WI MSA	79	367,085
Minneapolis-St. Paul, MN-WI MSA	81	2,538,776
Mobile, AL MSA	79	476,923
Monroe, LA MSA	77	142,191
Montgomery, AL MSA	77	292,517
New Orleans, LA MSA	84	1,285,262
Oklahoma City, OK MSA	83	958,839
Orlando, FL MSA	78	1,224,844
Pensacola, FL MSA	84	344,406
Peoria-Pekin, IL MSA	80	339,172

Table C-4. Metropolitan areas and rural counties with 1995-1997 measured design values within 15% of the 8-hour standard.

Name	Design Value (ppb)	Pop'n.
Pittsfield, MA MSA	77	88,695
Roanoke, VA MSA	78	224,592
Rochester, NY MSA	83	1,062,470
Rockford, IL MSA	79	329,676
Rocky Mount, NC MSA	84	133,369
Sarasota-Bradenton, FL MSA	76	489,483
Savannah, GA MSA	72	257,899
Shreveport-Bossier City, LA MSA	82	376,330
Springfield, IL MSA	76	189,550
Springfield, MO MSA	78	264,346
Syracuse, NY MSA	79	742,237
Tampa-St. Petersburg-Clearwater, FL MSA	82	2,067,959
Utica-Rome, NY MSA	72	316,645
Victoria, TX MSA	78	74,361
Wichita, KS MSA	74	485,270
Williamsport, PA MSA	73	118,710
Wilmington, NC MSA	79	171,269
	sum	26,226,237
	MA count	52
	MA sum	24,306,857
	Cnty count	44
	Cnty sum	1,919,380

Table C-5. Metropolitan areas and rural counties with design values projected to exceed the 1-hour standard in 2007 with ROTR controls but without Tier 2/Sulfur controls.

Name	Design Value (ppb)	Pop'n.
Iberville LA	132	31,049
La Porte IN	131	107,066
Beaumont-Port Arthur, TX MSA	129	361,218
Hartford, CT MSA	125	1,157,585
Houston-Galveston-Brazoria, TX CMSA	175	3,731,029
Longview-Marshall, TX MSA	129	193,801
Memphis, TN-AR-MS MSA	125	1,007,306
New York-Northern New Jersey-Long Island, NY-NJ-CT-PA CMSA	136	19,549,649
Philadelphia-Wilmington-Atlantic City, PA-NJ-DE-MD CMSA	126	5,893,019
Washington-Baltimore, DC-MD-VA-WV CMSA	126	6,726,395
	sum	38,758,117
	MA count	8
	MA sum	38,620,002
	Cnty count	2
	Cnty sum	138,115

Table C-6. Metropolitan areas and rural counties with design values projected to exceed the 8-hour standard in 2007 with ROTR controls but without Tier 2/Sulfur controls.

Name	Design Value (ppb)	Pop'n.
Manitowoc WI	85	80,421
Mason MI	88	25,537
Iberville LA	91	31,049
La Porte IN	93	107,066
Atlanta, GA MSA	95	2,959,500
Barnstable-Yarmouth, MA MSA	89	134,954
Baton Rouge, LA MSA	88	528,261
Beaumont-Port Arthur, TX MSA	86	361,218
Benton Harbor, MI MSA	86	161,378
Biloxi-Gulfport-Pascagoula, MS MSA	88	312,368
Boston-Worcester-Lawrence, MA-NH-ME-CT CMSA	86	5,455,403
Charlotte-Gastonia-Rock Hill, NC-SC MSA	94	1,162,140
Chicago-Gary-Kenosha, IL-IN-WI CMSA	90	8,239,820
Cincinnati-Hamilton, OH-KY-IN CMSA	87	1,817,569
Cleveland-Akron, OH CMSA	86	2,859,644
Dallas-Fort Worth, TX CMSA	94	4,037,282
Grand Rapids-Muskegon-Holland, MI MSA	89	937,891
Hartford, CT MSA	88	1,157,585
Houston-Galveston-Brazoria, TX CMSA	109	3,731,029
Kansas City, MO-KS MSA	90	1,582,874
Knoxville, TN MSA	85	585,960
Memphis, TN-AR-MS MSA	90	1,007,306
Milwaukee-Racine, WI CMSA	94	1,607,183
Nashville, TN MSA	88	985,026
New York-Northern New Jersey-Long Island, NY-NJ-CT-PA CMSA	97	19,549,649
Philadelphia-Wilmington-Atlantic City, PA-NJ-DE-MD CMSA	94	5,893,019
Pittsburgh, PA MSA	95	2,394,811
St. Louis, MO-IL MSA	90	2,492,348
San Antonio, TX MSA	85	1,324,749
Springfield, MA MSA	87	587,884
Tulsa, OK MSA	87	708,954
Washington-Baltimore, DC-MD-VA-WV CMSA	93	6,726,395
	sum	79,546,273
	MA count	28
	MA sum	79,302,200
	Cnty count	4
	Cnty sum	244,073

Table C-7. Metropolitan areas and rural counties with design values projected to be less than the 8-hour standard but within 15% or it in 2007 with ROTR controls but without Tier 2/Sulfur controls.

Name	Design Value (ppb)	Pop'n.
Kewaunee WI	84	18878
Door WI	83	25690
Jefferson TN	80	33016
Chester SC	78	32170
Logan OH	73	42310
Knox OH	77	47473
Clinton OH	80	35415
Haywood NC	75	46942
Granville NC	83	38345
Caswell NC	74	20693
Jefferson NY	79	110943
Essex NY	78	37152
Ste. Genevieve MO	77	16037
Cass MI	83	49477
Benzie MI	79	12200
Kent MD	82	17842
Sagadahoc ME	82	33535
Knox ME	76	36310
Livingston KY	72	9062
Sussex DE	81	113229
Clay AL	72	13252
Simpson KY	72	15145
Rockingham NC	73	86064
Monroe MO	78	9104
Walworth WI	77	75000
Sharkey MS	74	7066
Ulster NY	72	165304
St Mary LA	76	58086
Union SC	73	30337
Pointe Coupee LA	77	22540
Lawrence PA	74	96246
Huron MI	73	34951
Jefferson WI	73	67783
Fond Du Lac WI	73	90083
Camden NC	74	5904
Dodge WI	72	76559
Columbia WI	76	45088
Hancock ME	72	46948
Adams MS	74	35356

Table C-7. Metropolitan areas and rural counties with design values projected to be less than the 8-hour standard but within 15% or it in 2007 with ROTR controls but without Tier 2/Sulfur controls.

Name	Design Value (ppb)	Pop'n.
Albany-Schenectady-Troy, NY MSA	72	861623
Allentown-Bethlehem-Easton, PA MSA	80	595081
Altoona, PA MSA	75	130542
Appleton-Oshkosh-Neenah, WI MSA	76	315121
Augusta-Aiken, GA-SC MSA	77	415220
Austin-San Marcos, TX MSA	77	846227
Birmingham, AL MSA	83	839942
Buffalo-Niagara Falls, NY MSA	77	1189340
Canton-Massillon, OH MSA	76	394106
Chattanooga, TN-GA MSA	82	424347
Columbia, SC MSA	74	453932
Columbus, GA-AL MSA	75	260862
Columbus, OH MSA	78	1345450
Corpus Christi, TX MSA	81	349894
Davenport-Moline-Rock Island, IA-IL MSA	74	350855
Dayton-Springfield, OH MSA	79	951270
Detroit-Ann Arbor-Flint, MI CMSA	84	5187171
Dover, DE MSA	79	110993
Elkhart-Goshen, IN MSA	79	156198
Erie, PA MSA	75	275572
Evansville-Henderson, IN-KY MSA	80	278990
Fayetteville, NC MSA	79	274713
Fort Wayne, IN MSA	81	456281
Green Bay, WI MSA	75	194594
Greensboro--Winston-Salem--High Point, NC MSA	80	1050304
Greenville, NC MSA	77	108480
Greenville-Spartanburg-Anderson, SC MSA	79	830539
Harrisburg-Lebanon-Carlisle, PA MSA	75	587986
Houma, LA MSA	81	182842
Huntsville, AL MSA	73	293047
Indianapolis, IN MSA	84	1380491
Jacksonville, FL MSA	79	906727
Jamestown, NY MSA	74	141895
Janesville-Beloit, WI MSA	78	139510
Johnson City-Kingsport-Bristol, TN-VA MSA	77	436047
Johnstown, PA MSA	74	241280
Kalamazoo-Battle Creek, MI MSA	75	429453
Lafayette, LA MSA	79	345053
Lake Charles, LA MSA	77	168134

Table C-7. Metropolitan areas and rural counties with design values projected to be less than the 8-hour standard but within 15% or it in 2007 with ROTR controls but without Tier 2/Sulfur controls.

Name	Design Value (ppb)	Pop'n.
Lakeland-Winter Haven, FL MSA	72	405382
Lancaster, PA MSA	83	422822
Lansing-East Lansing, MI MSA	74	432684
Lexington, KY MSA	75	405936
Lima, OH MSA	75	154340
Little Rock-North Little Rock, AR MSA	79	513026
Longview-Marshall, TX MSA	84	193801
Louisville, KY-IN MSA	77	949012
Madison, WI MSA	74	367085
Minneapolis-St. Paul, MN-WI MSA	79	2538776
Mobile, AL MSA	75	476923
Monroe, LA MSA	73	142191
New Orleans, LA MSA	80	1285262
Norfolk-Virginia Beach-Newport News, VA-NC MSA	78	1444710
Oklahoma City, OK MSA	83	958839
Orlando, FL MSA	78	1224844
Owensboro, KY MSA	73	87189
Pensacola, FL MSA	82	344406
Portland, ME MSA	83	221095
Providence-Fall River-Warwick, RI-MA MSA	82	1134350
Raleigh-Durham-Chapel Hill, NC MSA	82	858485
Reading, PA MSA	78	336523
Richmond-Petersburg, VA MSA	77	865640
Rochester, NY MSA	75	1062470
Rocky Mount, NC MSA	76	133369
Sarasota-Bradenton, FL MSA	76	489483
Scranton--Wilkes-Barre--Hazleton, PA MSA	75	638524
Sharon, PA MSA	81	121003
Sheboygan, WI MSA	83	103877
Shreveport-Bossier City, LA MSA	77	376330
South Bend, IN MSA	80	247052
Steubenville-Weirton, OH-WV MSA	73	142523
Tampa-St. Petersburg-Clearwater, FL MSA	83	2067959
Terre Haute, IN MSA	72	147585
Toledo, OH MSA	80	614128
Tyler, TX MSA	82	151309
Victoria, TX MSA	75	74361
Wichita, KS MSA	72	485270
Wilmington, NC MSA	72	171269

Table C-7. Metropolitan areas and rural counties with design values projected to be less than the 8-hour standard but within 15% or it in 2007 with ROTR controls but without Tier 2/Sulfur controls.

Name	Design Value (ppb)	Pop'n.
York, PA MSA	74	339574
Youngstown-Warren, OH MSA	81	600895
	sum	49,387,949
	MA count	80
	MA sum	47,630,414
	Cnty count	39
	Cnty sum	1,757,535

Table C-8. Metropolitan areas and rural counties with design values projected to exceed the 8-hour standard in 2007 with ROTR and Tier 2/Sulfur controls.

Name	Design Value (ppb)	Pop'n.
Mason MI	87	25,537
Iberville LA	90	31,049
La Porte IN	92	107,066
Atlanta, GA MSA	91	2,959,500
Barnstable-Yarmouth, MA MSA	87	134,954
Baton Rouge, LA MSA	86	528,261
Beaumont-Port Arthur, TX MSA	85	361,218
Benton Harbor, MI MSA	85	161,378
Biloxi-Gulfport-Pascagoula, MS MSA	87	312,368
Charlotte-Gastonia-Rock Hill, NC-SC MSA	90	1,162,140
Chicago-Gary-Kenosha, IL-IN-WI CMSA	90	8,239,820
Cincinnati-Hamilton, OH-KY-IN CMSA	88	1,817,569
Cleveland-Akron, OH CMSA	85	2,859,644
Dallas-Fort Worth, TX CMSA	92	4,037,282
Grand Rapids-Muskegon-Holland, MI MSA	87	937,891
Hartford, CT MSA	86	1,157,585
Houston-Galveston-Brazoria, TX CMSA	109	3,731,029
Kansas City, MO-KS MSA	88	1,582,874
Memphis, TN-AR-MS MSA	88	1,007,306
Milwaukee-Racine, WI CMSA	93	1,607,183
Nashville, TN MSA	86	985,026
New York-Northern New Jersey-Long Island, NY-NJ-CT-PA CMSA	97	19,549,649
Philadelphia-Wilmington-Atlantic City, PA-NJ-DE-MD CMSA	94	5,893,019
Pittsburgh, PA MSA	94	2,394,811
St. Louis, MO-IL MSA	87	2,492,348
Springfield, MA MSA	85	587,884
Tulsa, OK MSA	86	708,954
Washington-Baltimore, DC-MD-VA-WV CMSA	91	6,726,395
	sum	72,099,740
	MA count	25
	MA sum	71,936,088
	Cnty count	3
	Cnty sum	163,652

Table C-9. Metropolitan areas and rural counties with design values projected to exceed the 8-hour standard in 2010 with ROTR controls but without Tier 2/Sulfur controls.

Name	Design Value (ppb)	Pop'n.
Mason MI	87	25,537
Iberville LA	90	31,049
La Porte IN	92	107,066
Atlanta, GA MSA	94	2,959,500
Barnstable-Yarmouth, MA MSA	88	134,954
Baton Rouge, LA MSA	87	528,261
Beaumont-Port Arthur, TX MSA	85	361,218
Benton Harbor, MI MSA	85	161,378
Biloxi-Gulfport-Pascagoula, MS MSA	87	312,368
Boston-Worcester-Lawrence, MA-NH-ME-CT CMSA	85	5,455,403
Charlotte-Gastonia-Rock Hill, NC-SC MSA	93	1,162,140
Chicago-Gary-Kenosha, IL-IN-WI CMSA	90	8,239,820
Cincinnati-Hamilton, OH-KY-IN CMSA	87	1,817,569
Cleveland-Akron, OH CMSA	85	2,859,644
Dallas-Fort Worth, TX CMSA	93	4,037,282
Grand Rapids-Muskegon-Holland, MI MSA	88	937,891
Hartford, CT MSA	87	1,157,585
Houston-Galveston-Brazoria, TX CMSA	109	3,731,029
Kansas City, MO-KS MSA	89	1,582,874
Memphis, TN-AR-MS MSA	89	1,007,306
Milwaukee-Racine, WI CMSA	93	1,607,183
Nashville, TN MSA	87	985,026
New York-Northern New Jersey-Long Island, NY-NJ-CT-PA CMSA	97	19,549,649
Philadelphia-Wilmington-Atlantic City, PA-NJ-DE-MD CMSA	94	5,893,019
Pittsburgh, PA MSA	94	2,394,811
St. Louis, MO-IL MSA	89	2,492,348
Springfield, MA MSA	86	587,884
Tulsa, OK MSA	86	708,954
Washington-Baltimore, DC-MD-VA-WV CMSA	92	6,726,395
	sum	77,555,143
	MA count	26
	MA sum	77,391,491
	Cnty count	3
	Cnty sum	163,652

Table C-10. Metropolitan areas and rural counties with design values projected to exceed the 8-hour standard in 2010 with ROTR controls and Tier 2/Sulfur controls.

Name	Design Value (ppb)	Pop'n.
Mason MI	86	25,537
Iberville LA	89	31,049
La Porte IN	91	107,066
Atlanta, GA MSA	89	2,959,500
Barnstable-Yarmouth, MA MSA	85	134,954
Biloxi-Gulfport-Pascagoula, MS MSA	86	312,368
Charlotte-Gastonia-Rock Hill, NC-SC MSA	87	1,162,140
Chicago-Gary-Kenosha, IL-IN-WI CMSA	91	8,239,820
Cincinnati-Hamilton, OH-KY-IN CMSA	88	1,817,569
Dallas-Fort Worth, TX CMSA	90	4,037,282
Grand Rapids-Muskegon-Holland, MI MSA	86	937,891
Houston-Galveston-Brazoria, TX CMSA	110	3,731,029
Kansas City, MO-KS MSA	86	1,582,874
Memphis, TN-AR-MS MSA	86	1,007,306
Milwaukee-Racine, WI CMSA	92	1,607,183
New York-Northern New Jersey-Long Island, NY-NJ-CT-PA CMSA	98	19,549,649
Philadelphia-Wilmington-Atlantic City, PA-NJ-DE-MD CMSA	93	5,893,019
Pittsburgh, PA MSA	93	2,394,811
St. Louis, MO-IL MSA	85	2,492,348
Tulsa, OK MSA	85	708,954
Washington-Baltimore, DC-MD-VA-WV CMSA	90	6,726,395
	sum	65,458,744
	MA count	18
	MA sum	65,295,092
	Cnty count	3
	Cnty sum	163,652

Table C-11. One-hour county design values (ppb) and population

All 1-hour county design values are listed in this table. The design value headings in the table are defined as follows:

dv1—measured 1-hour design value 1995-1997.
bg1—projected design value in 2007 after ROTR.
nt110—interpolated design value in 2010 without Tier 2/Sulfur controls.
t107—projected design values in 2007 after ROTR and Tier 2/Sulfur (OMS4).
t110—interpolated design values in 2010 after ROTR and Tier 2/Sulfur.
t120—projected design values in 2020 after ROTR and Tier 2/Sulfur (OMS3).
u107—interpolated design values in 2007 after ROTR and Tier 2/Sulfur.

u110—interpolated design values in 2010 after ROTR and Tier 2/Sulfur.
u120—interpolated design values in 2020 after ROTR and Tier 2/Sulfur.

The "u" values correspond to today's proposal. The "t" values correspond to OMS3 and OMS4. For discussing the effects of today's proposal on design values, we projected design values using the rollback method for three modeling runs: 2007 post ROTR, OMS3, and OMS4. All other design values have been linearly interpolated based on NO_X. See the main text for further details.

Table C-11. One-hour county design values (ppb) and population

State	County	dv1	bg1	nt110	t107	t110	t120	u107	u110	u120	Pop'n.
AL	Clay	110	90	89	87	85	82	87	85	82	75,000
AL	Colbert	83	69	68	67	66	64	67	66	64	25,617
AL	Elmore	102	86	85	83	81	78	83	81	78	46,975
AL	Geneva	84	77	76	75	73	71	75	73	71	34,773
AL	Jefferson	132	117	116	114	112	108	114	112	108	31,679
AL	Lawrence	98	86	85	83	81	79	83	81	79	80,421
AL	Madison	102	87	86	84	82	79	84	82	79	18,878
AL	Mobile	111	105	104	103	101	98	103	101	98	67,783
AL	Montgomery	92	84	83	81	79	75	81	79	75	90,083
AL	Morgan	114	101	100	98	96	93	98	96	93	4,590
AL	Shelby	127	111	109	106	103	98	106	103	98	25,690
AL	Sumter	83	76	75	73	72	70	73	72	70	76,559
AR	Crittenden	122	111	110	108	106	103	108	106	103	45,088
AR	Montgomery	79	74	73	72	71	69	72	71	69	34,693
AR	Newton	83	78	77	76	74	72	76	74	72	25,466
AR	Pulaski	108	106	105	102	100	97	102	100	97	11,949
CT	Fairfield	138	124	123	123	122	121	123	122	121	56,942
CT	Hartford	138	122	121	121	119	117	121	119	117	45,723
CT	Litchfield	120	104	103	102	100	97	102	100	97	19,217
CT	Middlesex	135	116	115	113	111	109	113	111	109	35,845
CT	New Haven	157	136	135	133	131	129	133	131	129	51,373
CT	New London	144	125	124	122	120	117	122	120	117	35,303
CT	Tolland	127	111	110	108	106	104	108	106	104	33,016
DC	District of Columbia	125	107	106	106	106	106	106	106	106	15,795
DE	Kent	124	104	103	101	99	95	101	99	95	19,437
DE	New Castle	139	116	115	113	111	107	113	111	107	50,480
DE	Sussex	123	107	106	104	102	98	104	102	98	25,741
FL	Alachua	101	97	96	93	91	86	93	91	86	34,854

Table C-11. One-hour county design values (ppb) and population

State	County	dv1	bg1	nt110	t107	t110	t120	u107	u110	u120	Pop'n.
FL	Brevard	86	84	83	82	80	77	82	80	77	40,339
FL	Broward	103	103	103	103	103	103	103	103	103	73,712
FL	Duval	116	114	113	110	108	103	110	108	103	36,815
FL	Escambia	113	111	110	109	107	105	109	107	105	30,337
FL	Hillsborough	112	113	112	111	109	106	111	109	106	57,494
FL	Lee	88	87	86	85	84	82	85	84	82	61,851
FL	Leon	96	90	89	86	83	78	86	83	78	32,170
FL	Manatee	96	97	96	95	93	90	95	93	90	20,293
FL	Orange	106	107	106	103	100	94	103	100	94	23,862
FL	Osceola	96	95	94	92	90	86	92	90	86	96,246
FL	Palm Beach	89	83	82	80	78	75	80	78	75	121,082
FL	Pasco	92	89	88	86	84	81	86	84	81	36,490
FL	Pinellas	93	91	90	89	87	84	89	87	84	10,333
FL	Polk	99	96	95	93	91	88	93	91	88	31,969
FL	Sarasota	99	99	98	96	94	92	96	94	92	40,113
FL	Seminole	95	92	91	89	87	82	89	87	82	42,310
FL	St Johns	91	88	87	85	83	79	85	83	79	47,473
FL	St Lucie	82	80	79	78	76	73	78	76	73	35,415
FL	Volusia	89	87	86	83	81	77	83	81	77	15,419
GA	Bibb	122	107	105	102	99	92	102	99	92	11,268
GA	Chatham	85	78	77	76	74	72	76	74	72	86,064
GA	DeKalb	136	117	115	111	107	100	111	108	100	30,180
GA	Douglas	140	122	120	116	112	105	116	113	105	20,798
GA	Fannin	92	81	80	78	76	72	78	76	72	25,078
GA	Fulton	143	124	122	119	116	109	119	116	109	46,942
GA	Glynn	89	84	83	82	80	78	82	80	78	38,345
GA	Gwinnett	121	103	101	97	94	87	97	94	87	39,995
GA	Muscogee	108	98	96	93	90	84	93	90	84	20,693
GA	Paulding	112	97	95	92	89	83	92	89	83	5,904
GA	Richmond	118	105	104	101	98	93	101	98	93	165,304
GA	Rockdale	145	123	121	117	114	107	117	114	107	110,943
GA	Spalding	126	109	107	103	100	93	103	100	93	5,279
IA	Harrison	79	77	76	76	75	74	76	75	74	37,152
IA	Linn	75	71	70	70	69	68	70	69	68	38,592
IA	Palo Alto	70	68	67	67	66	65	67	66	65	74,929
IA	Polk	86	82	81	80	79	77	80	79	77	34,828

Table C-11. One-hour county design values (ppb) and population

State	County	dv1	bg1	nt110	t107	t110	t120	u107	u110	u120	Pop'n.
IA	Scott	95	90	89	88	87	86	88	87	86	70,121
IA	Story	87	83	82	81	80	78	81	80	78	35,410
IA	Van Buren	82	76	75	74	73	71	74	73	71	49,216
IA	Warren	74	70	69	69	68	66	69	68	66	16,037
IL	Adams	89	80	79	78	77	75	78	77	75	9,104
IL	Champaign	94	77	76	75	74	72	75	74	72	47,880
IL	Cook	127	124	124	125	125	127	124	125	126	7,066
IL	Du Page	103	95	94	94	93	92	94	93	92	65,581
IL	Effingham	97	79	78	77	76	74	77	76	74	75,555
IL	Hamilton	89	70	69	69	68	66	69	68	66	8,377
IL	Jersey	112	98	97	94	92	87	94	92	87	9,071
IL	Kane	116	102	101	101	99	97	101	99	97	35,356
IL	Lake	116	108	107	107	106	104	107	106	104	10,415
IL	Macon	100	83	82	80	78	76	80	78	76	19,776
IL	Macoupin	102	85	84	82	80	77	82	80	77	37,308
IL	Madison	128	108	107	105	103	98	105	103	98	25,537
IL	McHenry	108	97	96	96	94	92	96	94	92	34,951
IL	Peoria	95	82	81	80	79	77	80	79	77	49,477
IL	Randolph	94	82	81	80	79	77	80	79	77	12,200
IL	Rock Island	83	76	75	75	74	73	75	74	73	17,842
IL	Sangamon	98	83	82	80	78	76	80	78	76	35,308
IL	St Clair	108	97	96	95	93	90	95	93	90	49,767
IL	Will	108	92	91	90	89	87	90	89	87	33,535
IL	Winnebago	93	83	82	82	81	80	82	81	80	18,653
IN	Allen	106	95	94	93	92	90	93	92	90	52,602
IN	Clark	125	104	103	102	101	99	102	101	99	36,310
IN	De Kalb	82	73	72	71	70	69	71	70	69	115,904
IN	Elkhart	113	100	99	98	97	95	98	97	95	46,948
IN	Floyd	125	111	111	111	110	110	111	110	110	58,086
IN	Hamilton	116	102	101	100	99	98	100	99	98	22,540
IN	Hancock	120	105	104	104	103	102	104	103	102	31,049
IN	Johnson	102	84	83	83	82	80	83	82	80	17,526
IN	Kosciusko	100	87	86	85	84	82	85	84	82	30,083
IN	La Porte	146	131	130	129	127	125	129	127	125	10,361
IN	Lake	117	105	104	104	102	100	104	102	100	15,145
IN	Lawrence	100	75	74	73	72	71	73	72	71	49,489

Table C-11. One-hour county design values (ppb) and population

State	County	dv1	bg1	nt110	t107	t110	t120	u107	u110	u120	Pop'n.
IN	Madison	112	98	97	96	94	92	96	94	92	72,583
IN	Marion	115	99	98	98	97	95	98	97	95	30,283
IN	Morgan	103	83	82	82	81	79	82	81	79	9,628
IN	Porter	124	109	108	107	105	103	107	105	103	62,879
IN	Posey	99	83	82	81	80	79	81	80	79	9,062
IN	St Joseph	114	100	99	98	97	96	98	97	96	13,998
IN	Tippecanoe	104	85	84	84	83	81	84	83	81	89,240
IN	Vanderburgh	114	97	96	95	94	92	95	94	92	7,864
IN	Vigo	107	88	87	86	85	83	86	85	83	33,550
IN	Warrick	115	92	91	91	89	87	91	89	87	10,357
KS	Miami	114	112	111	110	109	107	110	109	107	31,506
KS	Pawnee	80	80	80	80	80	80	80	80	80	7,555
KS	Sedgwick	96	93	92	92	91	89	92	91	89	7,676
KS	Wyandotte	113	110	109	109	108	107	109	108	107	74,252
KY	Bell	92	74	73	72	70	68	72	70	68	10,669
KY	Boone	108	90	89	89	88	86	89	88	86	14,730
KY	Boyd	122	98	97	96	94	92	96	94	92	42,836
KY	Bullitt	116	94	93	92	90	88	92	90	88	107,066
KY	Campbell	115	99	98	97	95	93	97	95	93	65,294
KY	Christian	101	80	79	78	77	75	78	77	75	34,583
KY	Daviess	108	89	88	88	87	85	88	87	85	47,679
KY	Edmonson	118	96	95	94	92	90	94	92	90	8,499
KY	Fayette	101	90	89	89	88	87	89	88	87	31,704
KY	Graves	92	73	72	72	71	69	72	71	69	66,090
KY	Greenup	114	90	89	89	87	85	89	87	85	62,496
KY	Hancock	114	82	81	80	79	77	80	79	77	15,992
KY	Hardin	113	86	85	84	82	80	84	82	80	113,229
KY	Henderson	108	85	84	84	83	81	84	83	81	7,666
KY	Jefferson	120	100	100	100	99	99	100	99	99	7,841
KY	Jessamine	98	81	80	79	78	76	79	78	76	16,174
KY	Kenton	114	97	96	95	94	92	95	94	92	23,647
KY	Lawrence	95	72	71	70	69	67	70	69	67	13,252
KY	Livingston	108	91	90	89	88	86	89	88	86	292,594
KY	McCracken	100	81	80	79	78	76	79	78	76	181,276
KY	McLean	103	83	82	82	81	79	82	81	79	149,285
KY	Oldham	112	97	96	95	94	92	95	94	92	247,105

Table C-11. One-hour county design values (ppb) and population

State	County	dv1	bg1	nt110	t107	t110	t120	u107	u110	u120	Pop'n.
KY	Perry	90	77	76	74	73	71	74	73	71	291,130
KY	Pike	98	83	82	80	78	76	80	78	76	130,542
KY	Pulaski	94	76	75	74	73	71	74	73	71	140,510
KY	Scott	101	89	88	86	84	82	86	84	82	140,320
KY	Simpson	101	87	86	84	82	80	84	82	80	174,821
KY	Trigg	101	85	84	83	81	79	83	81	79	54,091
LA	Ascension	121	113	112	111	109	107	111	109	107	648,951
LA	Beauregard	117	106	105	105	104	103	105	104	103	71,120
LA	Bossier	98	92	91	90	89	87	90	89	87	545,837
LA	Caddo	101	95	94	93	91	89	93	91	89	54,457
LA	Calcasieu	116	104	103	103	102	100	103	102	100	352,910
LA	East Baton Rouge	131	122	121	118	116	112	118	116	112	41,611
LA	Grant	91	84	83	83	82	80	83	82	80	189,719
LA	Iberville	139	132	131	130	129	127	130	129	127	120,940
LA	Jefferson	107	103	102	102	101	100	102	101	100	18,375
LA	Lafayette	109	102	101	100	99	97	100	99	97	576,407
LA	Lafourche	127	122	121	120	119	118	120	119	118	146,601
LA	Livingston	127	118	117	115	113	110	115	113	110	186,605
LA	Orleans	96	89	88	88	87	85	88	87	85	380,105
LA	Ouachita	95	90	89	88	87	86	88	87	86	70,526
LA	Pointe Coupee	111	103	102	101	99	97	101	99	97	58,214
LA	St Bernard	98	91	90	90	89	88	90	89	88	19,419
LA	St Charles	115	110	109	108	107	107	108	107	107	239,397
LA	St James	119	112	111	110	109	107	110	109	107	80,509
LA	St John The Baptist	114	107	106	106	105	103	106	105	103	161,378
LA	St Mary	104	98	97	97	96	94	97	96	94	115,243
LA	West Baton Rouge	114	106	105	103	101	97	103	101	97	31,760
MA	Barnstable	131	118	117	115	113	110	115	113	110	651,525
MA	Berkshire	99	85	84	83	81	79	83	81	79	99,358
MA	Bristol	138	119	118	116	114	110	116	114	110	506,325
MA	Essex	113	100	99	98	96	93	98	96	93	245,845
MA	Hampden	126	115	114	114	112	110	114	112	110	164,587
MA	Hampshire	132	118	117	115	113	110	115	113	110	456,310
MA	Middlesex	109	95	94	93	91	89	93	91	89	670,080
MA	Plymouth	102	89	88	87	85	83	87	85	83	336,073
MA	Suffolk	95	86	86	86	85	84	86	85	84	1,398,468

Table C-11. One-hour county design values (ppb) and population

State	County	dv1	bg1	nt110	t107	t110	t120	u107	u110	u120	Pop'n.
MA	Worcester	108	93	92	90	88	85	90	88	85	709,705
MD	Anne Arundel	142	123	122	120	118	114	120	118	114	435,276
MD	Baltimore	130	112	111	109	107	103	109	107	103	104,233
MD	Baltimore City	137	122	121	120	118	116	120	118	116	120,005
MD	Calvert	105	85	84	82	80	78	82	80	78	663,906
MD	Carroll	115	94	93	91	89	87	91	89	87	260,120
MD	Cecil	152	126	125	123	121	116	123	121	116	220,756
MD	Charles	118	98	97	95	93	91	95	93	91	968,532
MD	Harford	145	126	125	122	120	116	122	120	116	131,761
MD	Kent	129	110	109	107	105	102	107	105	102	367,585
MD	Montgomery	118	98	97	96	94	91	96	94	91	168,767
MD	Prince George's	132	113	112	110	108	105	110	108	105	173,025
ME	Cumberland	121	107	106	105	103	100	105	103	100	295,039
ME	Hancock	115	100	99	97	95	91	97	95	91	128,776
ME	Kennebec	98	87	86	85	83	80	85	83	80	207,619
ME	Knox	119	104	103	101	99	96	101	99	96	511,433
ME	Oxford	79	71	70	69	67	64	69	67	64	110,605
ME	Penobscot	95	84	83	82	80	78	82	80	78	131,497
ME	Piscataquis	80	72	71	70	68	65	70	68	65	50,319
ME	Sagadahoc	125	109	108	107	105	101	107	105	101	285,536
ME	Somerset	92	83	82	80	78	75	80	78	75	128,181
ME	Washington	107	93	92	90	88	85	90	88	85	5,105,067
ME	York	126	113	112	110	108	106	110	108	106	128,932
MI	Allegan	137	120	119	118	117	115	118	117	115	475,594
MI	Benzie	108	97	96	95	93	91	95	93	91	317,471
MI	Berrien	119	103	102	101	100	98	101	100	98	516,418
MI	Cass	115	102	101	100	98	96	100	98	96	183,241
MI	Clinton	88	77	76	75	74	73	75	74	73	357,313
MI	Genesee	99	89	88	88	87	86	88	87	86	781,666
MI	Huron	110	98	97	96	95	93	96	95	93	291,479
MI	Ingham	97	87	86	85	84	83	85	84	83	113,909
MI	Kalamazoo	106	92	91	90	88	86	90	88	86	866,228
MI	Kent	124	111	110	109	107	105	109	107	105	150,187
MI	Lenawee	104	94	93	93	91	89	93	91	89	83,866
MI	Macomb	124	111	111	111	111	111	111	111	111	142,031
MI	Mason	125	113	112	112	110	108	112	110	108	57,589

Table C-11. One-hour county design values (ppb) and population

State	County	dv1	bg1	nt110	t107	t110	t120	u107	u110	u120	Pop'n.
MI	Mecosta	124	108	107	105	103	101	105	103	101	68,941
MI	Muskegon	136	121	120	120	118	116	120	118	116	215,499
MI	Oakland	117	105	104	104	103	103	104	103	103	142,585
MI	Ottawa	113	101	100	100	99	98	100	99	98	514,990
MI	Roscommon	99	87	86	86	85	83	86	85	83	81,129
MI	St Clair	119	108	107	106	104	102	106	104	102	122,354
MI	Washtenaw	104	94	93	92	90	88	92	90	88	1,412,140
MI	Wayne	114	104	103	103	102	101	103	102	101	99,821
MN	Anoka	106	103	103	103	102	101	103	102	101	271,126
MN	Dakota	91	88	88	88	87	87	88	87	87	285,720
MN	Lake	74	74	74	74	74	74	74	74	74	179,278
MN	St Louis	80	80	80	80	80	80	80	80	80	128,300
MN	Washington	103	100	99	99	98	96	99	98	96	37,068
MO	Clay	128	122	121	120	118	115	120	118	115	961,437
MO	Greene	101	90	89	87	85	81	87	85	81	66,929
MO	Jackson	88	85	84	83	82	80	83	82	80	291,145
MO	Jefferson	125	113	112	110	108	106	110	108	106	273,525
MO	Monroe	96	89	88	87	85	83	87	85	83	1,852,810
MO	Platte	116	112	111	110	109	107	110	109	107	1,170,103
MO	St Louis	119	106	105	103	100	95	103	100	95	264,036
MO	St Louis City	108	99	98	97	96	94	97	96	94	85,167
MO	St. Charles	131	117	116	113	111	107	113	111	107	150,979
MO	Ste Genevieve	108	96	95	94	92	90	94	92	90	148,723
MS	Adams	97	94	93	92	91	89	92	91	89	147,548
MS	Choctaw	81	73	72	71	70	68	71	70	68	573,809
MS	DeSoto	131	125	124	124	123	121	124	123	121	136,731
MS	Franklin	94	91	90	89	88	86	89	88	86	93,182
MS	Hancock	105	100	99	98	97	95	98	97	95	370,712
MS	Hinds	97	89	88	87	85	83	87	85	83	100,043
MS	Jackson	109	113	112	111	110	109	111	110	109	31,513
MS	Lauderdale	92	83	82	81	79	76	81	79	76	117,206
MS	Lee	96	88	87	85	83	81	85	83	81	327,140
MS	Madison	89	82	81	80	79	78	80	79	78	36,033
MS	Sharkey	95	89	88	88	87	85	88	87	85	717,400
MS	Warren	97	91	90	90	89	87	90	89	87	145,607
NC	Alexander	94	85	84	81	79	74	81	79	74	1,083,592

Table C-11. One-hour county design values (ppb) and population

State	County	dv1	bg1	nt110	t107	t110	t120	u107	u110	u120	Pop'n.
NC	Buncombe	86	78	77	75	73	69	75	73	69	2,111,687
NC	Caldwell	97	87	86	83	81	76	83	81	76	91,476
NC	Camden	93	82	81	80	78	75	80	78	75	282,937
NC	Caswell	111	93	92	90	88	83	90	88	83	430,459
NC	Chatham	103	84	83	80	78	74	80	78	74	110,993
NC	Cumberland	106	96	95	92	89	84	92	89	84	198,213
NC	Davie	105	92	91	88	86	81	88	86	81	156,198
NC	Duplin	89	80	79	77	75	72	77	75	72	95,195
NC	Durham	103	91	89	86	83	78	86	83	78	275,572
NC	Edgecombe	102	91	90	87	85	80	87	85	80	44,920
NC	Forsyth	115	105	104	101	98	93	101	98	93	165,058
NC	Franklin	110	93	91	88	85	80	88	85	80	43,044
NC	Granville	116	102	100	97	94	87	97	94	87	25,968
NC	Guilford	109	98	96	93	90	85	93	90	85	102,874
NC	Haywood	107	96	95	92	90	85	92	90	85	274,566
NC	Johnston	107	91	90	87	85	80	87	85	80	51,666
NC	Lincoln	105	93	92	89	87	82	89	87	82	335,113
NC	Martin	90	78	77	75	73	70	75	73	70	150,171
NC	Mecklenburg	123	121	119	116	113	106	116	113	106	300,836
NC	New Hanover	102	93	92	91	89	85	91	89	85	35,324
NC	Northampton	100	83	82	80	78	74	80	78	74	181,596
NC	Person	100	82	81	79	77	73	79	77	73	90,509
NC	Pitt	104	90	89	87	85	80	87	85	80	158,983
NC	Rockingham	113	100	99	96	93	88	96	93	88	500,631
NC	Rowan	122	107	106	103	100	94	103	100	94	187,768
NC	Swain	78	66	65	64	62	60	64	62	60	194,594
NC	Wake	118	110	108	105	101	94	105	102	94	265,878
NC	Yancey	108	92	91	89	87	84	89	87	84	347,420
ND	Cass	75	75	75	75	75	75	75	75	75	27,859
NE	Douglas	88	86	85	85	84	82	85	84	82	107,924
NE	Lancaster	69	67	66	66	65	65	66	65	65	226,800
NH	Belknap	89	80	79	79	77	75	79	77	75	145,196
NH	Carroll	88	79	78	76	75	73	76	75	73	93,894
NH	Cheshire	91	80	79	78	76	73	78	76	73	44,506
NH	Coos	101	91	90	88	86	83	88	86	83	237,813
NH	Grafton	77	69	68	67	66	64	67	66	64	41,172

Table C-11. One-hour county design values (ppb) and population

State	County	dv1	bg1	nt110	t107	t110	t120	u107	u110	u120	Pop'n.
NH	Hillsborough	111	98	97	95	93	91	95	93	91	254,957
NH	Merrimack	98	88	87	87	86	84	87	86	84	851,783
NH	Rockingham	130	117	116	114	112	110	114	112	110	143,196
NH	Strafford	101	91	90	89	87	85	89	87	85	128,699
NH	Sullivan	90	81	80	79	77	75	79	77	75	174,092
NJ	Atlantic	124	106	105	103	101	98	103	101	98	70,709
NJ	Bergen	122	108	107	106	105	103	106	105	103	27,544
NJ	Camden	137	119	118	116	114	111	116	114	111	85,860
NJ	Cumberland	115	96	95	93	91	87	93	91	87	2,818,199
NJ	Essex	114	98	97	97	96	94	97	96	94	217,399
NJ	Gloucester	128	112	111	109	107	104	109	107	104	191,707
NJ	Hudson	120	113	112	112	111	111	112	111	111	51,150
NJ	Hunterdon	119	102	101	100	98	95	100	98	95	96,827
NJ	Mercer	131	113	112	110	108	106	110	108	106	36,742
NJ	Middlesex	139	121	120	119	117	114	119	117	114	61,834
NJ	Monmouth	138	121	120	118	116	113	118	116	113	238,912
NJ	Morris	124	105	104	103	101	98	103	101	98	45,527
NJ	Ocean	149	125	124	122	120	115	122	120	115	108,936
NJ	Union	109	94	93	92	91	89	92	91	89	797,159
NY	Albany	105	94	93	91	89	87	91	89	87	130,669
NY	Bronx	123	121	121	121	121	121	121	121	121	55,920
NY	Chautauqua	104	90	89	88	86	84	88	86	84	88,109
NY	Chemung	88	78	77	76	75	73	76	75	73	254,441
NY	Dutchess	113	97	96	94	92	89	94	92	89	53,794
NY	Erie	91	79	78	78	77	75	78	77	75	77,982
NY	Essex	101	91	90	88	86	84	88	86	84	672,971
NY	Hamilton	97	86	85	84	82	79	84	82	79	83,829
NY	Herkimer	88	78	77	76	74	72	76	74	72	141,895
NY	Jefferson	110	99	98	97	95	92	97	95	92	139,510
NY	Kings	124	110	109	108	106	104	108	106	104	143,596
NY	Madison	89	79	78	77	75	73	77	75	73	163,029
NY	Monroe	102	93	92	91	90	88	91	90	88	223,411
NY	New York	121	114	113	113	112	112	113	112	112	153,411
NY	Niagara	102	93	92	92	91	90	92	91	90	57,867
NY	Oneida	95	85	84	83	81	79	83	81	79	23,466
NY	Onondaga	102	90	89	89	87	85	89	87	85	161,993

Table C-11. One-hour county design values (ppb) and population

State	County	dv1	bg1	nt110	t107	t110	t120	u107	u110	u120	Pop'n.
NY	Orange	115	99	98	97	95	93	97	95	93	633,232
NY	Putnam	122	105	104	102	100	97	102	100	97	85,969
NY	Queens	125	119	119	120	120	121	119	120	120	335,749
NY	Richmond	137	121	120	119	117	114	119	117	114	31,255
NY	Saratoga	101	91	90	88	87	85	88	87	85	51,043
NY	Schenectady	94	84	83	82	80	78	82	80	78	68,250
NY	Suffolk	138	120	119	118	116	112	118	116	112	164,762
NY	Ulster	97	84	83	81	79	77	81	79	77	130,598
NY	Wayne	102	91	90	89	88	86	89	88	86	168,134
NY	Westchester	121	104	103	102	100	98	102	100	98	405,382
OH	Allen	106	89	88	88	87	85	88	87	85	422,822
OH	Ashtabula	105	89	88	87	86	84	87	86	84	281,912
OH	Butler	125	104	103	102	100	98	102	100	98	57,883
OH	Clark	118	99	98	97	96	94	97	96	94	133,239
OH	Clermont	116	99	98	98	97	95	98	97	95	111,486
OH	Clinton	121	100	99	98	96	94	98	96	94	225,366
OH	Cuyahoga	108	94	93	92	90	88	92	90	88	23,867
OH	Delaware	99	85	84	84	83	81	84	83	81	30,508
OH	Franklin	107	88	87	86	85	83	86	85	83	109,755
OH	Geauga	112	100	99	99	97	95	99	97	95	213,641
OH	Greene	111	93	92	91	90	88	91	90	88	349,660
OH	Hamilton	119	112	112	112	112	113	111	112	112	104,948
OH	Jefferson	111	93	92	91	89	87	91	89	87	87,777
OH	Knox	113	96	95	94	93	91	94	93	91	64,404
OH	Lake	119	103	102	101	99	97	101	99	97	664,937
OH	Lawrence	113	87	86	86	84	82	86	84	82	47,567
OH	Licking	115	97	96	95	93	91	95	93	91	33,263
OH	Logan	100	84	83	82	80	78	82	80	78	149,967
OH	Lorain	101	91	90	89	88	86	89	88	86	367,085
OH	Lucas	111	100	99	98	97	95	98	97	95	383,545
OH	Madison	112	93	92	91	89	87	91	89	87	398,978
OH	Mahoning	109	95	94	93	91	88	93	91	88	67,910
OH	Medina	110	97	96	95	93	91	95	93	91	826,330
OH	Miami	110	93	92	91	90	88	91	90	88	49,939
OH	Montgomery	112	94	93	93	92	90	93	92	90	1,255,488
OH	Portage	114	101	100	98	96	94	98	96	94	72,831

Table C-11. One-hour county design values (ppb) and population

State	County	dv1	bg1	nt110	t107	t110	t120	u107	u110	u120	Pop'n.
OH	Preble	110	88	87	86	85	83	86	85	83	959,275
OH	Stark	107	93	92	91	90	88	91	90	88	175,034
OH	Summit	113	99	98	97	95	93	97	95	93	304,715
OH	Trumbull	109	95	94	92	90	87	92	90	87	95,328
OH	Union	75	63	62	62	61	59	62	61	59	243,641
OH	Warren	124	104	103	102	100	97	102	100	97	145,896
OH	Washington	110	84	83	82	80	78	82	80	78	275,227
OH	Wood	94	82	81	80	79	78	80	79	78	50,251
OK	Cleveland	102	101	100	98	96	94	98	96	94	378,643
OK	Comanche	92	86	85	84	83	81	84	83	81	142,191
OK	Latimer	100	95	94	93	92	90	93	92	90	49,210
OK	Mc Clain	95	91	90	89	87	85	89	87	85	209,085
OK	Oklahoma	110	110	109	108	106	104	108	106	104	103,281
OK	Okmulgee	94	92	91	90	89	87	90	89	87	35,061
OK	Tulsa	121	121	120	120	119	117	120	119	117	510,784
PA	Allegheny	133	121	120	120	118	116	120	118	116	81,021
PA	Beaver	105	93	92	91	90	89	91	90	89	67,675
PA	Berks	118	101	100	98	96	93	98	96	93	118,570
PA	Blair	114	95	94	92	90	88	92	90	88	20,879
PA	Bucks	137	115	114	112	110	106	112	110	106	42,437
PA	Cambria	102	86	85	84	82	80	84	82	80	39,996
PA	Dauphin	113	97	96	93	91	86	93	91	86	448,306
PA	Delaware	126	110	109	107	105	101	107	105	101	66,631
PA	Erie	105	89	88	87	85	83	87	85	83	496,938
PA	Franklin	114	92	91	90	89	87	90	89	87	804,219
PA	Lackawanna	110	96	95	94	92	89	94	92	89	433,203
PA	Lancaster	125	109	108	106	104	100	106	104	100	671,780
PA	Lawrence	101	90	89	87	85	82	87	85	82	827,645
PA	Lehigh	114	96	95	93	91	88	93	91	88	553,124
PA	Luzerne	110	90	89	88	86	84	88	86	84	1,321,864
PA	Lycoming	91	75	74	74	73	71	74	73	71	378,977
PA	Mercer	111	98	97	95	93	90	95	93	90	325,824
PA	Montgomery	122	104	103	101	99	96	101	99	96	1,951,598
PA	Northampton	116	98	97	96	94	91	96	94	91	421,353
PA	Perry	103	86	85	84	82	79	84	82	79	2,300,664
PA	Philadelphia	130	120	119	119	118	117	119	118	117	1,203,789

Table C-11. One-hour county design values (ppb) and population

State	County	dv1	bg1	nt110	t107	t110	t120	u107	u110	u120	Pop'n.
PA	Washington	117	90	89	88	86	84	88	86	84	825,380
PA	Westmoreland	125	107	106	104	102	99	104	102	99	83,941
PA	York	109	93	92	91	89	86	91	89	86	1,487,536
RI	Kent	133	114	113	110	108	105	110	108	105	874,866
RI	Providence	117	100	99	97	95	92	97	95	92	553,099
SC	Abbeville	93	82	81	79	77	73	79	77	73	107,776
SC	Aiken	104	92	91	89	87	82	89	87	82	307,647
SC	Anderson	114	103	101	98	95	90	98	95	90	778,206
SC	Barnwell	99	85	84	83	81	77	83	81	77	259,462
SC	Berkeley	94	84	83	82	80	77	82	80	77	493,819
SC	Charleston	102	94	93	91	89	87	91	89	87	133,793
SC	Cherokee	106	93	92	89	86	81	89	86	81	52,141
SC	Chester	107	97	96	93	91	86	93	91	86	599,611
SC	Darlington	94	82	81	79	77	73	79	77	73	174,253
SC	Edgefield	93	81	80	78	76	71	78	76	71	22,795
SC	Oconee	92	83	82	79	76	71	79	76	71	416,444
SC	Pickens	107	98	96	93	90	85	93	90	85	677,491
SC	Richland	107	96	95	92	89	83	92	89	83	107,728
SC	Spartanburg	117	106	105	102	99	92	102	99	92	287,529
SC	Union	98	89	88	85	83	79	85	83	79	87,189
SC	Williamsburg	85	74	73	72	70	68	72	70	68	86,915
SC	York	114	103	102	99	96	91	99	96	91	62,254
TN	Anderson	110	93	92	90	88	85	90	88	85	262,798
TN	Blount	124	110	109	106	104	100	106	104	100	182,827
TN	Bradley	106	92	91	88	86	81	88	86	81	71,347
TN	Coffee	105	87	86	85	83	80	85	83	80	441,946
TN	Davidson	110	102	101	101	100	99	101	100	99	502,824
TN	Dickson	120	101	100	99	97	94	99	97	94	541,174
TN	Dyer	112	100	99	97	95	92	97	95	92	1,585,577
TN	Giles	104	93	92	91	89	85	91	89	85	230,082
TN	Hamblen	96	80	79	77	75	73	77	75	73	547,651
TN	Hamilton	113	104	103	101	98	93	101	98	93	224,327
TN	Haywood	97	84	83	82	80	78	82	80	78	678,111
TN	Humphreys	102	86	85	84	82	80	84	82	80	138,053
TN	Jefferson	125	105	104	101	99	95	101	99	95	1,336,449
TN	Knox	120	110	109	107	105	102	107	105	102	370,321

Table C-11. One-hour county design values (ppb) and population

State	County	dv1	bg1	nt110	t107	t110	t120	u107	u110	u120	Pop'n.
TN	Lawrence	93	81	80	78	76	74	78	76	74	204,584
TN	Loudon	112	94	93	91	89	85	91	89	85	186,093
TN	Madison	64	55	54	53	52	50	53	52	50	139,352
TN	Putnam	99	83	82	80	78	76	80	78	76	243,135
TN	Rutherford	95	81	80	78	76	74	78	76	74	161,135
TN	Sevier	111	96	95	93	91	87	93	91	87	596,270
TN	Shelby	128	121	120	118	116	112	118	116	112	423,380
TN	Sullivan	111	99	98	97	95	93	97	95	93	36,414
TN	Sumner	124	108	107	105	103	100	105	103	100	81,306
TN	Williamson	110	99	98	96	94	91	96	94	91	38,759
TN	Wilson	108	97	96	94	92	88	94	92	88	181,835
TX	Bexar	121	118	117	116	114	111	116	114	111	336,523
TX	Brazoria	148	139	138	137	136	134	137	136	134	63,306
TX	Cameron	81	81	81	81	81	81	81	81	81	6,282
TX	Collin	132	120	119	118	116	112	118	116	112	217,881
TX	Dallas	134	123	122	121	119	116	121	119	116	209,274
TX	Denton	139	124	123	121	119	114	121	119	114	79,332
TX	Ellis	118	112	111	110	108	106	110	108	106	713,968
TX	Galveston	182	171	170	169	168	166	169	168	166	89,123
TX	Gregg	139	129	128	127	125	122	127	125	122	252,913
TX	Harris	189	175	175	176	176	177	175	176	176	56,558
TX	Hidalgo	78	77	77	77	77	77	77	77	77	212,907
TX	Jefferson	139	129	128	127	126	124	127	126	124	249,238
TX	Nueces	115	112	111	111	111	111	111	111	111	171,380
TX	Orange	121	112	111	111	110	108	111	110	108	993,529
TX	Smith	109	101	100	98	96	94	98	96	94	20,539
TX	Tarrant	133	120	119	117	115	112	117	115	112	262,852
TX	Travis	112	106	105	102	100	97	102	100	97	396,685
TX	Victoria	95	91	90	90	89	89	90	89	89	1,185,394
TX	Webb	90	90	90	90	90	90	90	90	90	277,776
VA	Alexandria City	124	108	108	108	107	106	108	107	106	211,707
VA	Arlington	123	107	107	107	106	105	107	106	105	216,935
VA	Caroline	109	92	91	88	86	81	88	86	81	219,039
VA	Charles City	119	102	101	99	97	94	99	97	94	328,149
VA	Chesterfield	114	97	96	94	92	88	94	92	88	121,003
VA	Fairfax	124	107	106	104	102	100	104	102	100	103,877

Table C-11. One-hour county design values (ppb) and population

State	County	dv1	bg1	nt110	t107	t110	t120	u107	u110	u120	Pop'n.
VA	Fauquier	97	75	74	73	71	69	73	71	69	248,253
VA	Frederick	102	80	79	78	76	74	78	76	74	86,088
VA	Hampton City	109	98	97	96	94	90	96	94	90	247,052
VA	Hanover	124	107	105	102	99	93	102	99	93	178,386
VA	Henrico	115	101	99	96	94	89	96	94	89	207,949
VA	Henry	101	82	81	79	77	74	79	77	74	146,568
VA	Madison	99	81	80	79	77	75	79	77	75	80,298
VA	Prince William	110	91	90	88	86	83	88	86	83	35,233
VA	Roanoke	94	81	80	78	76	72	78	76	72	468,973
VA	Stafford	110	91	90	88	86	82	88	86	82	69,120
VA	Suffolk City	108	91	90	88	86	83	88	86	83	192,493
VA	Wythe	94	72	71	70	68	66	70	68	66	834,054
VT	Bennington	99	89	88	87	85	81	87	85	81	851,659
VT	Chittenden	85	77	76	75	74	72	75	74	72	281,131
WI	Brown	108	99	98	97	95	93	97	95	93	106,107
WI	Columbia	104	97	96	95	93	91	95	93	91	462,361
WI	Dane	97	90	89	89	88	86	89	88	86	113,269
WI	Dodge	93	85	84	83	82	80	83	82	80	503,341
WI	Door	127	113	112	111	109	106	111	109	106	151,309
WI	Florence	80	74	73	73	72	70	73	72	70	250,836
WI	Fond Du Lac	96	88	87	87	86	84	87	86	84	65,797
WI	Jefferson	94	86	85	84	83	81	84	83	81	74,361
WI	Kenosha	129	117	116	114	112	110	114	112	110	182,132
WI	Kewaunee	121	109	108	106	104	102	106	104	102	427,239
WI	Manitowoc	126	113	112	110	108	106	110	108	106	736,014
WI	Marathon	84	79	78	77	76	75	77	76	75	729,268
WI	Milwaukee	126	118	117	116	114	112	116	114	112	692,134
WI	Oneida	78	74	73	72	71	70	72	71	70	606,900
WI	Outagamie	98	92	91	90	89	87	90	89	87	818,584
WI	Ozaukee	127	118	117	117	116	114	117	116	114	111,183
WI	Polk	85	82	81	80	79	78	80	79	78	170,936
WI	Racine	119	108	107	106	104	102	106	104	102	101,154
WI	Rock	103	95	94	93	92	90	93	92	90	757,027
WI	Sauk	90	85	84	83	82	80	83	82	80	123,372
WI	Sheboygan	123	109	108	107	105	103	107	105	103	215,686
WI	St Croix	88	85	84	84	83	81	84	83	81	61,236

Table C-11. One-hour county design values (ppb) and population

State	County	dv1	bg1	nt110	t107	t110	t120	u107	u110	u120	Pop'n.
WI	Vernon	85	81	80	80	79	78	80	79	78	51,372
WI	Walworth	100	92	91	90	89	87	90	89	87	48,741
WI	Washington	106	95	94	93	91	89	93	91	89	115,400
WI	Waukesha	109	99	98	97	95	93	97	95	93	863,518
WI	Winnebago	98	91	90	89	88	86	89	88	86	50,871
WV	Cabell	122	98	97	95	93	91	95	93	91	403,662
WV	Greenbrier	99	73	72	71	70	68	71	70	68	118,710
WV	Hancock	106	92	91	90	89	87	90	89	87	120,284
WV	Kanawha	110	91	90	88	86	82	88	86	82	339,574
WV	Ohio	107	85	84	83	81	79	83	81	79	264,806
WV	Wood	116	89	88	87	85	83	87	85	83	227,813

Table C-12. Eight-hour county design values (ppb) and population

All 8-hour county design values are listed in this table. The design value headings in the this table are defined as follows:

dv8—measured 8-hour design value 1995-1997.
bg8—projected design value in 2007 after ROTR.
nt810—interpolated design value in 2010 without Tier 2/Sulfur controls.
t807—projected design values in 2007 after ROTR and Tier 2/Sulfur (OMS4).
t810—interpolated design values in 2010 after ROTR and Tier 2/Sulfur.
t820—projected design values in 2020 after ROTR and Tier 2/Sulfur (OMS3).
u807—interpolated design values in 2007 after ROTR and Tier 2/Sulfur.
u810—interpolated design values in 2010 after ROTR and Tier 2/Sulfur.
u820—interpolated design values in 2020 after ROTR and Tier 2/Sulfur.

The "u" values correspond to today's proposal. The "t" values correspond to OMS3 and OMS4. For discussing the effects of today's proposal on design values, we projected county design values using the rollback method for three modeling runs: 2007 post ROTR, OMS3, and OMS4. All other design values have been linearly interpolated based on NO_X. See the main text for further details.

Table C-12. Eight-hour county design values (ppb) and population

State	County	dv8	bg8	nt810	t807	t810	t820	u807	u810	u820	cntypop
AL	Clay	86	72	71	70	68	66	70	68	66	13,252
AL	Elmore	77	65	64	63	61	59	63	61	59	49,210
AL	Geneva	69	63	62	61	60	58	61	60	58	23,647
AL	Jefferson	92	82	81	80	78	74	80	78	74	651,525

Table C-12. Eight-hour county design values (ppb) and population

State	County	dv8	bg8	nt810	t807	t810	t820	u807	u810	u820	cntypop
AL	Lawrence	81	70	69	68	67	65	68	67	65	31,513
AL	Madison	84	73	72	71	69	66	71	69	66	238,912
AL	Mobile	79	75	74	73	72	70	73	72	70	378,643
AL	Montgomery	70	63	62	61	59	57	61	59	57	209,085
AL	Shelby	95	83	82	80	78	74	80	78	74	99,358
AL	Sumter	66	60	59	58	57	55	58	57	55	16,174
AR	Crittenden	95	87	86	85	83	81	85	83	81	49,939
AR	Montgomery	67	63	62	61	60	58	61	60	58	7,841
AR	Newton	71	66	65	64	63	61	64	63	61	7,666
AR	Pulaski	81	79	78	77	75	72	77	75	72	349,660
CT	Fairfield	104	94	93	93	92	91	93	92	91	827,645
CT	Hartford	89	78	77	76	75	73	76	75	73	851,783
CT	Litchfield	94	81	80	79	77	75	79	77	75	174,092
CT	Middlesex	98	84	83	82	80	78	82	80	78	143,196
CT	New Haven	107	93	92	91	89	87	91	89	87	804,219
CT	New London	101	88	87	86	84	82	86	84	82	254,957
CT	Tolland	91	79	78	77	76	74	77	76	74	128,699
DC	District of Columbia	94	80	79	79	79	79	79	79	79	606,900
DE	Kent	94	79	78	77	75	72	77	75	72	110,993
DE	New Castle	99	83	82	81	79	76	81	79	76	441,946
DE	Sussex	93	81	80	79	77	74	79	77	74	113,229
FL	Brevard	71	69	68	68	66	64	68	66	64	398,978
FL	Broward	69	69	69	69	69	69	69	69	69	1,255,488
FL	Duval	81	79	78	77	75	72	77	75	72	672,971
FL	Escambia	84	82	81	81	79	77	81	79	77	262,798
FL	Hillsborough	82	83	82	81	80	78	81	80	78	834,054
FL	Lee	71	70	69	69	68	66	69	68	66	335,113
FL	Leon	66	61	60	59	57	53	59	57	53	192,493
FL	Manatee	75	76	75	74	72	70	74	72	70	211,707
FL	Orange	78	78	77	76	74	70	76	74	70	677,491
FL	Osceola	72	71	70	69	67	64	69	67	64	107,728
FL	Palm Beach	67	63	62	61	59	57	61	59	57	863,518
FL	Pasco	75	73	72	71	69	66	71	69	66	281,131
FL	Pinellas	73	72	71	70	69	67	70	69	67	851,659
FL	Polk	74	72	71	70	68	66	70	68	66	405,382
FL	Sarasota	76	76	75	74	72	70	74	72	70	277,776
FL	Seminole	72	70	69	67	65	62	67	65	62	287,529
FL	St Johns	72	69	68	67	65	62	67	65	62	83,829
FL	St Lucie	64	62	61	61	59	57	61	59	57	150,171
FL	Volusia	69	67	66	64	62	59	64	62	59	370,712
GA	Chatham	72	66	65	64	63	61	64	63	61	216,935
GA	DeKalb	100	86	85	82	79	74	82	79	74	545,837

Table C-12. Eight-hour county design values (ppb) and population

State	County	dv8	bg8	nt810	t807	t810	t820	u807	u810	u820	cntypop
GA	Fannin	76	66	65	63	61	58	63	61	58	15,992
GA	Fulton	110	95	94	91	89	84	91	89	84	648,951
GA	Glynn	75	70	69	68	67	65	68	67	65	62,496
GA	Gwinnett	91	78	77	74	71	66	74	71	66	352,910
GA	Muscogee	83	75	74	71	69	64	71	69	64	179,278
GA	Paulding	89	77	76	73	71	67	73	71	67	41,611
GA	Richmond	87	77	76	74	72	68	74	72	68	189,719
GA	Rockdale	106	90	89	86	83	78	86	83	78	54,091
IA	Linn	62	59	58	58	57	56	58	57	56	168,767
IA	Polk	66	62	61	61	60	59	61	60	59	327,140
IA	Scott	78	74	73	73	72	71	73	72	71	150,979
IA	Van Buren	68	63	62	61	60	59	61	60	59	7,676
IL	Adams	74	67	66	65	64	62	65	64	62	66,090
IL	Champaign	81	68	67	67	66	64	67	66	64	173,025
IL	Cook	91	90	90	91	91	93	90	91	92	5,105,067
IL	Du Page	75	70	70	70	69	69	70	69	69	781,666
IL	Effingham	81	67	66	66	65	63	66	65	63	31,704
IL	Jersey	84	72	71	70	68	64	70	68	64	20,539
IL	Kane	85	75	74	74	73	72	74	73	72	317,471
IL	Lake	86	81	81	81	80	79	81	80	79	516,418
IL	Macon	83	69	68	67	66	64	67	66	64	117,206
IL	Macoupin	83	69	68	67	65	63	67	65	63	47,679
IL	Madison	93	79	78	76	74	71	76	74	71	249,238
IL	McHenry	85	77	76	76	75	73	76	75	73	183,241
IL	Peoria	80	71	70	69	68	66	69	68	66	182,827
IL	Randolph	78	69	68	67	66	64	67	66	64	34,583
IL	Rock Island	70	65	64	64	63	62	64	63	62	148,723
IL	Sangamon	76	65	64	63	61	59	63	61	59	178,386
IL	St Clair	78	70	69	69	68	66	69	68	66	262,852
IL	Will	79	68	67	67	66	65	67	66	65	357,313
IL	Winnebago	79	71	70	70	69	68	70	69	68	252,913
IN	Allen	90	81	80	79	78	76	79	78	76	300,836
IN	Clark	92	76	75	74	73	72	74	73	72	87,777
IN	Elkhart	90	79	78	78	77	76	78	77	76	156,198
IN	Floyd	90	77	77	77	76	76	77	76	76	64,404
IN	Hamilton	97	84	83	83	82	82	83	82	82	108,936
IN	Hancock	95	83	82	82	81	80	82	81	80	45,527
IN	La Porte	104	93	92	92	91	89	92	91	89	107,066
IN	Lake	95	86	85	85	84	83	85	84	83	475,594
IN	Madison	91	79	78	78	76	74	78	76	74	130,669
IN	Marion	95	82	81	80	79	78	80	79	78	797,159
IN	Porter	96	85	84	84	83	81	84	83	81	128,932

Table C-12. Eight-hour county design values (ppb) and population

State	County	dv8	bg8	nt810	t807	t810	t820	u807	u810	u820	cntypop
IN	St. Joseph	91	80	79	79	78	77	79	78	77	247,052
IN	Vanderburgh	93	80	79	78	77	76	78	77	76	165,058
IN	Vigo	88	72	71	70	69	68	70	69	68	106,107
IN	Warrick	93	77	76	75	74	72	75	74	72	44,920
KS	Miami	74	72	71	71	70	69	71	70	69	23,466
KS	Pawnee	71	71	71	71	71	71	71	71	71	7,555
KS	Sedgwick	74	72	71	71	70	69	71	70	69	403,662
KS	Wyandotte	85	83	82	82	81	81	82	81	81	161,993
KY	Bell	76	62	61	60	59	57	60	59	57	31,506
KY	Boone	82	68	67	67	66	65	67	66	65	57,589
KY	Boyd	85	69	68	67	66	65	67	66	65	51,150
KY	Bullitt	85	70	69	68	67	66	68	67	66	47,567
KY	Campbell	90	79	78	77	76	74	77	76	74	83,866
KY	Christian	80	66	65	65	64	62	65	64	62	68,941
KY	Daviess	87	73	72	72	71	70	72	71	70	87,189
KY	Edmonson	82	68	67	67	66	64	67	66	64	10,357
KY	Fayette	85	75	74	74	73	73	74	73	73	225,366
KY	Graves	74	60	59	59	58	56	59	58	56	33,550
KY	Greenup	80	64	63	63	62	60	63	62	60	36,742
KY	Hancock	89	67	66	66	65	63	66	65	63	7,864
KY	Hardin	81	62	61	61	60	58	61	60	58	89,240
KY	Henderson	86	69	68	68	67	65	68	67	65	43,044
KY	Jefferson	91	75	75	75	74	74	75	74	74	664,937
KY	Jessamine	80	66	65	64	63	61	64	63	61	30,508
KY	Kenton	90	78	77	77	76	74	77	76	74	142,031
KY	Lawrence	70	53	52	52	51	50	52	51	50	13,998
KY	Livingston	86	72	71	71	70	69	71	70	69	9,062
KY	McCracken	80	65	64	64	63	61	64	63	61	62,879
KY	McLean	83	69	68	67	66	65	67	66	65	9,628
KY	Oldham	87	74	73	73	72	70	73	72	70	33,263
KY	Perry	69	58	57	57	56	54	57	56	54	30,283
KY	Pike	74	62	61	60	58	56	60	58	56	72,583
KY	Pulaski	76	61	60	60	59	58	60	59	58	49,489
KY	Scott	78	68	67	66	65	63	66	65	63	23,867
KY	Simpson	83	72	71	70	69	67	70	69	67	15,145
LA	Ascension	87	81	80	80	79	77	80	79	77	58,214
LA	Beauregard	75	69	68	68	67	66	68	67	66	30,083
LA	Bossier	79	74	73	73	72	70	73	72	70	86,088
LA	Caddo	82	77	76	75	74	72	75	74	72	248,253
LA	Calcasieu	85	77	76	76	75	75	76	75	75	168,134
LA	East Baton Rouge	95	88	87	86	84	81	86	84	81	380,105
LA	Grant	75	69	68	68	67	66	68	67	66	17,526

Table C-12. Eight-hour county design values (ppb) and population

State	County	dv8	bg8	nt810	t807	t810	t820	u807	u810	u820	cntypop
LA	Iberville	96	91	90	90	89	88	90	89	88	31,049
LA	Jefferson	83	80	79	79	78	78	79	78	78	448,306
LA	Lafayette	84	79	78	77	76	74	77	76	74	164,762
LA	Lafourche	85	81	81	81	80	79	81	80	79	85,860
LA	Livingston	88	82	81	80	78	76	80	78	76	70,526
LA	Orleans	71	66	65	65	64	63	65	64	63	496,938
LA	Ouachita	77	73	72	72	71	70	72	71	70	142,191
LA	Pointe Coupee	83	77	76	76	74	72	76	74	72	22,540
LA	St Bernard	80	75	74	74	73	72	74	73	72	66,631
LA	St Charles	81	77	76	76	75	75	76	75	75	42,437
LA	St James	84	79	78	77	76	75	77	76	75	20,879
LA	St John The Baptist	82	77	76	76	75	74	76	75	74	39,996
LA	St Mary	81	76	75	75	74	73	75	74	73	58,086
LA	West Baton Rouge	86	80	79	78	76	73	78	76	73	19,419
MA	Barnstable	100	89	88	87	85	83	87	85	83	186,605
MA	Berkshire	77	67	66	65	64	62	65	64	62	139,352
MA	Bristol	97	84	83	82	80	78	82	80	78	506,325
MA	Essex	89	79	78	77	75	73	77	75	73	670,080
MA	Hampden	89	81	80	80	79	78	80	79	78	456,310
MA	Hampshire	97	87	86	85	84	82	85	84	82	146,568
MA	Middlesex	87	76	75	75	73	71	75	73	71	1,398,468
MA	Plymouth	71	62	61	61	60	58	61	60	58	435,276
MA	Suffolk	76	70	70	70	70	70	70	70	70	663,906
MA	Worcester	87	75	74	73	71	69	73	71	69	709,705
MD	Anne Arundel	107	93	92	90	88	86	90	88	86	427,239
MD	Baltimore	96	82	81	79	77	75	79	77	75	692,134
MD	Baltimore City	103	93	92	91	90	89	91	90	89	736,014
MD	Calvert	85	69	68	67	65	63	67	65	63	51,372
MD	Carroll	93	76	75	74	73	71	74	73	71	123,372
MD	Cecil	110	92	91	90	88	85	90	88	85	71,347
MD	Charles	93	77	76	75	73	71	75	73	71	101,154
MD	Harford	107	93	92	91	89	86	91	89	86	182,132
MD	Kent	96	82	81	80	78	76	80	78	76	17,842
MD	Montgomery	93	78	77	76	74	72	76	74	72	757,027
MD	Prince George's	100	86	85	84	82	80	84	82	80	729,268
ME	Cumberland	94	83	82	80	78	76	80	78	76	243,135
ME	Hancock	83	72	71	70	69	67	70	69	67	46,948
ME	Kennebec	75	67	66	66	64	62	66	64	62	115,904
ME	Knox	87	76	75	74	72	70	74	72	70	36,310
ME	Oxford	59	53	52	52	50	48	52	50	48	52,602
ME	Penobscot	73	65	64	64	62	60	64	62	60	146,601
ME	Piscataquis	64	58	57	56	55	53	56	55	53	18,653

Table C-12. Eight-hour county design values (ppb) and population

State	County	dv8	bg8	nt810	t807	t810	t820	u807	u810	u820	cntypop
ME	Sagadahoc	95	82	81	80	78	76	80	78	76	33,535
ME	Somerset	69	62	61	61	59	57	61	59	57	49,767
ME	York	96	85	84	83	81	79	83	81	79	164,587
MI	Allegan	98	86	85	85	84	83	85	84	83	90,509
MI	Benzie	88	79	78	78	77	75	78	77	75	12,200
MI	Berrien	98	86	85	85	84	82	85	84	82	161,378
MI	Cass	94	83	82	81	80	78	81	80	78	49,477
MI	Clinton	74	64	63	63	62	61	63	62	61	57,883
MI	Genesee	84	75	75	75	74	73	75	74	73	430,459
MI	Huron	82	73	72	72	71	69	72	71	69	34,951
MI	Ingham	83	74	73	73	72	71	73	72	71	281,912
MI	Kalamazoo	87	75	74	74	73	71	74	73	71	223,411
MI	Kent	88	79	78	77	76	75	77	76	75	500,631
MI	Lenawee	83	75	74	74	73	71	74	73	71	91,476
MI	Macomb	91	82	82	82	81	81	82	81	81	717,400
MI	Mason	98	88	87	87	86	84	87	86	84	25,537
MI	Muskegon	99	89	88	87	86	84	87	86	84	158,983
MI	Oakland	78	71	70	70	69	68	70	69	68	1,083,592
MI	Ottawa	84	75	74	73	72	71	73	72	71	187,768
MI	St. Clair	92	84	83	82	81	80	82	81	80	145,607
MI	Washtenaw	83	74	73	72	71	70	72	71	70	282,937
MI	Wayne	88	80	79	79	79	79	79	79	79	2,111,687
MN	Anoka	81	79	79	79	78	78	79	78	78	243,641
MN	Dakota	68	66	66	66	65	65	66	65	65	275,227
MN	Lake	63	63	63	63	63	63	63	63	63	10,415
MN	St Louis	66	66	66	66	66	66	66	66	66	198,213
MN	Washington	74	72	71	71	70	69	71	70	69	145,896
MO	Clay	94	90	89	88	86	84	88	86	84	153,411
MO	Greene	78	70	69	68	66	63	68	66	63	207,949
MO	Jackson	73	70	69	69	68	66	69	68	66	633,232
MO	Jefferson	90	83	82	79	78	76	79	78	76	171,380
MO	Monroe	84	78	77	76	74	72	76	74	72	9,104
MO	Platte	86	81	81	82	81	79	82	81	79	57,867
MO	St Louis City	83	76	75	75	74	73	75	74	73	396,685
MO	St. Charles	100	90	89	87	85	82	87	85	82	212,907
MO	St. Louis	88	78	77	75	74	72	75	74	72	993,529
MO	Ste. Genevieve	87	77	76	75	73	70	75	73	70	16,037
MS	Adams	77	74	73	73	72	70	73	72	70	35,356
MS	Choctaw	55	49	48	48	47	46	48	47	46	9,071
MS	DeSoto	88	84	83	83	82	81	83	82	81	67,910
MS	Hancock	80	76	75	74	73	72	74	73	72	31,760
MS	Hinds	76	70	69	68	67	65	68	67	65	254,441

Table C-12. Eight-hour county design values (ppb) and population

State	County	dv8	bg8	nt810	t807	t810	t820	u807	u810	u820	cntypop
MS	Jackson	86	88	87	87	86	85	87	86	85	115,243
MS	Lauderdale	72	65	64	63	62	60	63	62	60	75,555
MS	Lee	75	68	67	66	65	63	66	65	63	65,581
MS	Madison	77	71	70	69	68	67	69	68	67	53,794
MS	Sharkey	80	74	73	73	72	71	73	72	71	7,066
MS	Warren	76	71	70	70	69	68	70	69	68	47,880
NC	a Alexander	79	71	70	68	66	62	68	66	62	27,544
NC	Buncombe	75	67	66	65	63	59	65	63	59	174,821
NC	Caldwell	79	71	70	68	66	63	68	66	63	70,709
NC	Camden	83	74	73	72	70	68	72	70	68	5,904
NC	Caswell	89	74	73	71	69	66	71	69	66	20,693
NC	Chatham	85	71	70	68	66	63	68	66	63	38,759
NC	Cumberland	87	79	78	76	74	69	76	74	69	274,566
NC	Davie	88	78	77	75	73	69	75	73	69	27,859
NC	Duplin	72	65	64	62	60	58	62	60	58	39,995
NC	Durham	83	74	73	71	69	64	71	69	64	181,835
NC	Edgecombe	84	76	75	72	70	66	72	70	66	56,558
NC	Forsyth	89	80	79	77	75	71	77	75	71	265,878
NC	Franklin	86	73	72	69	67	63	69	67	63	36,414
NC	Granville	94	83	82	79	76	71	79	76	71	38,345
NC	Guilford	85	76	75	73	71	66	73	71	66	347,420
NC	Haywood	85	75	74	72	70	67	72	70	67	46,942
NC	Johnston	87	76	75	73	71	67	73	71	67	81,306
NC	Lincoln	86	77	76	73	71	67	73	71	67	50,319
NC	Martin	75	65	64	63	61	58	63	61	58	25,078
NC	Mecklenburg	97	94	93	90	87	82	90	87	82	511,433
NC	New Hanover	79	72	71	70	68	66	70	68	66	120,284
NC	Northampton	86	71	70	69	67	64	69	67	64	20,798
NC	Person	84	68	67	65	63	60	65	63	60	30,180
NC	Pitt	88	77	76	74	72	68	74	72	68	107,924
NC	Rockingham	84	73	72	70	68	65	70	68	65	86,064
NC	Rowan	93	82	81	79	77	73	79	77	73	110,605
NC	Swain	66	57	56	55	53	51	55	53	51	11,268
NC	Wake	89	82	81	78	75	70	78	75	70	423,380
NC	Yancey	84	71	70	69	67	65	69	67	65	15,419
ND	Cass	67	67	67	67	67	67	67	67	67	102,874
NE	Douglas	67	65	64	64	63	63	64	63	63	416,444
NE	Lancaster	56	54	54	54	53	53	54	53	53	213,641
NH	Belknap	64	57	56	56	55	53	56	55	53	49,216
NH	Carroll	62	55	54	53	52	51	53	52	51	35,410
NH	Cheshire	74	66	65	64	63	61	64	63	61	70,121
NH	Coos	77	70	69	67	65	63	67	65	63	34,828

Table C-12. Eight-hour county design values (ppb) and population

State	County	dv8	bg8	nt810	t807	t810	t820	u807	u810	u820	cntypop
NH	Grafton	57	51	50	50	49	47	50	49	47	74,929
NH	Hillsborough	87	77	76	75	74	72	75	74	72	336,073
NH	Merrimack	71	63	62	62	61	60	62	61	60	120,005
NH	Rockingham	95	86	85	84	82	80	84	82	80	245,845
NH	Strafford	78	71	70	69	68	66	69	68	66	104,233
NH	Sullivan	71	64	63	62	61	59	62	61	59	38,592
NJ	Atlantic	100	87	86	85	83	81	85	83	81	224,327
NJ	Bergen	94	84	83	82	81	80	82	81	80	825,380
NJ	Camden	106	92	91	90	88	85	90	88	85	502,824
NJ	Cumberland	93	78	77	76	74	71	76	74	71	138,053
NJ	Essex	92	79	78	78	77	76	78	77	76	778,206
NJ	Gloucester	105	92	91	90	88	86	90	88	86	230,082
NJ	Hudson	98	94	94	95	94	94	95	94	94	553,099
NJ	Hunterdon	98	83	82	81	79	76	81	79	76	107,776
NJ	Mercer	101	88	87	86	84	82	86	84	82	325,824
NJ	Middlesex	103	89	88	87	86	84	87	86	84	671,780
NJ	Monmouth	100	87	86	85	83	81	85	83	81	553,124
NJ	Morris	100	84	83	82	80	78	82	80	78	421,353
NJ	Ocean	108	92	91	89	87	84	89	87	84	433,203
NJ	Union	83	71	70	69	68	66	69	68	66	493,819
NY	Albany	81	72	71	71	70	68	71	70	68	292,594
NY	Bronx	95	97	97	98	98	99	97	98	98	1,203,789
NY	Chautauqua	85	74	73	72	71	69	72	71	69	141,895
NY	Chemung	73	65	64	63	62	60	63	62	60	95,195
NY	Dutchess	90	78	77	76	74	72	76	74	72	259,462
NY	Erie	76	66	65	65	64	63	65	64	63	968,532
NY	Essex	86	78	77	76	74	72	76	74	72	37,152
NY	Hamilton	75	67	66	65	64	62	65	64	62	5,279
NY	Herkimer	70	62	61	61	60	58	61	60	58	65,797
NY	Jefferson	88	79	78	77	75	73	77	75	73	110,943
NY	Kings	88	79	78	77	76	74	77	76	74	2,300,664
NY	Madison	77	69	68	67	66	64	67	66	64	69,120
NY	Monroe	81	74	73	73	72	70	73	72	70	713,968
NY	Niagara	85	77	76	76	75	74	76	75	74	220,756
NY	Oneida	72	64	63	63	62	60	63	62	60	250,836
NY	Onondaga	79	70	69	69	68	66	69	68	66	468,973
NY	Orange	91	79	78	77	76	74	77	76	74	307,647
NY	Putnam	90	78	77	76	74	72	76	74	72	83,941
NY	Queens	91	90	90	90	90	92	89	90	91	1,951,598
NY	Richmond	103	92	91	90	88	86	90	88	86	378,977
NY	Saratoga	76	68	67	67	66	64	67	66	64	181,276
NY	Schenectady	74	66	65	65	64	62	65	64	62	149,285

Table C-12. Eight-hour county design values (ppb) and population

State	County	dv8	bg8	nt810	t807	t810	t820	u807	u810	u820	cntypop
NY	Suffolk	102	89	88	86	84	82	86	84	82	1,321,864
NY	Ulster	82	72	71	70	68	66	70	68	66	165,304
NY	Wayne	83	75	74	73	72	71	73	72	71	89,123
NY	Westchester	94	82	81	80	79	77	80	79	77	874,866
OH	Allen	89	75	74	74	73	72	74	73	72	109,755
OH	Ashtabula	85	74	73	73	72	70	73	72	70	99,821
OH	Butler	93	77	76	76	75	74	76	75	74	291,479
OH	Clark	93	79	78	77	76	74	77	76	74	147,548
OH	Clermont	89	76	75	75	74	72	75	74	72	150,187
OH	Clinton	97	80	79	78	77	75	78	77	75	35,415
OH	Cuyahoga	88	77	76	75	74	73	75	74	73	1,412,140
OH	Franklin	87	73	72	71	70	69	71	70	69	961,437
OH	Hamilton	95	87	87	88	88	88	88	88	88	866,228
OH	Jefferson	84	71	70	69	68	66	69	68	66	80,298
OH	Knox	91	77	76	76	75	73	76	75	73	47,473
OH	Lake	99	86	85	85	84	82	85	84	82	215,499
OH	Lawrence	82	65	64	64	63	61	64	63	61	61,834
OH	Licking	92	78	77	77	76	74	77	76	74	128,300
OH	Logan	86	73	72	71	70	68	71	70	68	42,310
OH	Lorain	87	78	77	76	75	74	76	75	74	271,126
OH	Lucas	89	80	79	79	78	76	79	78	76	462,361
OH	Madison	91	76	75	74	73	71	74	73	71	37,068
OH	Mahoning	90	78	77	77	75	73	77	75	73	264,806
OH	Medina	89	78	77	77	76	74	77	76	74	122,354
OH	Miami	88	75	74	73	72	71	73	72	71	93,182
OH	Montgomery	91	76	75	75	74	73	75	74	73	573,809
OH	Portage	88	77	76	76	74	72	76	74	72	142,585
OH	Preble	86	70	69	68	67	65	68	67	65	40,113
OH	Stark	88	76	75	75	74	73	75	74	73	367,585
OH	Summit	91	80	79	79	78	76	79	78	76	514,990
OH	Trumbull	93	81	80	79	77	75	79	77	75	227,813
OH	Warren	99	83	82	81	79	77	81	79	77	113,909
OH	Washington	89	69	68	67	66	64	67	66	64	62,254
OK	Cleveland	79	78	77	76	74	72	76	74	72	174,253
OK	Comanche	60	57	56	56	55	54	56	55	54	111,486
OK	Mc Clain	77	74	73	72	71	69	72	71	69	22,795
OK	Oklahoma	83	83	82	81	80	78	81	80	78	599,611
OK	Tulsa	88	87	86	86	85	84	86	85	84	503,341
PA	Allegheny	105	95	94	94	93	91	94	93	91	1,336,449
PA	Beaver	87	76	75	75	74	72	75	74	72	186,093
PA	Berks	92	78	77	76	74	71	76	74	71	336,523
PA	Blair	90	75	74	73	72	70	73	72	70	130,542

Table C-12. Eight-hour county design values (ppb) and population

State	County	dv8	bg8	nt810	t807	t810	t820	u807	u810	u820	cntypop
PA	Bucks	102	86	85	83	81	79	83	81	79	541,174
PA	Cambria	88	74	73	72	71	69	72	71	69	163,029
PA	Dauphin	88	75	74	72	70	67	72	70	67	237,813
PA	Delaware	100	87	86	85	83	81	85	83	81	547,651
PA	Erie	87	75	74	73	72	70	73	72	70	275,572
PA	Franklin	86	71	70	69	68	66	69	68	66	121,082
PA	Lackawanna	86	75	74	73	72	70	73	72	70	219,039
PA	Lancaster	96	83	82	81	79	76	81	79	76	422,822
PA	Lawrence	84	74	73	72	70	68	72	70	68	96,246
PA	Lehigh	95	80	79	78	76	73	78	76	73	291,130
PA	Luzerne	90	74	73	72	71	69	72	71	69	328,149
PA	Lycoming	73	61	60	60	59	57	60	59	57	118,710
PA	Mercer	92	81	80	78	76	74	78	76	74	121,003
PA	Montgomery	97	83	82	81	79	76	81	79	76	678,111
PA	Northampton	90	76	75	74	72	70	74	72	70	247,105
PA	Perry	84	70	69	68	66	64	68	66	64	41,172
PA	Philadelphia	102	94	94	94	93	92	94	93	92	1,585,577
PA	Washington	95	74	73	73	71	69	73	71	69	204,584
PA	Westmoreland	88	76	75	74	73	71	74	73	71	370,321
PA	York	87	74	73	72	70	68	72	70	68	339,574
RI	Kent	96	82	81	79	77	75	79	77	75	161,135
RI	Providence	87	74	73	72	71	69	72	71	69	596,270
SC	a Abbeville	77	70	69	67	65	62	67	65	62	23,862
SC	Aiken	81	73	72	70	68	64	70	68	64	120,940
SC	Anderson	88	79	78	76	74	70	76	74	70	145,196
SC	Barnwell	81	71	70	68	66	64	68	66	64	20,293
SC	Berkeley	71	63	62	61	60	58	61	60	58	128,776
SC	Charleston	76	70	69	68	67	65	68	67	65	295,039
SC	Cherokee	84	74	73	71	69	65	71	69	65	44,506
SC	Chester	87	78	77	75	73	70	75	73	70	32,170
SC	Darlington	78	68	67	66	64	61	66	64	61	61,851
SC	Edgefield	76	66	65	63	61	58	63	61	58	18,375
SC	Oconee	76	68	67	65	63	59	65	63	59	57,494
SC	Pickens	83	76	75	72	70	66	72	70	66	93,894
SC	Richland	83	74	73	71	69	64	71	69	64	285,720
SC	Spartanburg	86	79	78	75	73	68	75	73	68	226,800
SC	Union	81	73	72	70	68	65	70	68	65	30,337
SC	Williamsburg	70	61	60	59	58	56	59	58	56	36,815
SC	York	82	75	74	72	70	66	72	70	66	131,497
TN	Anderson	87	75	74	72	70	68	72	70	68	68,250
TN	Blount	95	83	82	81	79	76	81	79	76	85,969
TN	Davidson	88	82	81	81	80	79	81	80	79	510,784

Table C-12. Eight-hour county design values (ppb) and population

State	County	dv8	bg8	nt810	t807	t810	t820	u807	u810	u820	cntypop
TN	Hamilton	90	82	81	79	77	73	79	77	73	285,536
TN	Haywood	82	71	70	69	68	66	69	68	66	19,437
TN	Humphreys	77	65	64	64	63	61	64	63	61	15,795
TN	Jefferson	96	80	79	78	76	73	78	76	73	33,016
TN	Knox	95	85	84	83	81	78	83	81	78	335,749
TN	Putnam	80	67	66	65	64	62	65	64	62	51,373
TN	Rutherford	79	67	66	65	63	61	65	63	61	118,570
TN	Sevier	93	81	80	78	76	73	78	76	73	51,043
TN	Shelby	95	90	89	88	86	84	88	86	84	826,330
TN	Sullivan	88	77	76	76	75	73	76	75	73	143,596
TN	Sumner	99	88	87	86	84	81	86	84	81	103,281
TN	Williamson	88	80	79	78	76	74	78	76	74	81,021
TN	Wilson	90	80	79	78	76	73	78	76	73	67,675
TX	Bexar	87	85	84	84	83	82	84	83	82	1,185,394
TX	Brazoria	92	87	86	86	85	84	86	85	84	191,707
TX	Cameron	66	66	66	66	66	66	66	66	66	260,120
TX	Collin	101	93	92	91	89	87	91	89	87	264,036
TX	Dallas	95	89	88	88	87	85	88	87	85	1,852,810
TX	Denton	104	94	93	92	90	87	92	90	87	273,525
TX	Ellis	82	78	77	76	75	73	76	75	73	85,167
TX	Galveston	105	99	98	98	97	97	98	97	97	217,399
TX	Gregg	91	84	83	83	81	79	83	81	79	104,948
TX	Harris	117	109	109	110	110	111	109	110	110	2,818,199
TX	Hidalgo	56	55	55	55	55	55	55	55	55	383,545
TX	Jefferson	93	86	85	85	84	82	85	84	82	239,397
TX	Nueces	83	81	81	81	81	81	81	81	81	291,145
TX	Orange	86	80	79	79	78	77	79	78	77	80,509
TX	Smith	89	82	81	80	79	77	80	79	77	151,309
TX	Tarrant	97	89	88	87	86	84	87	86	84	1,170,103
TX	Travis	81	77	76	75	74	72	75	74	72	576,407
TX	Victoria	78	75	74	74	73	73	74	73	73	74,361
TX	Webb	60	60	60	60	60	60	60	60	60	133,239
VA	Alexandria City	87	76	75	75	75	75	75	75	75	111,183
VA	Arlington	91	79	79	79	78	78	79	78	78	170,936
VA	Caroline	84	70	69	67	65	62	67	65	62	19,217
VA	Charles City	90	77	76	75	73	70	75	73	70	6,282
VA	Chesterfield	87	74	73	71	69	67	71	69	67	209,274
VA	Fairfax	92	79	78	78	76	74	78	76	74	818,584
VA	Fauquier	81	64	63	62	61	59	62	61	59	48,741
VA	Frederick	84	67	66	65	63	61	65	63	61	45,723
VA	Hampton City	87	78	77	76	74	72	76	74	72	133,793
VA	Hanover	90	77	76	74	72	68	74	72	68	63,306

Table C-12. Eight-hour county design values (ppb) and population

State	County	dv8	bg8	nt810	t807	t810	t820	u807	u810	u820	cntypop
VA	Henrico	90	77	76	74	72	69	74	72	69	217,881
VA	Henry	82	67	66	64	62	60	64	62	60	56,942
VA	Madison	86	71	70	69	67	65	69	67	65	11,949
VA	Prince William	88	73	72	71	69	67	71	69	67	215,686
VA	Roanoke	78	66	65	64	62	59	64	62	59	79,332
VA	Stafford	86	69	68	67	65	63	67	65	63	61,236
VA	Suffolk City	82	70	69	68	66	63	68	66	63	52,141
VA	Wythe	78	61	60	59	58	56	59	58	56	25,466
VT	Bennington	79	71	70	69	67	65	69	67	65	35,845
VT	Chittenden	69	63	62	61	60	59	61	60	59	131,761
WI	Brown	82	75	74	74	73	71	74	73	71	194,594
WI	Columbia	81	76	75	74	73	71	74	73	71	45,088
WI	Dane	79	74	73	73	72	70	73	72	70	367,085
WI	Dodge	78	72	71	71	70	68	71	70	68	76,559
WI	Door	92	83	82	81	80	78	81	80	78	25,690
WI	Florence	64	60	59	59	58	57	59	58	57	4,590
WI	Fond Du Lac	79	73	72	72	71	70	72	71	70	90,083
WI	Jefferson	80	73	72	72	71	69	72	71	69	67,783
WI	Kenosha	96	88	87	86	85	83	86	85	83	128,181
WI	Kewaunee	93	84	83	82	81	79	82	81	79	18,878
WI	Manitowoc	95	85	84	83	82	80	83	82	80	80,421
WI	Marathon	71	67	66	66	65	63	66	65	63	115,400
WI	Milwaukee	94	89	88	87	86	84	87	86	84	959,275
WI	Oneida	64	61	60	59	58	57	59	58	57	31,679
WI	Outagamie	80	75	74	74	73	71	74	73	71	140,510
WI	Ozaukee	98	94	93	93	92	90	93	92	90	72,831
WI	Polk	69	66	65	65	64	63	65	64	63	34,773
WI	Racine	92	85	84	84	82	80	84	82	80	175,034
WI	Rock	85	78	77	77	76	75	77	76	75	139,510
WI	Sauk	74	70	69	68	67	66	68	67	66	46,975
WI	Sheboygan	92	83	82	81	80	79	81	80	79	103,877
WI	St Croix	67	65	64	64	63	62	64	63	62	50,251
WI	Vernon	69	66	65	65	64	63	65	64	63	25,617
WI	Walworth	83	77	76	76	75	73	76	75	73	75,000
WI	Washington	80	74	73	73	72	70	73	72	70	95,328
WI	Waukesha	81	75	74	73	72	70	73	72	70	304,715
WI	Winnebago	81	76	75	74	73	71	74	73	71	140,320
WV	Cabell	88	71	70	69	68	66	69	68	66	96,827
WV	Greenbrier	83	61	60	59	58	57	59	58	57	34,693
WV	Hancock	85	73	72	72	71	69	72	71	69	35,233
WV	Kanawha	81	68	67	65	63	61	65	63	61	207,619
WV	Ohio	86	68	67	67	66	64	67	66	64	50,871

Table C-12. Eight-hour county design values (ppb) and population

State	County	dv8	bg8	nt810	t807	t810	t820	u807	u810	u820	cntypop
WV	Wood	89	70	69	68	67	65	68	67	65	86,915

Table C-13. Metropolitan areas and rural counties with design values that exceeded the 1-hour standard prior to ROTR controls, and were projected to meet but remain within 15% of the 1-hour standard after ROTR controls.

Name	Design Value (ppb)	Pop'n.
Manitowoc WI	113	80,421
Door WI	113	25,690
Mason MI	113	25,537
Kent MD	110	17,842
Sagadahoc ME	109	33,535
Atlanta, GA MSA	124	2,959,500
Barnstable-Yarmouth, MA MSA	118	134,954
Baton Rouge, LA MSA	122	528,261
Birmingham, AL MSA	117	839,942
Boston-Worcester-Lawrence, MA-NH-ME-CT CMSA	119	5,455,403
Chicago-Gary-Kenosha, IL-IN-WI CMSA	124	8,239,820
Dallas-Fort Worth, TX CMSA	124	4,037,282
Grand Rapids-Muskegon-Holland, MI MSA	121	937,891
Houma, LA MSA	122	182,842
Kansas City, MO-KS MSA	122	1,582,874
Lancaster, PA MSA	109	422,822
Louisville, KY-IN MSA	111	949,012
Milwaukee-Racine, WI CMSA	118	1,607,183
Pittsburgh, PA MSA	121	2,394,811
Providence-Fall River-Warwick, RI-MA MSA	114	1,134,350
St. Louis, MO-IL MSA	117	2,492,348
Springfield, MA MSA	118	587,884
	sum	34,670,204
	MA count	17
	MA sum	34,487,179
	Cnty count	5
	Cnty sum	183,025

Appendix C. References

1. U.S. EPA. Green Book Web Site: http://www.epa.gov/oar/oaqps/greenbook/oytc.html.

Appendix D: EPA's Legal Authority for Proposing Gasoline Sulfur Controls

We are proposing gasoline sulfur controls pursuant to our authority under Section 211(c)(1) of the Clean Air Act. This section gives us the authority to "control or prohibit the manufacture, introduction into commerce, offering for sale, or sale" of any fuel or fuel additive (A) whose emission products, in the judgment of the Administrator, cause or contribute to air pollution "which may be reasonably anticipated to endanger the public health or welfare" or (B) whose emission products "will impair to a significant degree the performance of any emission control device or system which is in general use, or which the Administrator finds has been developed to a point where in a reasonable time it would be in general use" were the fuel control or prohibition adopted. The following sections describe current our regulatory requirements that affect gasoline sulfur content, and explain our bases for proposing to control gasoline sulfur under Section 211(c)(1).

A. EPA's Current Regulatory Requirements for Gasoline

We currently have regulatory requirements for conventional and reformulated gasoline (RFG), adopted under Sections 211(c) and 211(k) of the Act. RFG is required to be sold in certain ozone nonattainment areas. Gasoline sold in the rest of the country is subject to the conventional gasoline requirements. See 40 CFR part 80.

Both the RFG and conventional gasoline (CG) requirements include a NOx performance standard that requires refiners to achieve a certain level of NOx control compared to1990 baseline levels. As a practical matter, compliance with this performance standard results in limiting sulfur levels in RFG. The NOx reductions required by the Phase 2 RFG requirements, effective on January 1, 2000, are expected to result in RFG sulfur levels of about 150 ppm. In addition, EPA's regulations require compliance with the RFG and CG standards (including the NOx performance standard) to be calculated using the Complex Model beginning in 1998. This model contains range limits for RFG for a number of fuel parameters that affect NOx performance, including a range of zero to 500 ppm for sulfur. Therefore, the requirement to use the Complex Model effectively limits sulfur levels in RFG to no more than 500 ppm. The sulfur Complex Model range limit for RFG is the only direct regulation of sulfur content under Section 211(c)(1). However, the NOx performance standards for RFG and CG have an indirect effect on sulfur content.[mmm]

All gasoline is subject to Section 211(f) of the Act, which prohibits fuel or fuel additive

[mmm]Because sulfur is directly or indirectly controlled by EPA requirements, and will be controlled directly under today's proposal, states are preempted from initiating sulfur control programs unless they are identical to the federal requirements. See the discussion in Section V.B on this subject.

manufactures from introducing into commerce, or increasing the concentration in use of, any fuel or fuel additive for general use in light duty motor vehicles which is not "substantially similar" to the fuel used in the certification of model year 1975 or later vehicles or engines. We have interpreted "substantially similar" for unleaded gasoline to include any gasoline meeting the 1988 ASTM specifications for unleaded gasoline (ASTM D 4814-88[nnn]), which limits the sulfur content of unleaded gasoline to 0.1 weight percent (1000 ppm) sulfur.

B. How the Proposed Gasoline Sulfur Control Program Meets the CAA Section 211(c) Criteria

Under Section 211(c)(1), EPA may adopt a fuel control if at least one of the following two criteria is met: 1) the emission products of the fuel cause or contribute to air pollution which may reasonably be anticipated to endanger public health or welfare, or 2) the emission products of the fuel will significantly impair emissions control systems in general use or which would be in general use were the fuel control to be adopted. We are proposing to control sulfur levels in gasoline based on both of these criteria. Under the first criterion, we believe that emissions products of sulfur in gasoline used in Tier 1 and LEV technology vehicles contribute to ozone pollution, air toxics, and PM. Under the second criterion, we believe that gasoline sulfur in fuel that will be used in Tier 2 technology vehicles will significantly impair the emissions control systems expected to be used in such vehicles. The following sections summarize our analysis of each criterion.

1. Health and Welfare Concerns of Air Pollution Caused by Sulfur in Gasoline

We believe that the emission products of gasoline sulfur contribute to air pollution that can reasonably be anticipated to endanger public health and welfare. The combustion products of the sulfur-containing compounds in gasoline (SO_2 and other sulfur oxides) contribute to air pollution that has adverse impacts on public health and welfare. The greatest impact of gasoline sulfur on pollution is the increase in emissions of hydrocarbons (including hazardous air pollutants such as benzene and 1,3-butadiene), NOx, particulate matter, and compounds such as nitrates and sulfates that become particulates in the atmosphere. As explained below and in the RIA, these increased emissions result primarily from the adverse impact of high sulfur levels on the automotive catalysts used in the vehicles which have recently entered the fleet or will be used to comply with the proposed Tier 2 standards. The health and welfare implications of the emissions of these compounds are discussed in greater detail in Section III of the Preamble.

Section 211(c)(2)(A) requires that, prior to adopting a fuel control based on a finding that the fuel's emission products contribute to air pollution that can reasonably be anticipated to endanger public health or welfare, EPA consider "all relevant medical and scientific evidence

[nnn]Standard Specification for Automotive Spark-Ignition Engine Fuel

available, including consideration of other technologically or economically feasible means of achieving emission standards under [section 202 of the Act]." EPA's analysis of the medical and scientific evidence relating to the emissions impact of sulfur in gasoline is described in more detail in the RIA.

2. Impact of Gasoline Sulfur Emission Products on Emission Control Systems

EPA believes that sulfur in gasoline can significantly impair the emissions control technology of vehicles designed to meet the proposed Tier 2 emissions standards. We know that gasoline sulfur has a negative impact on vehicle emission controls. This is not a new development. Vehicles depend on the catalytic converter to oxidize or reduce emissions of HC, CO, and NOx. Sulfur and sulfur compounds attach or "adsorb" to the precious metals which are required to convert these emissions. Sulfur also blocks sites on the catalyst designed to store oxygen which are necessary to optimize NOx emissions conversions. While the amount of sulfur contamination can vary depending on the metals used in the catalyst and other aspects of the design and operation of the vehicle, some level of sulfur contamination will occur in any catalyst.

For older vehicles designed to meet Tier 0 and Tier 1 emission standards, this sulfur contamination increases emissions of NMHC and NOx by almost 17 percent when one of these vehicles is operated on gasoline containing 330 ppm sulfur (approximately the current national average sulfur level) compared to operation on gasoline with 30 ppm sulfur (which is close to California's current average sulfur level, and is the average sulfur level proposed in this notice). Thus, Tier 0 and Tier 1 vehicles have higher emissions when they are exposed to sulfur levels substantially higher than the proposed sulfur standard. This increase is generally not enough to cause a vehicle to exceed the full useful life emission standards in practice, because car manufacturers design the vehicles with a margin of safety to compensate for deterioration in emissions performance over the life of the vehicle. However, it does lead to greater in-use emissions than achieved with the proposed control on gasoline sulfur content.

The sulfur impact on the catalysts used in later model vehicles is clearly significant. High sulfur levels have been shown to significantly impair the emissions control systems of cleaner, later technology vehicles. The California LEV standards and Federal NLEV standards, as well as California's new LEV-II standards and our proposed Tier 2 standards, require catalysts to be extremely efficient to adequately reduce emissions over the full useful life of the vehicle. Recent test programs conducted by the automotive and oil industries show that LEV and ULEV vehicles can experience, on average, a 40 percent increase in NMHC and 134 percent increase in NOx emissions when operated on 330 ppm sulfur fuel compared to 30 ppm sulfur fuel. This level of emissions increase is significant enough that it would undermine the technical and economic feasibility of the Tier 2 standards proposed today.

This level of impact on emission control system efficiency would mean actual in-use emissions reductions from the proposed tier 2 standards would be undercut to such a degree that the resulting limited in-use emissions reductions would not warrant the expense imposed by the

Tier 2 standards, and would not achieve the in-use emissions reductions from these motor vehicles needed to address the air quality problems described elsewhere in this notice. In addition, the concerns about irreversibility of the damage to the catalyst mean it would not be feasible to design an emission control system that would offset this level of impact on the efficiency of the control system in order to comply over the useful life of the vehicles. Average sulfur levels in the U.S. are currently high enough to significantly impair the emissions control systems in new technology vehicles, and to potentially cause these vehicles to fail emission standards required for vehicles up through 100,000 miles (or more) of operation.

Based on this information, we have concluded that the sensitivity of automotive catalysts to sulfur has increased to such a degree in vehicle technology currently available, and expected to be used to meet the proposed Tier 2 standards, that sulfur levels in gasoline must be reduced to enable these catalysts to operate properly. Not only will harmful emissions from vehicles on the road today be reduced through lowering gasoline sulfur levels, but the emissions control systems expected to be used to attain the proposed Tier 2 standards will be significantly impaired if sulfur levels are not substantially reduced from current levels. A lesser reduction in gasoline sulfur levels nationwide would likely require us to reduce the stringency of the proposed Tier 2 standards. The same kind of analysis for Tier 0 and Tier 1 vehicles could arguably support a determination that gasoline sulfur levels significantly impair the emissions control systems of these vehicles. This is because the effect of sulfur in reducing catalyst efficiency and thereby increasing emissions exists for all vehicles at issue here (Tier 0 through tier 2), presenting more a question of difference in degree than in the nature of the effects.

Sulfur in gasoline can also significantly impair the onboard diagnostic (OBD) systems in current and future vehicles. EPA regulations require all vehicles to be equipped with OBD systems that monitor catalyst performance and other emissions-related performance, and warns the vehicle owner if the emissions control system is not functioning properly. In a 1997 staff paper, EPA concluded that sulfur in gasoline can directly impact OBD systems by affecting the OBD system's oxygen sensors.[1] It is possible that high sulfur levels may impair the OBD system in such a way that it does not recognize an improperly functioning catalyst, and fails to warn the owner. In addition, it is not clear that the conditions which may reverse some of sulfur's effect on the catalyst will also reverse this impact on the OBD system's oxygen sensors. The impact of sulfur on OBD systems in cleaner technology vehicles may be even more significant, since the OBD malfunction thresholds are expressed as multiples of the applicable hydrocarbon standard. Therefore, the impact of sulfur on OBD systems in vehicles meeting more stringent hydrocarbon standards would be more significant in relative terms.

3. Sulfur Levels that Tier 2 Vehicles Can Tolerate

We believe that Tier 2 vehicles that operate on gasoline will have to use fuel with sulfur levels no greater than 80 ppm to avoid significant impairment of their emissions control systems. Furthermore, on average, these vehicles will not be able to be exposed to sulfur levels substantially greater than 30 ppm to achieve the desired emission performance and avoid

significantly impairing the emissions control system. These conclusions are based on data collected on vehicles currently sold in California or being developed for sale in California and the Northeast (the latter under the NLEV program).

The test data from industry test programs and individual automotive and catalyst manufacturers show that even very low levels of sulfur have some impact on catalyst performance. The data also show that the greatest increase in emissions comes as the sulfur level is increased from the lowest levels. At higher sulfur levels, the catalyst is approaching the point of being saturated with sulfur, and its performance is already impaired, such that an additional increase in sulfur content has a smaller impact on emissions. This trend applies generally for all of the regulated pollutants (NMHC, CO, NOx). However, for most vehicles, the impact is greatest for NOx.

While the overall trends demonstrate that high sulfur levels significantly impair the emissions control system of newer technology vehicles, the data also shows that some vehicles are much less sensitive to sulfur than others. The reasons for these vehicle-to-vehicle variations are not fully understood. We have identified a number of factors involved in the vehicle design and operation which appear to contribute to the variation. To summarize briefly, sulfur sensitivity is impacted not only by the catalyst formulation (the types and amounts of precious metals used in the catalyst) but also by the following factors:

the materials used to provide oxygen storage capacity in the catalyst, as well as the general design of the catalyst,

- the location of the catalyst relative to the engine, which impacts the temperatures inside the catalyst,

the mix of air and fuel entering the engine over the course of operation, which is varied by the engine's computer in response to the driving situation and affects the mix of gases entering the catalyst from the engine, and

the speeds the car is driven at and the load the vehicle is carrying, which also impact the temperatures experienced by the catalyst.

All of these factors contribute not only to the degree to which sulfur will poison a catalyst, but also whether and how easily the sulfur will be removed during a vehicle's normal operation. This cycle of sulfur collection (adsorption) and removal (desorption) in the catalyst is what ultimately affects sulfur's net impact on emissions and the emissions control system, both short and long term. Since these factors vary for every vehicle, the sulfur impact varies for every vehicle to some degree. There is no single factor that guarantees that a vehicle will be very sensitive or very insensitive to sulfur. None of the data that we have reviewed indicates a vehicle design which is completely insensitive to sulfur, or even capable of tolerating average sulfur levels above 30 ppm without a significant impairment of its emissions control system.

Based on the data and information obtained from catalyst manufacturers, we have also concluded that there are no viable emission control alternatives that could achieve the same level of emission standards without reducing commercial gasoline sulfur levels, as explained in the next section.

4. Sulfur Sensitivity of Other Catalysts

Section 211(c)(2)(B) requires that, prior to adopting a fuel control based on a significant impairment to vehicle emissions control systems, EPA consider available scientific and economic data, including a cost benefit analysis comparing emissions control devices or systems which are or will be in general use that require the proposed fuel control with such devices or systems which are or will be in general use that do not require the proposed fuel control. As described below, we conclude that the emissions control systems expected to be used to meet the proposed Tier 2 standards would be significantly impaired by operation on high sulfur gasoline. Our analysis of the available scientific and economic data can be found in the Preamble, including an analysis of the environmental benefits of the proposed control, an analysis of the costs and the technological feasibility of controlling sulfur to the proposed levels, and a cost-benefit analysis of the proposed sulfur control and Tier 2 vehicle emissions standards. Under Section 211(c)(2)(B), EPA is also required to compare the costs and benefits of achieving vehicle emissions standards through emissions control systems that are not sulfur-sensitive, if any such systems are or are will be in general use.

We have determined that there are not (and will not be in the foreseeable future) emission control devices available for gasoline-powered vehicles that can meet the proposed Tier 2 emission standards and would not be significantly impaired by gasoline with high sulfur levels. All catalysts are sensitive to sulfur to some degree. As explained in Section IV.A of the Preamble, we cannot identify one or more factors that definitively determine sulfur sensitivity, because sulfur sensitivity seems to be due to a combination of many factors that vary by vehicle. Hence, it is not possible to identify alternative designs that can tolerate existing (or even intermediate) sulfur levels and that can reasonably be expected to be applied to all cars and light trucks meeting Tier 2 standards.

As described in Section IV.A. of the Preamble, EPA anticipates that all the gasoline vehicle technologies expected to be used to meet the proposed Tier 2 standards will require the use of low sulfur gasoline. If we do not control gasoline sulfur to the proposed levels, we will not be able to set Tier 2 standards as stringent as those we are proposing today. Moreover, vehicles already on the road would continue to emit at higher levels than they would if operated on low sulfur fuel. Consequently, EPA concludes that the benefits that would be achieved through implementation of the proposed vehicle and sulfur control programs cannot be achieved through the use of emission control technology that is not sulfur-sensitive.

This also means that if EPA were to adopt vehicle emissions control standards without controlling gasoline sulfur content, the standards would be significantly less stringent than those

proposed today based on what would be technologically feasible with current sulfur levels. The cost of the vehicle emissions control technology would likely be similar to the costs of meeting the proposed Tier 2 standards, because the same technologies would be used. However, the emissions benefits of those technologies would be significantly less than what would be achieved by the program proposed today, because the emissions control technology for gasoline vehicles currently in use, and expected to be used in the future, would be significantly impaired by high sulfur fuel.

5. Effect of Gasoline Sulfur Control on the Use of Other Fuels or Fuel Additives

Section 211(c)(2)(C) requires that, prior to prohibiting a fuel or fuel additive, EPA establish that such prohibition will not cause the use of another fuel or fuel additive "which will produce emissions which endanger the public health or welfare to the same or greater degree" than the prohibited fuel or additive. This finding is required by the Act only prior to prohibiting a fuel or additive, not prior to controlling a fuel or additive. Since EPA is not proposing to prohibit sulfur in gasoline, but rather to control the levels of sulfur in gasoline, this finding is not required prior to regulation. However, EPA does not believe that the proposed sulfur control will result in the use of any other fuel or additive that will produce emissions that will endanger public health or welfare to the same or greater degree as the emissions produced by gasoline with uncontrolled sulfur levels.

We believe that gasoline formulated to meet the proposed low sulfur standards will have a net benefit to public health due to reduced emissions of harmful compounds. The composition of the emissions from combustion of low sulfur gasolines will be different than the composition of the emissions from the high sulfur gasolines they replace. Furthermore, other changes to the composition of the gasoline are likely to accompany the reduction in sulfur content. While some of these changes may involve increases in the content of certain compounds that tend to lead to more harmful emission products, we believe that the improved catalyst performance enabled by the low sulfur fuel will more than offset any slight increase in harmful emissions that would otherwise result (if sulfur levels remained constant but the other properties were increased).

It is difficult to quantify this impact because it depends on the specific approaches that each refiner takes to reduce their gasolines' sulfur levels, as well as the composition of the gasoline overall. However, some general trends can be identified, and based on these trends we have drawn the conclusion that low sulfur gasoline will pose no new, increased risk to human health relative to the higher sulfur gasoline it replaces.

Some refiners already make gasolines that meet the proposed standards. Others will make modest changes in the way in which they blend refinery streams to produce low sulfur gasoline. But most refiners will have to install some desulfurization technology and/or otherwise substantially change their operation. If a refiner chooses a traditional route to desulfurize gasoline, he will likely select a desulfurization technology which has the undesirable side effect of reducing the octane content of the gasoline streams. To make up that octane, the refiner has

several options. All of these options, whether increasing the aromatics or olefins content of the gasoline through other processing changes, or through the addition of oxygenates such as ethanol or MTBE, could lead to increased emissions of air toxics (benzene, 1,3-butadiene, aldehydes) if the emissions performance of the vehicle catalyst remained constant. However, since low sulfur gasoline will enable very low emitting catalysts and will improve the performance of existing catalysts, the catalyst will be able to convert these toxic emissions into less harmful compounds. Because of the diversity among refineries, it is impossible to estimate with any certainty how many refiners may choose this route.

If a refiner chooses one of the improved technologies for sulfur removal, the technologies on which much of our economic analysis for this proposal is based (as discussed in Sections IV.C and IV.D of the Preamble), there will be less of a need to increase high octane compounds in the gasoline. These improved technologies are designed to reduce the octane loss that occurs with the traditional technologies. Because the need to increase high octane components is reduced if these technologies are used, the net benefit of low sulfur gasoline is even greater, because there are even fewer toxic compounds for the catalyst to have to convert. (No catalyst yet developed is able to convert 100 percent of the pollutants that come from the engine.)

Appendix D. References

1. *EPA Staff Paper on Gasoline Sulfur Issues* (EPA420-R-98-004), May 1998.