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

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Engine Programs and Compliance Division
Office of Mobile Sources
U.S. Environmental Protection Agency

Executive Summary

Vehicle Standards

Today's action sets new federal emission standards ("Tier 2 standards") for passenger cars, light trucks, and larger passenger vehicles. The program is designed to focus on reducing the emissions most responsible for the ozone and particulate matter (PM) impact from these vehicles -- nitrogen oxides (NOx) and non-methane organic gases (NMOG), consisting primarily of hydrocarbons (HC) and contributing to ambient volatile organic compounds (VOC). The program will also, for the first time, apply the same set of federal standards to all passenger cars, light trucks, and medium-duty passenger vehicles. Light trucks include "light light-duty trucks" (or LLDTs), rated at less than 6000 pounds gross vehicle weight and "heavy light-duty trucks" (or HLDTs), rated at more than 6000 pounds gross vehicle weight).[1] "Medium-duty passenger vehicles" (or MDPVs) form a new class of vehicles introduced by this rule that includes SUVs and passenger vans rated at between 8,500 and 10,000 GVWR. The program thus ensures that essentially all vehicles designed for passenger use in the future will be very clean vehicles.

The Tier 2 standards finalized today will 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 will phase in beginning in 2004, with the standards to be fully phased in by 2007.[2] For heavy LDTs and MDPVs, the Tier 2 standards will 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 the primary Tier 2 standards will have to meet an interim average standard of 0.30 g/mi NOx, equivalent to the current NLEV standards for LDVs.[3] During the period 2004-2008, heavy LDTs and MDPVs not certified to the final Tier 2 standards will phase in to an interim program with an average standard of 0.20 g/mi NOx, with those not covered by the phase-in meeting a per-vehicle standard (i.e., an emissions "cap") of 0.60 g/mi NOx (for HLDTs) and 0.09

[1] A vehicle's "Gross Vehicle Weight Rating," or GVWR, is the curb weight of the vehicle plus its maximum recommended load of passengers and cargo.

[2] 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 (larger light trucks are not covered). For further comparison, the standards met by today's Tier 1 vehicles range from 0.60 g/mi to 1.53 g/mi.

[3] 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. of this preamble.

g/mi NOx (for MDPVs). The average standards for NOx will allow manufacturers to comply with the very stringent new standards in a flexible way, assuring that the average emissions of a company's production meet the target emission levels while allowing the manufacturer to choose from several more- and less-stringent emission categories for certification.

We are also setting stringent particulate matter standards that will be especially important if there is substantial future growth in the sales of diesel vehicles. With higher sales of diesel cars and light trucks, these vehicles could easily contribute between one-half and two percent of the PM10 concentration allowed by the NAAQS, with some possibility that the contribution could be as high as five to 40 percent in some roadside situations with heavy traffic. These increases would make attainment even more difficult for eight counties which we already predict to need further emission reductions even without an increase in diesel sales, and would put at risk another 18 counties which are now within 10 percent of a NAAQS violation. Thus, by including a more stringent PM standard in the program finalized today, we help address environmental concerns about the potential growth in the numbers of light-duty diesels on the road -- even if that growth is substantial. The new requirements also include more stringent hydrocarbon controls (exhaust NMOG and evaporative emissions standards).

Gasoline Sulfur Standards

The other major part of today's action will significantly reduce average gasoline sulfur levels nationwide. We expect these reductions could begin to phase in as early as 2000, with full compliance for most refiners occurring by 2006. Refiners will generally install advanced refining equipment to remove sulfur during the production of gasoline. Importers of gasoline will be required to import and market only gasoline meeting the sulfur limits. Temporary, less stringent standards will apply to refineries who produce fuel for use in the Geographic Phase-in Area[4] through 2006 and a few small refiners through 2007.

This significant new control of gasoline sulfur content will have two important effects. The lower sulfur levels will enable the much-improved emission control technology necessary to meet the stringent vehicle standards of today's rule to operate effectively over the useful life of the new vehicles. In addition, as soon as the lower sulfur gasoline is available, all gasoline vehicles already on the road will have reduced emissions–from less degradation of their catalytic converters and from fewer sulfur compounds in the exhaust.

Today's action will require that most refiners and importers meet a corporate average gasoline sulfur standard of 120 ppm and a cap of 300 ppm beginning in 2004. By 2006, the cap will be reduced to 80 ppm and most individual refineries must produce gasoline averaging no

[4]Alaska, Colorado, Idaho, Montana, New Mexico, North Dakota, Utah, and Wyoming

more than 30 ppm sulfur. The program builds upon the existing regulations covering gasoline composition 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. We intend for the credit program to ease compliance uncertainties by providing refiners the flexibility to phase in early controls in 2000-2003 and use credits gained in these years to delay some control until as late as 2006. As finalized today, the program will achieve the needed environmental benefits while providing substantial flexibility to refiners.

Cost-Effectiveness of the Tier2/Sulfur Program

A comparison of the costs of our program with the emission reductions it is estimated to achieve leads us to conclude that it is a cost-effective means of reducing pollution. As shown in Chapter VI, the cost-effectiveness of Tier 2/gasoline sulfur falls within the range of cost-effectiveness of 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 finalizing 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 are expected to result from our standards near full implementation in 2030. We estimate that our Tier 2/gasoline sulfur standards would, in the long term, result in substantial benefits, such as: the yearly avoidance of approximately 4300 premature deaths, approximately 2300 cases of bronchitis, and significant numbers of hospital visits, lost work days, and multiple respiratory ailments (especially those that affect children). Our standards will also produce welfare benefits relating to agricultural crop damage, visibility, and nitrogen deposition in rivers and lakes. Total monetized benefits, however, are driven primarily by the value placed on the reductions in premature deaths. The adoption of a value for the projected reduction in the risk of premature mortality is the subject of continuing discussion within the economic and public policy analysis community within and outside the Administration. In response to the sensitivity on this issue, we provide estimates reflecting two alternative approaches. The first approach–supported by some in the above community and preferred by EPA–uses a Value of a Statistical Life (VSL) approach developed for the Clean Air Act Section 812 benefit-cost studies. This VSL estimate of $5.9 million (1997$) was derived from a set of 26 studies identified by EPA using criteria established in Viscusi (1992), as those most appropriate for environmental policy analysis applications.

An alternative, age-adjusted approach is preferred by some others in the above

community both within and outside the Administration. This approach was also developed for the Section 812 studies and addresses concerns with applying the VSL estimate –reflecting a valuation derived mostly from labor market studies involving healthy working-age manual laborers– to PM-related mortality risks that are primarily associated with older populations and those with impaired health status. This alternative approach leads to an estimate of the value of a statistical life year (VSLY), which is derived directly from the VSL estimate. It differs only in incorporating an explicit assumption about the number of life years saved and an implicit assumption that the valuation of each life year is not affected by age.[5] The mean VSLY is $360,000 (1997$); combining this number with a mean life expectancy of 14 years yields an age-adjusted VSL of $3.6 million (1997$).

Both approaches are imperfect, and raise difficult methodological issues which are discussed in depth in the recently published Section 812 Prospective Study, the draft EPA Economic Guidelines, and the peer-review commentaries prepared in support of each of these documents. For example, both methodologies embed assumptions (explicit or implicit) about which there is little or no definitive scientific guidance. In particular, both methods adopt the assumption that the risk versus dollars trade-offs revealed by available labor market studies are applicable to the risk versus dollar trade-offs in an air pollution context.

EPA currently prefers the VSL approach because, essentially, the method reflects the direct, application of what EPA considers to be the most reliable estimates for valuation of premature mortality available in the current economic literature. While there are several differences between the labor market studies EPA uses to derive a VSL estimate and the particulate matter air pollution context addressed here, those differences in the affected populations and the nature of the risks imply both upward and downward adjustments. For example, adjusting for age differences may imply the need to adjust the $5.9 million VSL downward as would adjusting for health differences, but the involuntary nature of air pollution-related risks and the lower level of risk-aversion of the manual laborers in the labor market studies may imply the need for upward adjustments. In the absence of a comprehensive and balanced set of adjustment factors, EPA believes it is reasonable to continue to use the $5.9 million value while acknowledging the significant limitations and uncertainties in the available literature. Furthermore, EPA prefers not to draw distinctions in the monetary value assigned to the lives saved even if they differ in age, health status, socioeconomic status, gender or other characteristic of the adult population.

Those who favor the alternative, age-adjusted approach (i.e. the VSLY approach)

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[5] Specifically, the VSLY estimate is calculated by amortizing the $5.9 million mean VSL estimate over the 35 years of life expectancy associated with subjects in the labor market studies. The resulting estimate, using a 5 percent discount rate, is $360,000 per life-year saved in 1997 dollars. This annual average value of a life-year is then multiplied times the number of years of remaining life expectancy for the affected population (in the case of PM-related premature mortality, the average number of $ life-years saved is 14.

emphasize that the value of a statistical life is not a single number relevant for all situations. Indeed, the VSL estimate of $5.9 million (1997 dollars) is itself the central tendency of a number of estimates of the VSL for some rather narrowly defined populations. When there are significant differences between the population affected by a particular health risk and the populations used in the labor market studies - as is the case here - they prefer to adjust the VSL estimate to reflect those differences. While acknowledging that the VSLY approach provides an admittedly crude adjustment (for age though not for other possible differences between the populations), they point out that it has the advantage of yielding an estimate that is not presumptively biased. Proponents of adjusting for age differences using the VSLY approach fully concur that enormous uncertainty remains on both sides of this estimate - upwards as well as downwards - and that the populations differ in ways other than age (and therefore life expectancy). But rather than waiting for all relevant questions to be answered, they prefer a process of refining estimates by incorporating new information and evidence as it becomes available.

The results indicate that using EPAs preferred approach to valuing reductions in premature mortality, total monetary benefits realized after nearly a full turnover of the fleet to Tier 2 vehicles would be approximately $25.2 billion in 2030. Using the alternative, age-adjusted approach to value reductions in premature mortality yields total monetized benefits of $13.9 billion in 2030. Comparing this estimate of the economic benefits with the adjusted cost estimate indicates that the net economic benefit of the tier 2/gasoline sulfur standards to society are approximately $20 billion in 2030. Using the alternative, age-adjusted approach to valuing premature mortality, net benefits are approximately $8.5 billion. Due to the uncertainties associated with this estimate of net benefits, it should be considered along with other components of this RIA, such as: total cost, cost-effectiveness, and other considerations of benefits and costs that could not be monetized.

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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

GPA	Geographic Phase-in Area
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
MDPV	medium-duty passenger 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

We prepared this Regulatory Impact Analysis (RIA) for our final rule on Tier 2 Motor Vehicle Emissions Standards and Gasoline Sulfur Control Requirements. The purpose of this RIA is to present our 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.

This chapter summarizes the events that lead to today's action as well as the provisions incorporated within it. 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 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 rule, including the impact of the 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 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 vehicle and fuel 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 standards to the expected costs.

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

A. Background Information for Today's Final Rule

Through the Clean Air Act, Congress directed EPA 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. On July 31, 1998, we submitted our *Tier 2 Report to Congress*, a formal report which contained the results of our draft Tier 2 Study.[1] In our study, we examined the appropriateness of requiring more stringent emission standards for new passenger cars and light-duty trucks.

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. We also found ample evidence that technologies would be available to meet more stringent Tier 2 standards. The Tier 2 Study also 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.

In addition, on May 1, 1998, we released our *Staff Paper on Gasoline Sulfur Issues* which presented our 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. 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, we stated in a Notice of Proposed Rulemaking (May 13, 1999, 64 FR 26004) that new, more stringent emission standards are indeed needed, technologically feasible, and cost effective. In June, 1999, we held four public hearings to obtain feedback on our proposal.

B. Overview of the Final Rule

Today's final rule, described below, incorporates changes to the proposed program based upon updated analyses as well as comments heard at the public hearings and those submitted in

[1] On April 28, 1998, We 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 we received.

writing.

1. Vehicle Emission Standards

Today's action sets new federal emission standards ("Tier 2 standards") for passenger cars, light trucks, and larger passenger vehicles. The program is designed to focus on reducing the emissions most responsible for the ozone and particulate matter (PM) impact from these vehicles -- nitrogen oxides (NOx) and non-methane organic gases (NMOG), consisting primarily of hydrocarbons (HC) and contributing to ambient volatile organic compounds (VOC). The program will also, for the first time, apply the same set of federal standards to all passenger cars, light trucks, and medium-duty passenger vehicles. Light trucks include "light light-duty trucks" (or LLDTs), rated at less than 6000 pounds gross vehicle weight and "heavy light-duty trucks" (or HLDTs), rated at more than 6000 pounds gross vehicle weight).[2] "Medium-duty passenger vehicles" (or MDPVs) form a new class of vehicles introduced by this rule that includes SUVs and passenger vans rated at between 8,500 and 10,000 GVWR. The program thus ensures that essentially all vehicles designed for passenger use in the future will be very clean vehicles.

The Tier 2 standards finalized today will 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 will phase in beginning in 2004, with the standards to be fully phased in by 2007.[3] For heavy LDTs and MDPVs, the Tier 2 standards will 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 the primary Tier 2 standards will have to meet an interim average standard of 0.30 g/mi NOx, equivalent to the current NLEV standards for LDVs.[4] During the period 2004-2008, heavy LDTs and MDPVs not certified to the final Tier 2 standards will phase in to an interim program with an average standard of 0.20 g/mi NOx, with those not covered by the phase-in meeting a per-vehicle standard (i.e., an emissions "cap") of 0.60 g/mi NOx (for HLDTs) and 0.09 g/mi NOx (for MDPVs). The average standards for NOx will allow manufacturers to comply with the very stringent new standards in a flexible way, assuring that the average emissions of a

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[2] A vehicle's "Gross Vehicle Weight Rating," or GVWR, is the curb weight of the vehicle plus its maximum recommended load of passengers and cargo.

[3] 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 (larger light trucks are not covered). For further comparison, the standards met by today's Tier 1 vehicles range from 0.60 g/mi to 1.53 g/mi.

[4] 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. of this preamble.

company's production meet the target emission levels while allowing the manufacturer to choose from several more- and less-stringent emission categories for certification.

We are also setting stringent particulate matter standards that will be especially important if there is substantial future growth in the sales of diesel vehicles. With higher sales of diesel cars and light trucks, these vehicles could easily contribute between one-half and two percent of the PM10 concentration allowed by the NAAQS, with some possibility that the contribution could be as high as five to 40 percent in some roadside situations with heavy traffic. These increases would make attainment even more difficult for eight counties which we already predict to need further emission reductions even without an increase in diesel sales, and would put at risk another 18 counties which are now within 10 percent of a NAAQS violation. Thus, by including a more stringent PM standard in the program finalized today, we help address environmental concerns about the potential growth in the numbers of light-duty diesels on the road -- even if that growth is substantial. The new requirements also include more stringent hydrocarbon controls (exhaust NMOG and evaporative emissions standards).

2. Gasoline Sulfur Standards

The other major part of today's action will significantly reduce average gasoline sulfur levels nationwide. We expect these reductions could begin to phase in as early as 2000, with full compliance for most refiners occurring by 2006. Refiners will generally install advanced refining equipment to remove sulfur during the production of gasoline. Importers of gasoline will be required to import and market only gasoline meeting the sulfur limits. Temporary, less stringent standards will apply to refineries who produce fuel for use in the Geographic Phase-in Area[5] through 2006 and a few small refiners through 2007.

This significant new control of gasoline sulfur content will have two important effects. The lower sulfur levels will enable the much-improved emission control technology necessary to meet the stringent vehicle standards of today's rule to operate effectively over the useful life of the new vehicles. In addition, as soon as the lower sulfur gasoline is available, all gasoline vehicles already on the road will have reduced emissions -- from less degradation of their catalytic converters and from fewer sulfur compounds in the exhaust.

Today's action will require that most refiners and importers meet a corporate average gasoline sulfur standard of 120 ppm and a cap of 300 ppm beginning in 2004. By 2006, the cap will be reduced to 80 ppm and most refineries must produce gasoline averaging no more than 30 ppm sulfur. The program builds upon the existing regulations covering gasoline composition 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. We intend for the

[5]Alaska, Colorado, Idaho, Montana, New Mexico, North Dakota, Utah, and Wyoming

credit program to ease compliance uncertainties by providing refiners the flexibility to phase in early controls in 2000-2003 and use credits gained in these years to delay some control until as late as 2006. As finalized today, the program will achieve the needed environmental benefits while providing substantial flexibility to refiners.

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. Health and Welfare Effects of 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.[1] 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 precursors to 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.

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

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 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.

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, chronic bronchitis and chronic asthma.

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 from 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.

Evidence also exists of a possible relationship between daily increases in ozone levels and increases in daily mortality levels. While the magnitude of this relationship is still too uncertain to allow for direct quantification, the full body of evidence indicates a likely positive

relationship between ozone exposure and premature mortality.

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.[34] These problems are caused in part by emissions of nitrogen oxides 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.[5] 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 the value placed on scenic views.

Section II.D. further describes information about visibility impairment and regional haze.

B. Health and Welfare Effects of 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.[2] 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.

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

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

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.

Scientific studies have linked particulate matter (alone or in combination with other air pollutants) with a series of health effects.[6] 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 reduction 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.[3] 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 9 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.

[3]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.[7]

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 1999, EPA promulgated a program to address regional haze in the nation's most treasured national parks and wilderness areas (see 64 FR 35714, July 1, 1999).

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.[8] 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.[9] The Commission identifies mobile source pollutants of concern as VOC, NO_X, and elemental and organic carbon.

Chapter II References

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

3. U.S. EPA, 1995, Review of National Ambient Air Quality Standards for Nitrogen Dioxide, Assessment of Scientific and Technical Information, OAQPS Staff Paper, EPA-452/R-95-005

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

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

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

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

9. "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 action will 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 action will 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 for LDVs and LDTs under 6000 pounds and Tier 1 for LDTs above 6000 pounds on in-use fuel as currently specified; sulfur levels for Conventional Gasoline are estimated at 330 ppm[1], summertime Phase 2 RFG levels are estimated at 150 ppm (i.e., baseline case). "With Tier 2/Sulfur" refers to implementation of 120 ppm sulfur nationwide in 2004, 90 ppm in 2005 and 30 ppm in 2006 in conjunction with the phase-in of NOx, VOC, and PM vehicles standards finalized under today's action (i.e., control case).[2]

For the proposal, separate emission inventories were used as the basis for the inventory projections, air quality analysis and cost-benefit analysis. The emission inventory estimates were based on updated estimates of on-highway mobile source emissions as planned for use in EPA's MOBILE6 model, using a spreadsheet program known as the Tier 2 Model. However, the air quality and cost-benefit analyses presented in the proposal were based on previous work which relied on both MOBILE5 and the Tier 2 model. This discrepancy has been reconciled for the final rule. Subsequent to the proposal, new emission inventories were generated for every county in the nation in 1996, 2007 and 2030. These inventories reflect the on-highway mobile source emission updates contained in the NPRM version of the Tier 2 Model, and were used as the basis

[1]For NOx and VOC, the modeling performed in support of our air quality and cost-benefit analyses was based on a sulfur baseline of 330 ppm for conventional gasoline. This estimate has since been updated to 300 ppm, reflecting recent in-use fuel data and our expectation that refiners will shift sulfur to summertime conventional gasoline in order to meet the Phase 2 RFG NOx performance specification. This change has been incorporated into our updated Tier 2 Model, as detailed in a memorandum from John Koupal to Docket A-97-10 entitled "Development of Light-Duty Emission Inventory Estimates in the Final Rulemaking for Tier 2 and Sulfur Standards". Our PM and SOx estimates are based on PART5, which uses a sulfur level of 339 ppm for conventional gasoline.

[2]These sulfur levels would occur under our Sulfur Averaging, Banking and Trading (ABT) program, for which reduced sulfur levels could occur as early as 2000. We did not include sulfur reductions prior to 2004 in our air quality analysis inventory estimates, but early sulfur reductions were accounted for in our updated Tier 2 Model.

for the inventory projections, air quality analysis and cost-benefit analysis (an updated version of the Tier 2 Model, which incorporates data and comments received subsequent to the proposal, is discussed below). Specifically, the modeling 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 modeling 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. The final rule modeling also incorporates planned changes in emission rates for heavy-duty gasoline and diesel vehicles, as well as the effects of heavy-duty NOx defeat device.

The inventories generated from this round of modeling are presented as our "official" inventory estimates in this chapter; since they formed the basis of our final rule air quality analysis this work is referred to as the "air quality analysis" modeling, to distinguish from subsequent inventory modeling performed using updated inputs. These estimates of on-highway emissions were generated in several steps: First, MOBILE5 and PART5 where run for every county in the country. Next, multiplicative adjustment factors were applied to the output of MOBILE5 to account for changes planned for MOBILE6 for light-duty and heavy-duty vehicles; for 2007 and 2030, multiplicative adjustment factors were also developed which incorporated the benefits of the Tier 2/Sulfur program, for all pollutants. Finally, excess NOx emissions due to air conditioning usage were applied as a function of ambient temperature.[1] This approach enabled a significant improvement over what was done in the proposal, in that the final rule inventories are estimated on a county-by-county basis using locally-specific modeling inputs and assumptions where available, "corrected" (for NOx and VOC) to our best estimate of MOBILE6 (at the time of the proposal) with and without Tier 2/Sulfur control. Thus the 47-state numbers presented here are not based just on national default inputs as was done for the proposal, but instead are based on the sum of the inventories for every county in the 47 states, including local average temperatures, fleet characteristics, I/M programs, fuel properties, and roadway type/speed distributions. Likewise, the city-specific inventories presented here, which are based on the same county-specific inventories, are substantially more accurate than the ones presented in the proposal, which are based on national default modeling input.

In the proposal, we used a combination of methods to project future highway vehicle miles traveled (VMT). The proposal approach used the 1997 National Emissions Trends (NET) Report VMT up to 2010, a compounded growth rate of 2.1 percent from 2010 to 2015 and a simple linear growth rate of 2.1 percent after 2015. For the final rule, we have chosen to project future growth using a linear extrapolation of the NET projections. This is a simpler, more consistent approach, which results in lower estimates of future VMT (a simple linear growth rate of 1.7 percent from 2007 to 2030). Total light-duty VMT estimates were split into light-duty vehicle (LDV), light-duty trucks below 6,000 pounds (LDT1/2) and light-duty trucks above 6,000 pounds (LDT3/4) using the methodology developed for the proposal,[2] accounting for the recent growth trends in LDT sales.

For the final rule, we have also updated the emission inventories for stationary, area, and nonroad sources. The development of inventories for all sources are provided in a separate document available in the Tier 2 docket.[3]

This section focuses on projections of the emissions inventory with and without today's action for the United States excluding California, Alaska, and Hawaii,[3] derived from the final rule air quality analysis. Estimates from the final rule air quality analysis were also used to generate the relative contribution of light-duty vehicles and trucks to the total NOx and VOC inventories nationwide, as well as four urban areas: New York, Chicago, Atlanta and Charlotte. Comprehensive inventories (47-state and four city) are presented in Appendix A with and without Tier 2/sulfur control for 1996, 2007 and 2030, the three years for which the inventories were generated. For VOC and NOx, the nationwide inventories are presented as "annualized summer tons," meaning that inventory results for a typical July day were multiplied by 365 days. The purpose of this is solely to present a consistent comparison of emission trends and reductions based on summer conditions; the actual air quality and cost-benefit analyses relied on the seasonal inventories generated in the air quality analysis.[4] Nationwide SOx and PM results presented in this section are true annual estimates.

For purposes of the analysis presented in this section, we also needed to estimate inventories in other years between 2007 and 2030. Estimates for light-duty vehicles and trucks in these intermediate years were derived from the NPRM version of the Tier 2 Model, adjusted to reflect differences in this model and the air quality analysis results.[4] To estimate stationary and area source inventories in other years, we did a simple linear interpolation of the 2007 and 2030 estimates. For nonroad and on-highway inventories, we know that the emissions inventory is non-linear between those years due to fleet turnover. To estimate intervening years, we first calculated the ratio of the air quality analysis nonroad and on-highway inventories in 2007 and 2030 to the inventories generated for the proposal for these sectors for those same years. Then we interpolated between the 2007 and 2030 ratios to estimate the ratio that we would expect in intervening years. We then multiplied those interpolated ratios by the NPRM inventories for those years. The result is an estimate of what the inventories would have been if we had done

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[3]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.

[4] In 2007, the 47-state annual VOC emissions reductions from the Tier 2/Sulfur program are approximately 13% larger than the annualized summer VOC emissions reductions (the smaller evaporative VOC emissions reductions in non-summer conditions are more than offset by higher exhaust VOC emissions reductions during colder weather), while the annual 47-state NOx emissions reductions are 6-7% smaller than the annualized NOx emissions reductions.

complete county-by-county inventories for them.

As mentioned, for the final rule air quality analysis the modeling assumptions and inputs for light-duty vehicles and trucks were identical to those included in the NPRM version of the Tier 2 Model. Subsequent to the air quality analysis modeling, our Tier 2 Model was updated to reflect several new inputs stemming from a) our response to Tier 2 comments, b) new sulfur sensitivity data and c) alignment with methodologies planned for use in MOBILE6, as well as changes to the sulfur control program.[5] Results from the updated Tier 2 Model are presented side-by-side with the air quality analysis inventory modeling results for VOC and NOx. The major updates to the model are summarized below:

1) Tier 1 and later NOx emission rates were updated to reflect a significantly larger sample of vehicles certified to the 0.4 gram/mile NOx standard, in response to comments.
2) Sulfur effects for LDV and LDT LEVs were increased significantly, in response to new data showing that the effect of sulfur on emissions is much larger when a vehicle operates on high sulfur fuel for a few thousand miles.
3) The model incorporates the effects of sulfur irreversibility, which results when vehicles sustain permanent catalyst degradation from exposure to sulfur levels higher than what they typically operate on. Inventory estimates are presented for irreversibility levels consistent with those discussed in Appendix B.
4) The model incorporated the effects of representative in-use activity data planned for use in MOBILE6, including vehicle speed, roadway type, and trip activity.
5) The Tier 2/Sulfur control case reflects the sulfur program contained in today's action, as well as the effects of Averaging, Banking and Trading (ABT), interim provisions for small refiners, and the geographic phase-in of low sulfur fuel.

With these updates, the Tier 2 Model now includes many of the key exhaust elements planned for MOBILE6, and is the most up-to-date tool available for assessing trends in nationwide light-duty exhaust emissions and the emission reductions gained from the Tier 2/Sulfur program. Overall, the updated model indicates that NOx and exhaust VOC emissions without Tier 2/Sulfur control will be substantially higher than originally projected either in the proposal or by the air quality analysis modeling, particularly for NOx. Although the inventory estimates, air quality results and economic benefits assessment presented in this document show conclusively the need for and benefit of today's action, we believe based on the updated Tier 2 Model that the estimates of emissions reductions underlying these analyses are in fact very conservative.

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.A-1 and Figure III.A-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 mentioned, the air quality analysis inventory results are based on annualized summer day results in 2007 and 2030, with intermediate years developed based on the NPRM version of the Tier 2 Model. As shown, the estimates derived from the air quality analysis modeling show total light-duty emissions declining from approximately 3.6 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 3.7 million tons by 2030, such that the gains from the Tier 1, NLEV and SFTP control programs are more than offset by VMT growth.

The estimates derived from the updated Tier 2 Model suggest a much more dire situation. While the updated modeling estimates are similar to the air quality analysis estimates in 2000, emissions are projected to rise steadily from this point; by 2030, emission are projected to increase 50 percent from the 2000 levels.

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

Year	*Light-Duty Emissions: Air Quality Analysis Modeling*	*Contribution by Vehicle Class*			*Light-Duty Emissions: Updated Tier 2 Model*
		LDV	*LDT1/2*	*LDT3/4*	
2000	3,591,547	52.1%	30.0%	17.9%	3,548,883
2004	3,362,528	43.5%	37.1%	19.4%	3,612,395
2007	3,095,698	37.3%	41.0%	21.7%	3,681,990
2010	2,962,093	33.0%	42.7%	24.3%	3,817,070
2015	2,968,707	28.6%	44.3%	27.1%	4,116,074
2020	3,160,155	26.9%	45.2%	27.8%	4,502,761
2030	3,704,747	27.1%	45.5%	27.4%	5,323,860

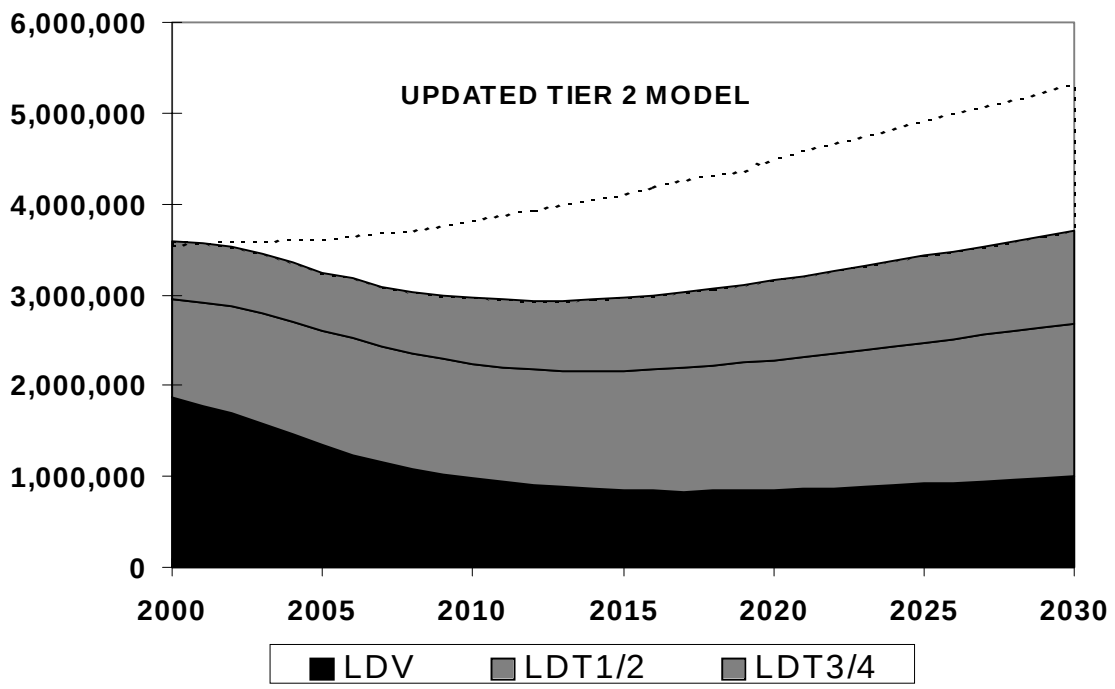

Figure III.A-1. 47-State Light-Duty NOx Emissions Without Tier 2/Sulfur (Annualized Summer Tons)

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 nearly 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.A-1, the decrease in overall light-duty emission levels estimated in the air quality analysis modeling 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 updated Tier 2 Model shows that emission gains from these control programs are completely offset by high sulfur sensitivity for LEVs, VMT growth and the increased penetration of light-duty trucks.

Figures III.A-2 and III.A-3 show our projections of the contribution of light-duty vehicles and trucks to the total NOx inventory (i.e., NOx emissions from all sources, including stationary, area, nonroad) in the 47 states and in Atlanta based on the air quality analysis modeling for a typical ozone season day. Table III.A-2 shows this same contribution across all four cities from 2007 through 2030 based on the air quality analysis modeling, and for the 47 states based on the air quality analysis modeling and the updated Tier 2 Model. Across the 47 states, the air quality analysis modeling estimates that cars and trucks produce 16 percent of total emissions in 2007, growing to nearly one-fifth of total NOx emissions by 2030. The updated modeling projects a light-duty contribution of 19 percent in 2007, growing to one-quarter by 2030. In all cases, the relative contribution of cars and trucks to total NOx emissions is projected to grow steadily.

Light-duty NOx contribution in urban areas is generally higher than in 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. Atlanta provides the most striking example of this; the air quality analysis modeling projects that 34 percent of all NOx emissions will be produced by cars and trucks in 2007, growing to 41 percent by 2030. [5] The light-duty contribution in New York and Charlotte

[5]The air quality analysis modeling reflects a baseline sulfur level of 330 ppm for Atlanta, our estimate of national average conventional gasoline at the time of the proposal. Atlanta has recently implemented a summertime lower sulfur fuel program requiring 150 ppm fuel in 1999 and 30 ppm fuel in 2003; Georgia has submitted a SIP revision including this program and requested EPA's approval of a waiver of federal preemption and the SIP revision. Approval of the waiver and SIP revision is still pending.

are higher than the national estimates, while the contribution in Chicago is slightly less than the 47-state estimate. Based on the national results, our updates to the modeling would result in even larger contributions from cars and trucks in these cities, and in urban areas nationwide.

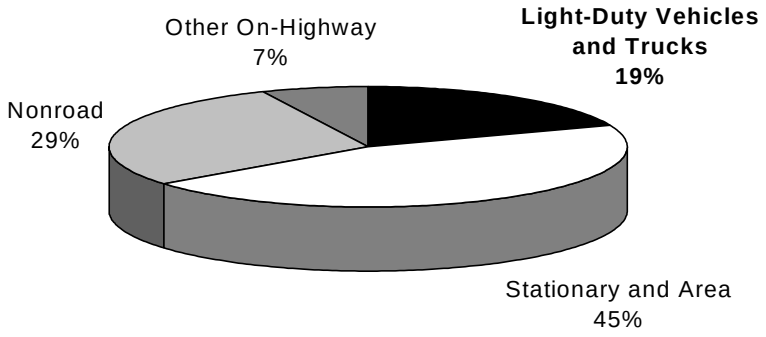

Figure III.A-2. Breakdown of Total 2030 47 State NOx Inventory Without Tier 2

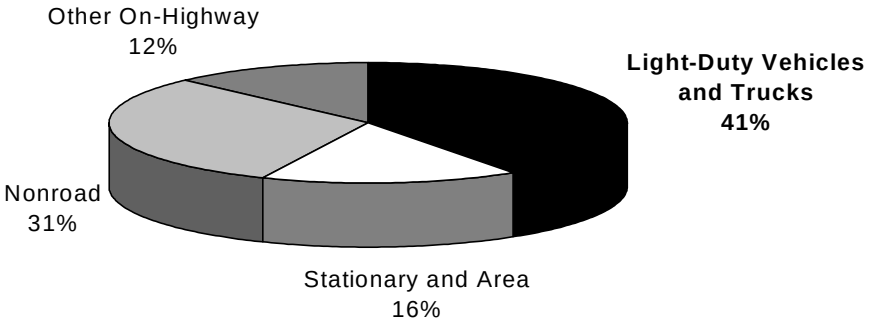

Figure III.A-3. Breakdown of Total 2030 Atlanta NOx Inventory Without Tier 2

Table III.A-2. Light-Duty Contribution to Total NOx Inventory Without Tier 2/Sulfur (Typical Ozone Season Day)

Year	*Air Quality Analysis Modeling*					*Updated Model*
	47-State	*New York*	*Chicago*	*Atlanta*	*Charlotte*	*47-State*
2007	16%	18%	14%	34%	24%	19%
2010	16%	-	-	-	-	20%
2015	17%	-	-	-	-	22%
2020	17%	-	-	-	-	23%
2030	19%	22%	16%	41%	27%	25%

b. NOx Reductions Due To Tier 2/Sulfur

Today's action will provide substantial reductions in NOx emissions from cars and trucks. The implementation of low sulfur fuel will 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 2028 the projected upward trend in light-duty NOx emissions that would occur with no control. Table III.A-3 contains annual tons of NOx we project will be reduced by today's action, encompassing benefits of low sulfur fuel and the introduction of Tier 2 light-duty vehicle and light-duty truck standards. Figure III.A-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.A-3. 47-State Light-Duty NOx Reductions Due To Tier 2/Sulfur (Annualized Summer Tons)

Year	*Air Quality Analysis Modeling*			*Updated Tier 2 Model*		
	Emissions Reduced	*Percent Reduction in Baseline Inventory*		*Emissions Reduced*	*Percent Reduction in Baseline Inventory*	
		Light-Duty	*All Sources**		*Light-Duty*	*All Sources**
2004	338,231	10%	-	326,556	9%	-
2007	856,471	28%	5%	956,512	26%	5%
2010	1,235,882	42%	7%	1,554,442	41%	8%
2015	1,816,767	61%	10%	2,527,309	61%	13%
2020	2,220,210	70%	12%	3,205,571	71%	16%
2030	2,795,551	75%	15%	4,049,687	76%	20%

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

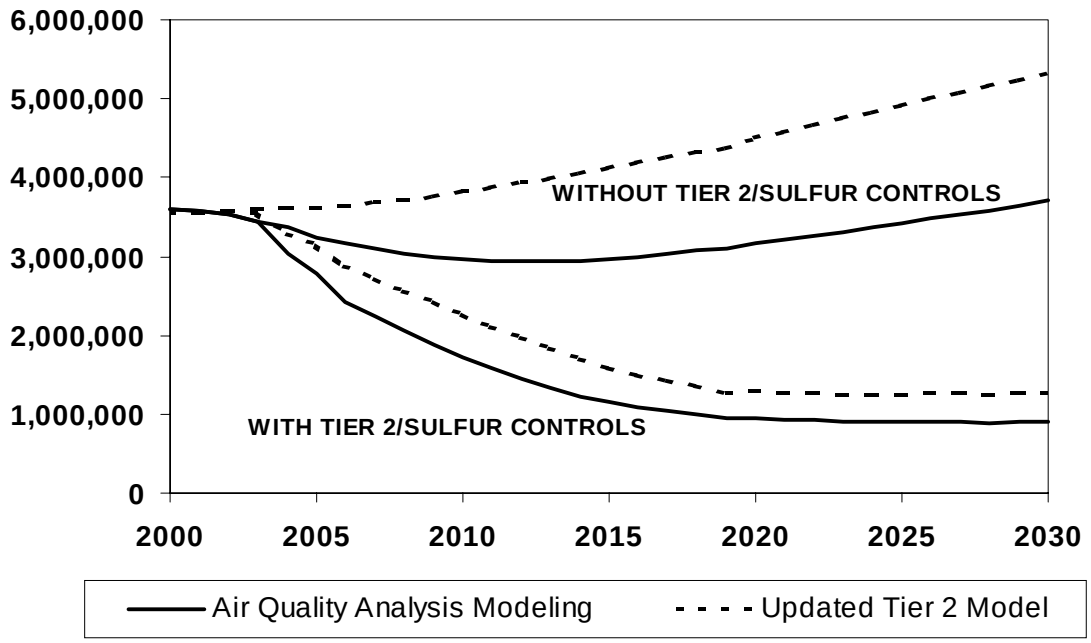

Figure III.A-4. 47-State Light-Duty NOx Emissions With Tier 2/Sulfur (Annualized Summer Tons)

The projected reductions in 2004 are based on 120 ppm sulfur fuel, reflecting our final Tier 2 sulfur program. Our modeling shows an immediate benefit of over 300,000 tons in 2004, a 10 percent drop in uncontrolled light-duty emissions; this is the equivalent of emissions produced by 19 million pre-Tier 2 cars and trucks.[8,6] In the early years of sulfur control, nearly all of the benefits would be due to reduced emissions from Tier 0, Tier 1 and NLEV vehicles. Although not shown, emission reductions due to sulfur control could be realized as early as 2000 under the sulfur ABT program.

After 2004, emissions 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 70 percent reduction in 2020 light-duty emissions without Tier 2/Sulfur, equivalent to the emissions from nearly 164 million pre-Tier 2 cars and trucks. Total U.S. NOx emissions from all human sources would be reduced by 12 to 16 percent.

We project that light-duty emissions will 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 will consist of Tier 2 vehicles. The benefit of 2.8 million tons projected by the air quality analysis modeling represents a three-quarters reduction in 2030 light-duty emissions without Tier 2/Sulfur, equivalent to the emissions from over 200 million pre-Tier 2 cars and trucks. These emission reductions are projected to be 15 percent of total NOx emissions in that year in the absence of today's action. The benefits projected by the updated modeling are even more substantial: emission reductions of over four million tons are projected, representing a 76 percent reduction of baseline light-duty emissions and a one-fifth reduction in NOx from all sources.

The estimated percentage reductions in total inventory presented in Table III.A-3 include benefits that will be realized from 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 when 30 ppm fuel is in place. In addition, reductions from "Medium Duty Passenger Vehicles" (e.g. passenger vehicles above 8500 pounds included as part of Tier 2 vehicle program) are estimated to be approximately 37,000 tons in 2030.

Concurrently, we project that the light-duty contribution to total NOx emissions will drop significantly. Figures III.A-5 and III.A-6 show our 2030 projections of this contribution in the 47 states and in Atlanta with Tier 2/Sulfur control. Table III.A-4 shows this same contribution across the 47 states from 2007 through 2030, and in the four cities in 2007 and 2030. In 2030, the air quality analysis modeling projects that the light-duty contribution will drop to five percent

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

nationally, from 19 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. Based on the air quality analysis modeling we project that with Tier 2/Sulfur control, car and truck emissions would contribute six percent of total emissions in New York (down from 22 percent), four percent in Chicago (down from 16 percent), six percent in Charlotte (down from 27 percent), and 11 percent in Atlanta (down from 41 percent) in 2030.

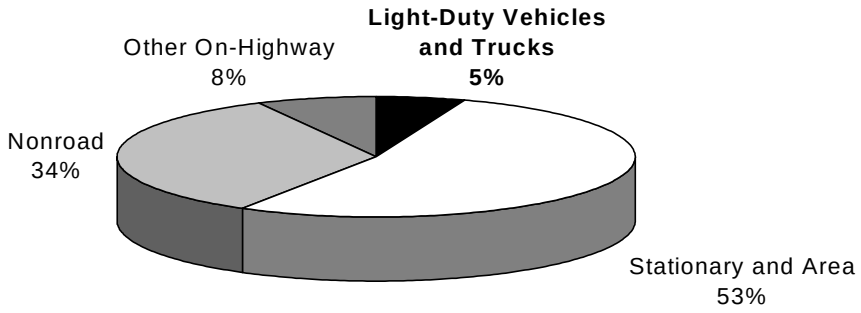

Figure III.A-5. Breakdown of Total 2030 47-State NOx Inventory With Tier 2/Sulfur

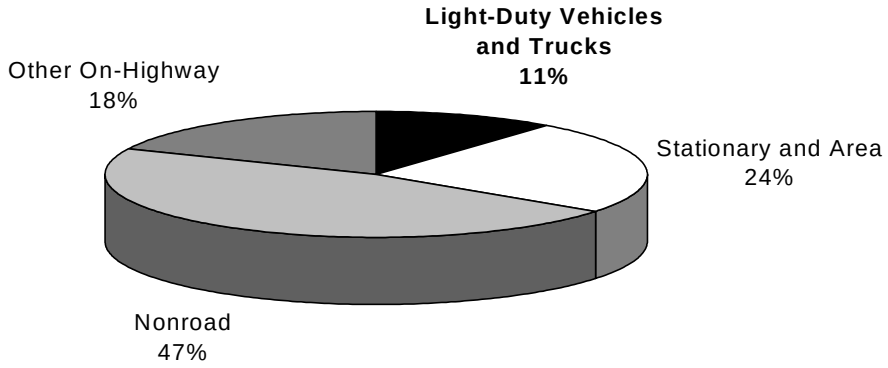

Figure III.A-6. Breakdown of Total 2030 Atlanta NOx Inventory With Tier 2/Sulfur

Table III.A-4. Light-Duty Contribution to Total NOx Inventory With Tier 2/Sulfur (Typical Ozone Season Day)

Year	*Air Quality Analysis Modeling*					*Updated Model*
	47-State	*New York*	*Chicago*	*Atlanta*	*Charlotte*	*47-State*
2007	12%	15%	11%	26%	18%	14%
2010	10%	-	-	-	-	13%
2015	7%	-	-	-	-	10%
2020	6%	-	-	-	-	8%
2030	5%	6%	4%	11%	6%	8%

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.A-5 and Figure III.A-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 2.8 million tons to 1.7 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 1.8 million tons by 2020 and 2.1 million tons by 2030. As shown in Figure III.A-7, our updated modeling projects much higher emissions, and an upturn in total light-duty VOC beginning in 2015.

Table III.A-5. 47-State Light-Duty VOC Emissions Without Tier 2/Sulfur (Annualized Summer Tons)

Year	*Light-Duty Emissions: Air Quality Analysis Modeling*	*Contribution by Emission Source / Vehicle Class*				*Light-Duty Emissions: Updated Tier 2 Model*
		Evaporative (All LDV/LDT)	*Exhaust*			
			LDV	*LDT1/2*	*LDT3/4*	
2000	2,751,002	48%	23%	15%	14%	3,202,293
2004	2,323,874	50%	19%	18%	13%	2,794,249
2007	2,026,945	53%	16%	17%	13%	2,544,842
2010	1,828,506	55%	14%	17%	14%	2,356,512
2015	1,733,981	57%	11%	17%	16%	2,291,030
2020	1,788,057	57%	10%	18%	16%	2,389,757
2030	2,108,765	57%	9%	18%	15%	2,845,573

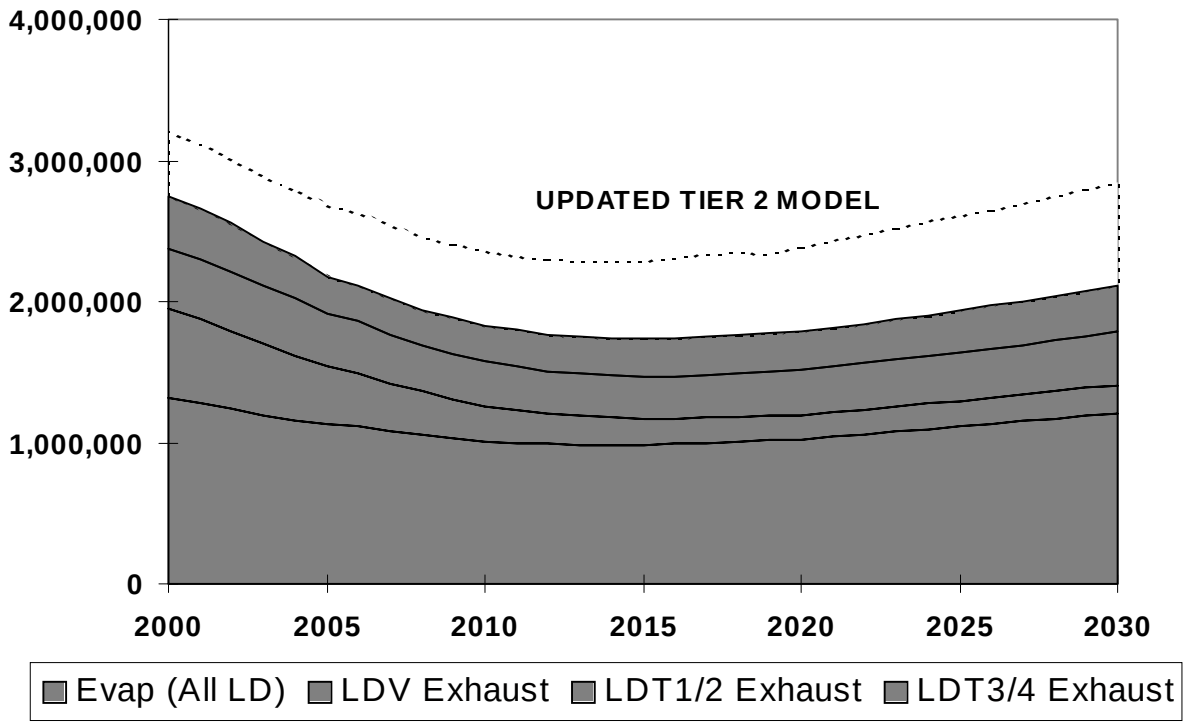

Figure III.A-7. 47-State Light-Duty VOC Emissions Without Tier 2/Sulfur (Annualized Summer Tons)

Evaporative emissions are projected to be about 50 percent of the light-duty inventory in 2000, with this percent contribution rising steadily through 2030. Exhaust emissions from trucks also play an increasingly significant role in shaping the overall VOC trend. In 2000, we project that trucks will produce approximately 56 percent of exhaust VOC emissions; by 2015, trucks account for 75 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.

Figures III.A-8 and III.A-9 show our projections of the contribution of light-duty vehicles and trucks to the total anthropogenic (i.e., human-caused) 2030 VOC inventory in the 47 states and in Atlanta (on an annualized summer basis) that were used in the air quality and economic benefits analysis. Table III.A-6 shows this same contribution across the 47 states and all four cities from 2007 through 2030. Nationally, cars and trucks produce 13 percent of total VOC emissions in 2007; this percentage declines in subsequent years before stabilizing at 11 percent by 2015. Relative to the national average, the light-duty contributions are lower in New York and Chicago and higher in Atlanta and Charlotte. For the latter two cities, we project that cars and trucks will contribute 17 and 15 percent of all VOC emissions in 2007.

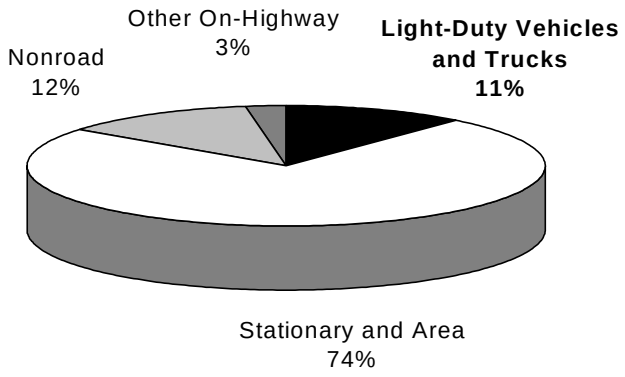

Figure III.A-8. Breakdown of Total 2030 47-State VOC Inventory Without Tier 2/Sulfur

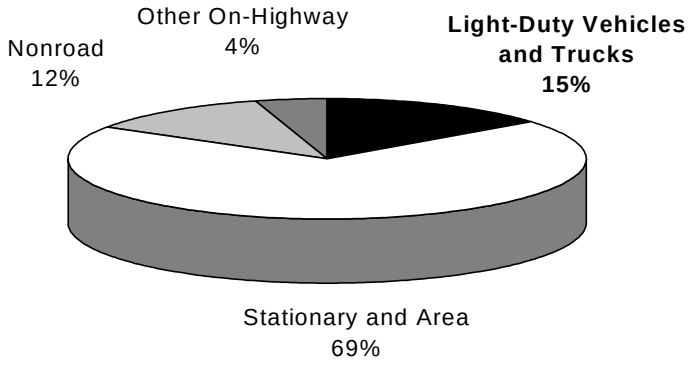

Figure III.A-9. Breakdown of Total 2030 Atlanta VOC Inventory Without Tier 2/Sulfur

Table III.A-6. Light-Duty Contribution to Total VOC Inventory Without Tier 2/Sulfur (Typical Ozone Season Day)

Year	*Air Quality Analysis Modeling*					*Updated Modeling*
	47 State	*New York*	*Chicago*	*Atlanta*	*Charlotte*	*47 State*
2007	13%	6%	6%	17%	15%	15%
2010	12%	-	-	-	-	14%
2015	11%	-	-	-	-	14%
2020	11%	-	-	-	-	14%
2030	11%	6%	5%	15%	12%	15%

b. VOC Reductions Due To Tier 2/Sulfur

Table III.A-7 contains annual nationwide tons of VOC we project will be reduced due to today's action, 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.A-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.A-7. 47-State Light-Duty VOC Reductions Due to Tier 2/Sulfur (Annualized Summer Tons)

Year	*Air Quality Analysis Modeling*			*Updated Tier 2 Model*		
	Emissions Reduced	*Percent Reduction in Baseline Inventory*		*Emissions Reduced*	*Percent Reduction in Baseline Inventory*	
		Light-Duty	*All Sources**		*Light-Duty*	*All Sources**
2004	85,688	4%	-	127,957	5%	-
2007	143,507	7%	0.9%	262,174	10%	1.6%
2010	178,886	10%	1.1%	349,126	15%	2.1%
2015	244,080	14%	1.5%	491,336	21%	2.9%
2020	305,470	17%	1.8%	615,239	26%	3.5%
2030	400,968	19%	2.2%	806,343	28%	4.2%

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

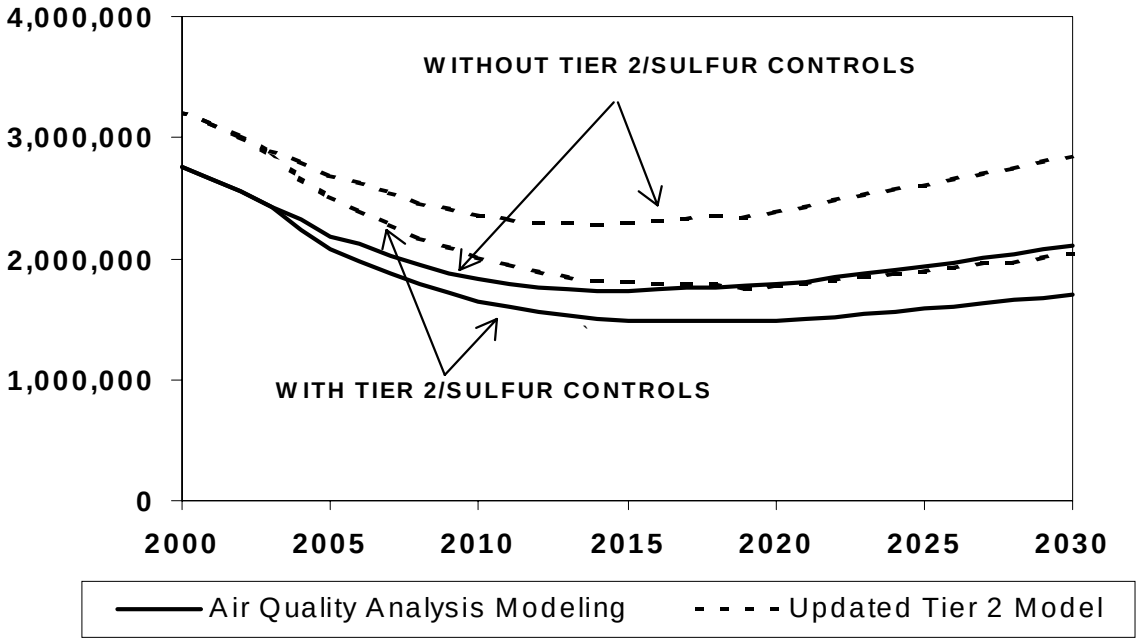

Figure III.A-10. 47-State Light-Duty VOC Emissions With Tier 2/Sulfur (Annualized Summer Tons)

Although not shown, emission reductions due to sulfur control could be realized as early as 2000 under the sulfur ABT program. In 2004, we project that the implementation of 120 ppm fuel will 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 seven million pre-Tier 2 cars and trucks. After 2004, further sulfur reductions and the introduction of LDT2s, LDT3s, and LDT4s complying with the Tier 2 NMOG standard and operating on low sulfur fuel reduce emission further. By 2030, the air quality analysis modeling projects that baseline light-duty VOC emissions are reduced 19 percent due to Tier 2/Sulfur control, the equivalent of emissions from 51 million pre-Tier 2 cars and trucks. This represents a 2.2 percent reduction of the total anthropogenic VOC inventory. Our more recent modeling suggests that reductions will in fact be significantly larger than the air quality analysis results; by 2030, light-duty VOC emissions are reduced nearly 30 percent, and total anthropogenic VOC emissions reduced 4.2 percent. Tier 2/Sulfur control is projected to delay the upturn in light-duty VOC emissions by five years.

It should be noted that both the air quality analysis modeling and updated Tier 2 Model assume a Tier 2 fleet average NMOG level of 0.09 grams/mile, which is the highest fleet average possible under the certification bin system. A more likely fleet average is in the range of 0.07 to

0.08 grams/mile; the actual VOC emission reductions realized from today's action will thus be even larger than presented here.

We project that heavy-duty gasoline vehicles would decrease emissions by approximately 4,500 tons per year in 2007 due to sulfur control; these reductions are included in the estimates of mobile source and all source percent reductions contained in Table III.A-7. In addition, reductions from "Medium Duty Passenger Vehicles" (e.g. passenger vehicles above 8500 pounds included as part of Tier 2 vehicle program) are estimated to be at least 9,500 tons in 2030.

Figures III.A-11 and III.A-12 show the contribution of light-duty cars and trucks to total 2030 VOC inventory in the 47 states and in Atlanta with Tier 2/Sulfur control. Table III.A-8 shows this same contribution across the 47 states in 2007, 2010, 2015 and 2030, and in the four cities in 2007 and 2030. By 2030, we project that the light-duty contribution will drop to 9 percent nationally, from 11 percent without Tier 2/Sulfur control. This trend will 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 will contribute four percent of total emissions in New York and Chicago in 2030 (down from six and five percent, respectively), eight percent in Charlotte (down from 12 percent), and 11 percent in Atlanta (down from 15 percent).

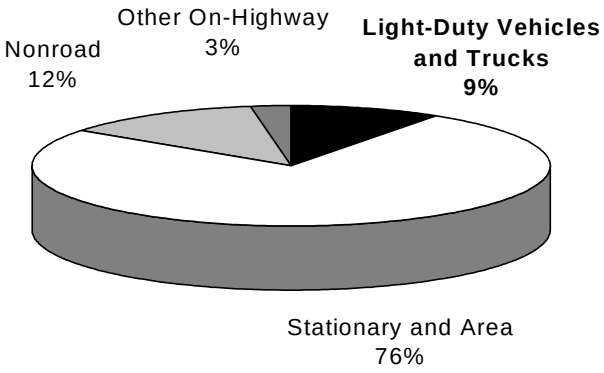

Figure III.A.-11. Breakdown of Total 2030 47-State VOC Inventory With Tier 2/Sulfur

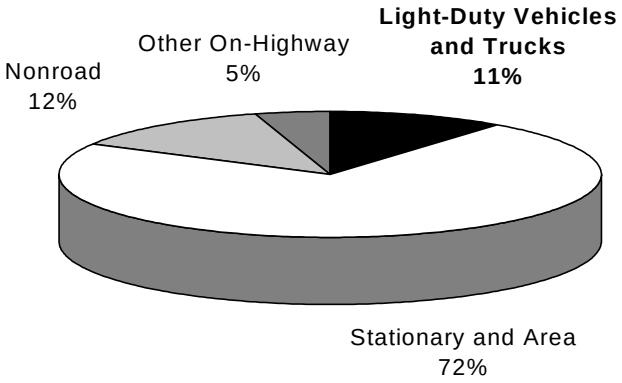

Figure III.A-12. Breakdown of Total 2030 Atlanta VOC Inventory With Tier 2/Sulfur

Table III.A-8. Light-Duty Contribution to Total VOC Inventory With Tier 2/Sulfur (Typical Ozone Season Day)

Year	*Air Quality Analysis Modeling*					*Updated Modeling*
	47 State	*New York*	*Chicago*	*Atlanta*	*Charlotte*	*47 State*
2007	12%	6%	5%	15%	14%	14%
2010	11%	-	-	-	-	13%
2015	9%	-	-	-	-	11%
2020	9%	-	-	-	-	11%
2030	9%	4%	4%	11%	8%	11%

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.A-9 and Figure III.A-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 196,000 tons of SOx; by 2030, this level is projected to be 314,000 tons, an increase of 60 percent. The absolute emission estimates presented in Table III.A.-9 are based on a 330 ppm average sulfur level for conventional gasoline; using our updated estimate for conventional gasoline of 300 ppm conventional gasoline, the values in this table would be reduced by approximately eight percent.

Table III.A-9. 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	-	196,334	-	49%	34%	16%
2004	-	206,258	-	42%	42%	16%
2007	18,052,276	216,626	1.2%	37%	47%	16%
2010	17,949,631	230,781	1.3%	33%	50%	17%
2015	17,792,528	253,109	1.4%	29%	53%	18%
2020	17,607,934	274,016	1.6%	27%	54%	18%
2030	17,242,341	313,998	1.8%	27%	55%	18%

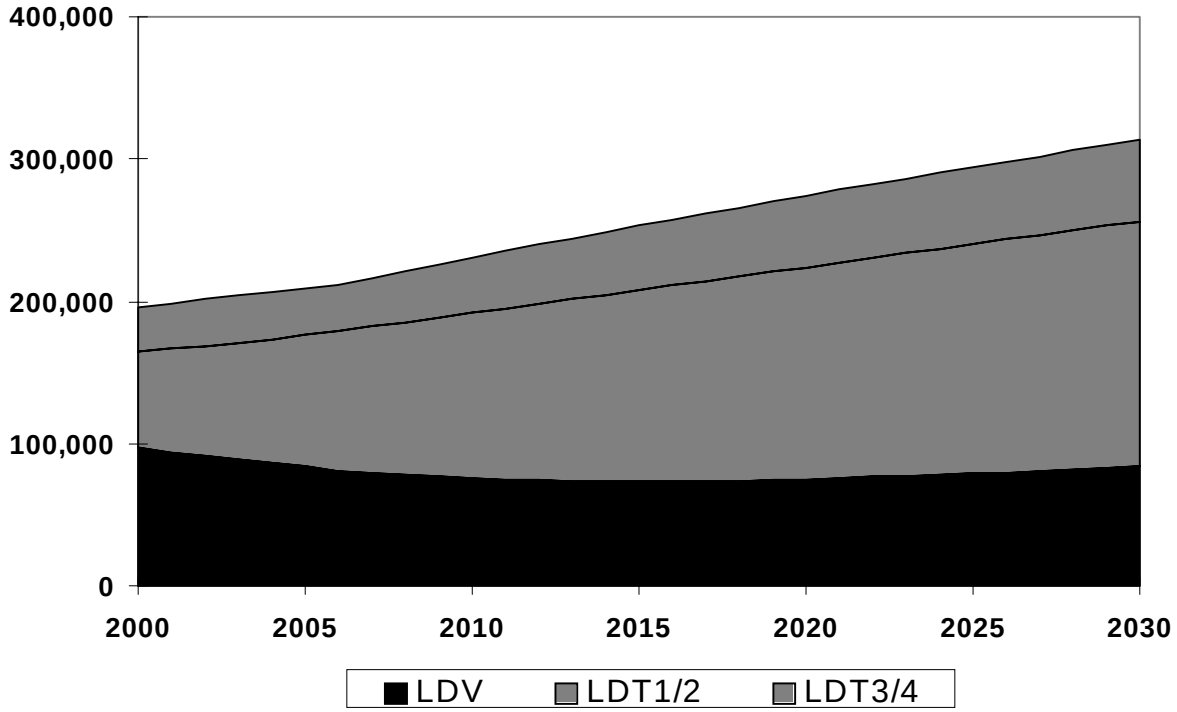

Figure III.A-13. 47-State Light-Duty SOx Emissions Without Sulfur Control (Annual Tons)

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 2015.

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.A-10 contains annual nationwide tons of gaseous SOx we project will be reduced from light-duty vehicles and trucks due to sulfur control. Figure III.A-14 shows SOx emissions after sulfur control, broken down by LDV, LDT1/2 and LDT3/4.

Table III.A-10. 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	206,258	82,408	123,850	60%	-
2007	216,626	22,847	193,779	89%	1.2%
2010	230,781	24,302	206,479	89%	1.4%
2015	253,109	26,652	226,457	89%	1.5%
2020	274,016	28,837	245,179	89%	1.6%
2030	313,998	32,982	281,016	89%	1.9%

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

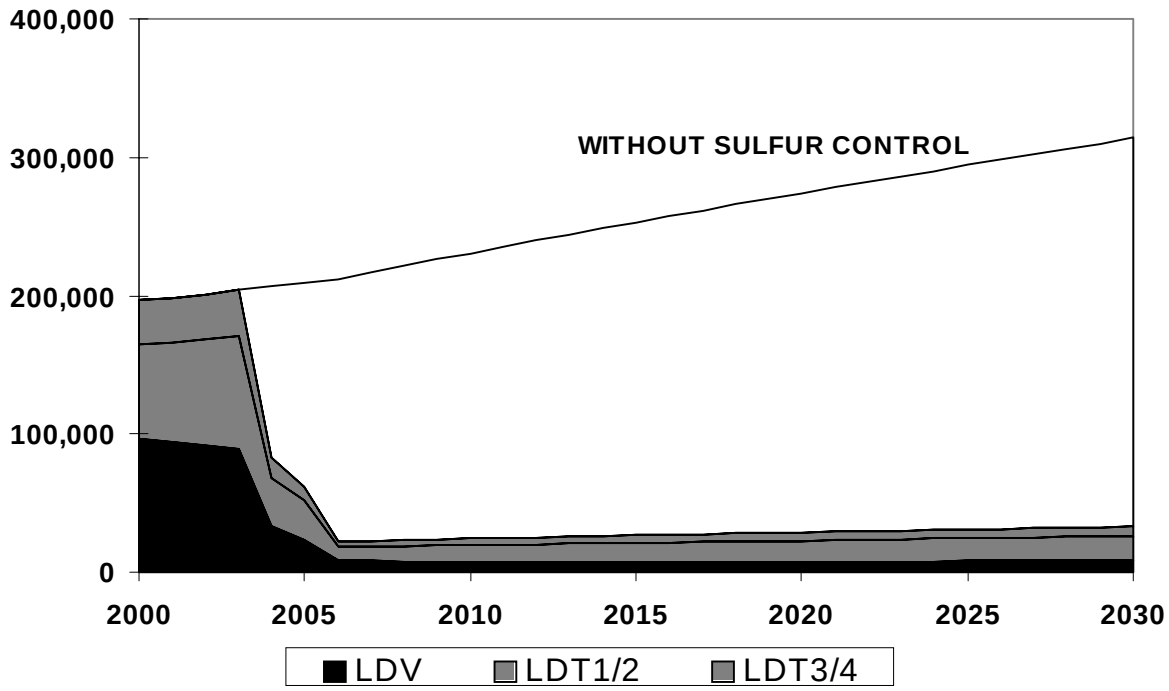

Figure III.A-14. 47-State Light-Duty SOx Emissions With Sulfur Control (Annual Tons)

As shown, a significant reduction in light-duty SOx emissions would be realized immediately with sulfur control. The reductions presented above presume 120 ppm in 2004 and 90 ppm in 2005 under the sulfur ABT program; reductions could be realized as early as 2000 under this program. We project that nearly 90 percent of light-duty SOx emissions will be reduced when 30 ppm fuel is introduced in 2006. This relative reduction will remain constant beyond 2006 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 16,000 tons by 2030. In addition, emissions from all gasoline-powered nonroad equipment would be reduced due to sulfur control. 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.A-10.

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 with and without Tier 2/Sulfur control under two sales scenarios: a "no growth" scenario, for which current diesel sales trends were assumed to continue, and an "increased growth" scenario, based on projections developed by A.D. Little, Inc. known as the "Most Likely" scenario. These projections estimate that diesels will grow to nine percent of light-duty vehicle sales and 24 percent of light-duty truck sales by 2015.[7] The inventory results presented in this section are for direct exhaust PM_{10} emissions, 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 $PM_{2.5}$ emissions are presented separately in Appendix A.

a. "No Growth" Diesel Sales Scenario

i. Light-Duty Direct Exhaust PM_{10} 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 from the light-duty vehicle fleet 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.A-11 and Figure III.A-15. In 2000, we project that approximately 36,000 tons will be emitted annually by light-duty cars and trucks. This level is projected to exceed 48,000 tons in 2020 and reach nearly 56,000 tons in 2030. The absolute emission estimates presented in Table III.A.-11 are based on a 330 ppm average sulfur level for conventional gasoline; using our updated estimate for conventional gasoline of 300 ppm conventional gasoline, the values in this table would be reduced by approximately six percent.

Table III.A-11. 47 State Light-Duty Direct Exhaust PM_{10} 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	-	38,729	-	7%	47%	28%	19%
2004	-	38,551	-	4%	45%	37%	14%
2007	2,907,819	40,365	1.4%	2%	40%	43%	14%
2010	2,945,927	42,385	1.4%	2%	36%	47%	15%
2015	3,058,635	45,887	1.5%	2%	32%	50%	16%
2020	3,168,482	49,577	1.6%	2%	31%	51%	16%
2030	3,431,450	56,861	1.7%	2%	30%	51%	17%

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

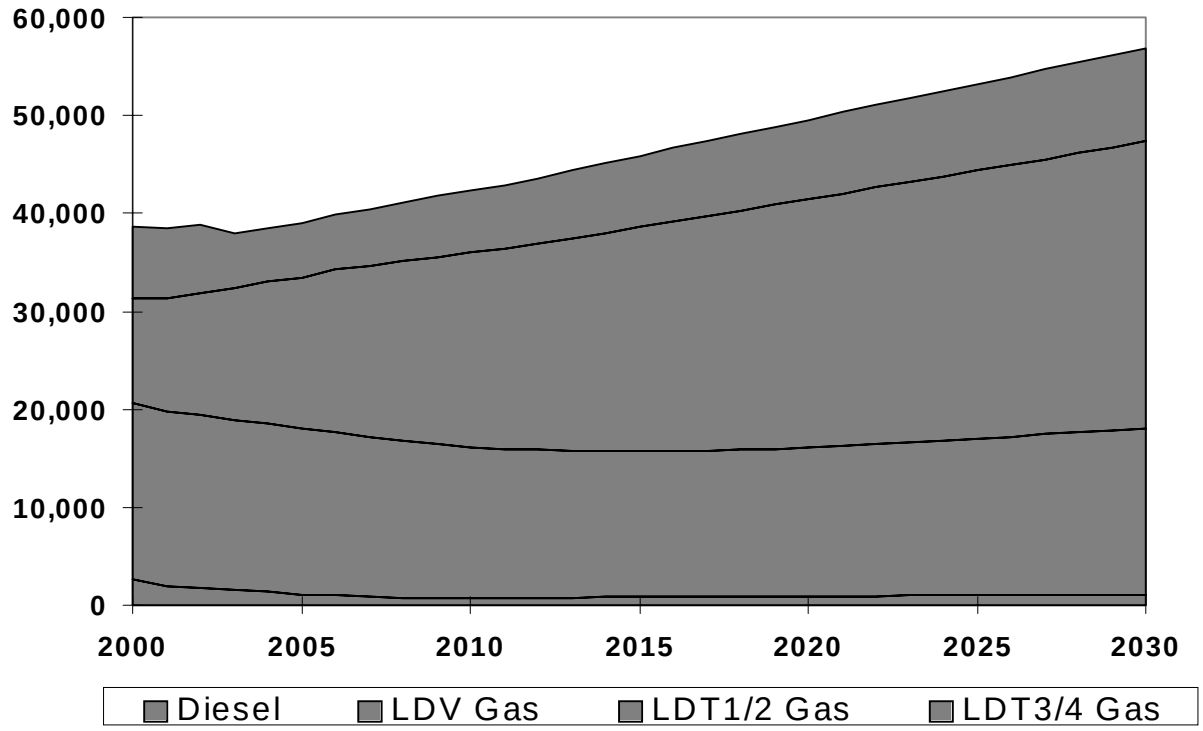

Figure III.A-15. 47-State Light-Duty Direct Exhaust PM_{10} Emissions Without Tier 2/Sulfur - No Diesel Growth (Annual Tons)

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_{10} inventory to grow to 70 percent by 2030.

ii. Direct Exhaust PM_{10} 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.A-12 contains annual nationwide tons of direct exhaust PM_{10} we project will be reduced from light-duty vehicles and trucks due to Tier 2/Sulfur control. Figure III.A-16 shows PM_{10} 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.A-12. 47-State Light-Duty Direct Exhaust PM_{10} 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	38,551	24,424	14,127	37%	-
2007	40,365	16,938	23,427	58%	0.8%
2010	42,385	17,254	25,131	59%	0.9%
2015	45,887	17,937	27,950	61%	0.9%
2020	49,577	18,891	30,686	62%	1.0%
2030	56,861	20,857	36,004	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.

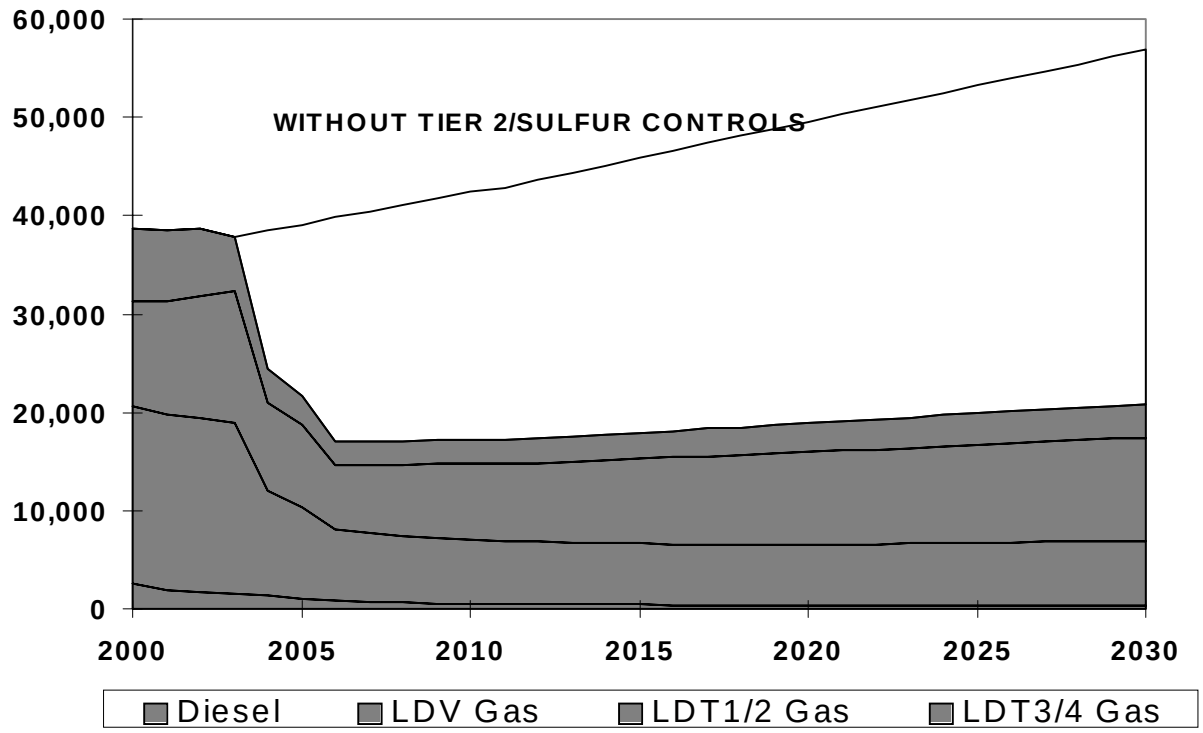

Figure III.A-16. 47-State Light-Duty Direct Exhaust PM_{10} Emissions With Tier 2/Sulfur - No Diesel Growth (Annual Tons)

Reductions from gasoline vehicles would result almost entirely from sulfur control, rather than the proposed PM_{10} exhaust standards. PM_{10} 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_{10} standards contained in today's proposal. As shown, a significant reduction in light-duty PM_{10} emissions would be realized immediately with sulfur control. The reductions presented above presume 120 ppm in 2004 and 90 ppm in 2005 under the sulfur ABT program; reductions could be realized as early as 2000 under this program. We project that nearly 60 percent of light-duty PM_{10} emissions will be reduced when 30 ppm fuel is introduced in 2006.

In addition to light-duty PM benefits, sulfur control would reduce PM_{10} emissions from heavy-duty gasoline vehicles. We estimate these benefits would be approximately 1,100 tons per year beginning with 30 ppm fuel, increasing to 1,500 tons by 2030. Across all sources, we project Tier 2/Sulfur control would reduce direct PM_{10} from all non-natural sources by about one percent.

b. "Increased Growth" Sales Scenario

Our "increased growth" scenario has been revised since the proposal. For the proposal, the increased growth scenario was developed with the intent of analyzing an upper bound for diesel growth, and assumed very aggressive levels of diesel penetration in the light truck market. Since the proposal, we have derived more realistic growth assumptions based on work by A.D Little, Inc.; the resulting growth scenario is referred to as the A.D. Little "Most Likely" diesel growth scenario. The original A.D. Little methodology presented sales penetrations for LDVs and LDTs in five-year increments, through 2015. We filled in the missing years using linear interpolation, and assumed no growth beyond 2015. For this analysis, we assumed that diesel LDT sales penetration would be distributed equally between the four truck classes. The resulting diesel sales penetrations are shown in Table III.A-13.

Table III.A-13. Diesel LDT Sales Penetration Under Increased Growth Scenario

Model Year	*Diesel Sales Penetration*	
	LDV	*LDT*
2001	0.1%	0.1%
2002	0.1%	1.5%
2003	0.1%	3.0%
2004	0.1%	4.5%
2005	0.3%	6.0%
2006	0.7%	8.2%
2007	1.0%	10.4%
2008	1.3%	12.6%
2009	1.7%	14.8%
2010	2.0%	17.0%
2011	3.4%	18.4%
2012	4.8%	19.8%
2013	6.2%	21.2%
2014	7.6%	22.6%
2015 and later	9.0%	24.0%

i. Light-Duty Direct Exhaust PM_{10} Trends Without Tier 2/Sulfur

Our projections for light-duty direct exhaust PM_{10} under the increased diesel sales scenario are shown in Table III.A-14 and Figure III.A-17. As expected, this scenario is projected to result in dramatic increases in light-duty PM_{10} emissions. 2010 baseline emissions are approximately 54,000 tons, 28 percent higher than the 42,000 tons projected in the no growth diesel case from Table III.A-11. However, by 2030, we project this scenario would result in direct PM emissions of 123,000 tons, over two times higher than the emissions projected for the no growth scenario in the same year.

Table III.A-14. 47 State Light-Duty Direct Exhaust PM_{10} 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	38,729	7%	93%
2004	39,418	6%	94%
2007	44,749	13%	87%
2010	54,094	26%	74%
2015	76,309	47%	52%
2020	97,708	58%	42%
2030	122,608	63%	37%

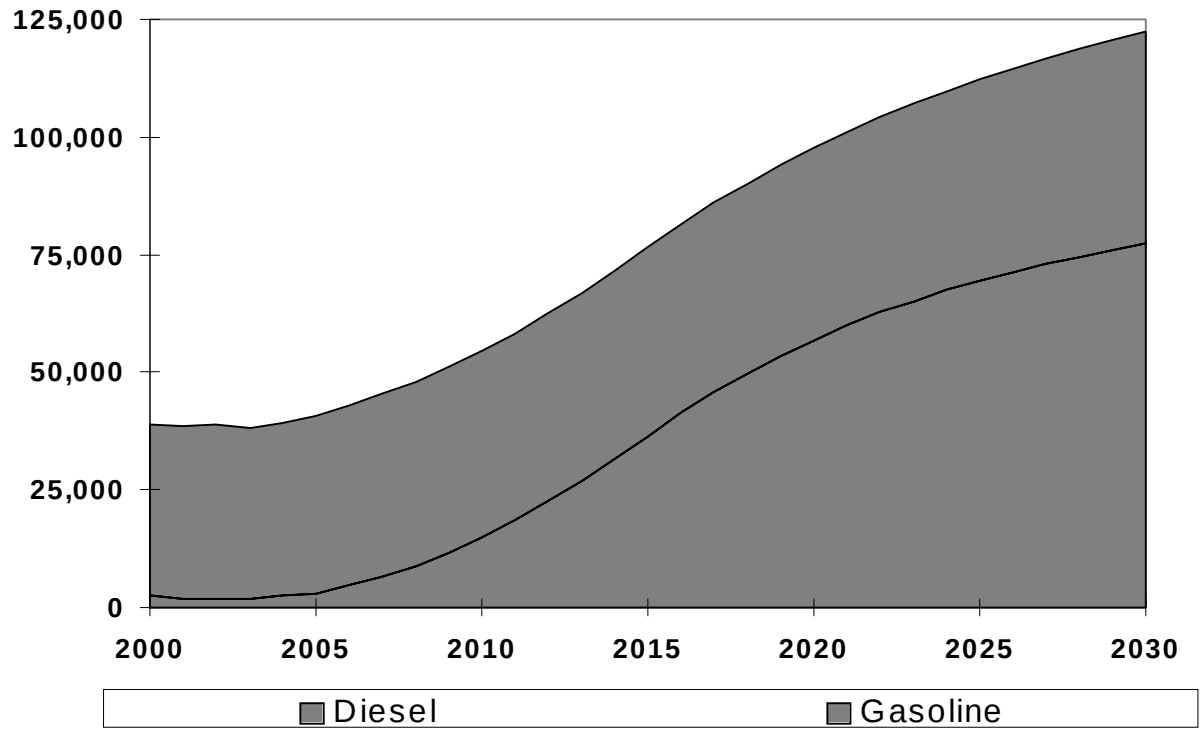

Figure III.A-17: 47-State Light-Duty Direct Exhaust PM_{10} Without Tier 2/Sulfur - Increased Diesel Sales (Annual Tons)

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 2007, we project diesels would already account for 13 percent of all light-duty emissions. Diesel contribution grows to over 25 percent by 2010 and over 60 percent by 2030.

ii. Direct Exhaust PM_{10} 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.A-15 contains reductions in direct exhaust PM_{10} emissions due to Tier 2/Sulfur standards for the increased diesel sales penetration case. Figure III.A-18 shows these emissions with Tier 2/Sulfur control, broken down by diesel and gasoline. It should be noted that these emission reductions assume an average PM certification standard of 0.01 grams per mile for all vehicles, and hence reflect a "best case" scenario for diesel growth. Under the certification bin system, it is likely that many diesels would certify in the 0.02 g/mi PM bin; under the "worst-case" scenario in which all diesels certify in this bin, we project that emissions in 2030 would be approximately 8,000 tons higher than the "With Tier

2/Sulfur" scenario shown in Table III.A-15.[9]

Table III.A-15. 47-State Light-Duty Direct Exhaust PM_{10} 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	39,418	25,184	14,234	36%	-
2007	44,749	19,017	25,732	58%	0.9%
2010	54,094	19,502	34,592	64%	1.2%
2015	76,309	20,511	55,798	73%	1.8%
2020	97,708	21,928	75,780	78%	2.4%
2030	122,608	24,838	97,770	80%	2.8%

* 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.

In 2004, 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. By 2015, over 70 percent of baseline light-duty exhaust PM_{10} inventory is reduced. By 2030, 80 percent of the baseline emissions would be reduced, nearly 3 percent of total inventory. As shown, today's action would largely serve to mitigate the PM_{10} emission increases which would result from rapid diesel market penetration.

[9] Under this "worst-case" PM scenario, all diesels under the A.D. Little "Most Likely" diesel sales case (Table III.A.-13) would certify in a bin with a 0.02 g/mi PM standard (0.2 or 0.15 g/mi NOx). The remaining vehicles (all gasoline) would certify in bins with a PM standard of 0.01 g/mi and a NOx standard or 0.07 g/mi or less.

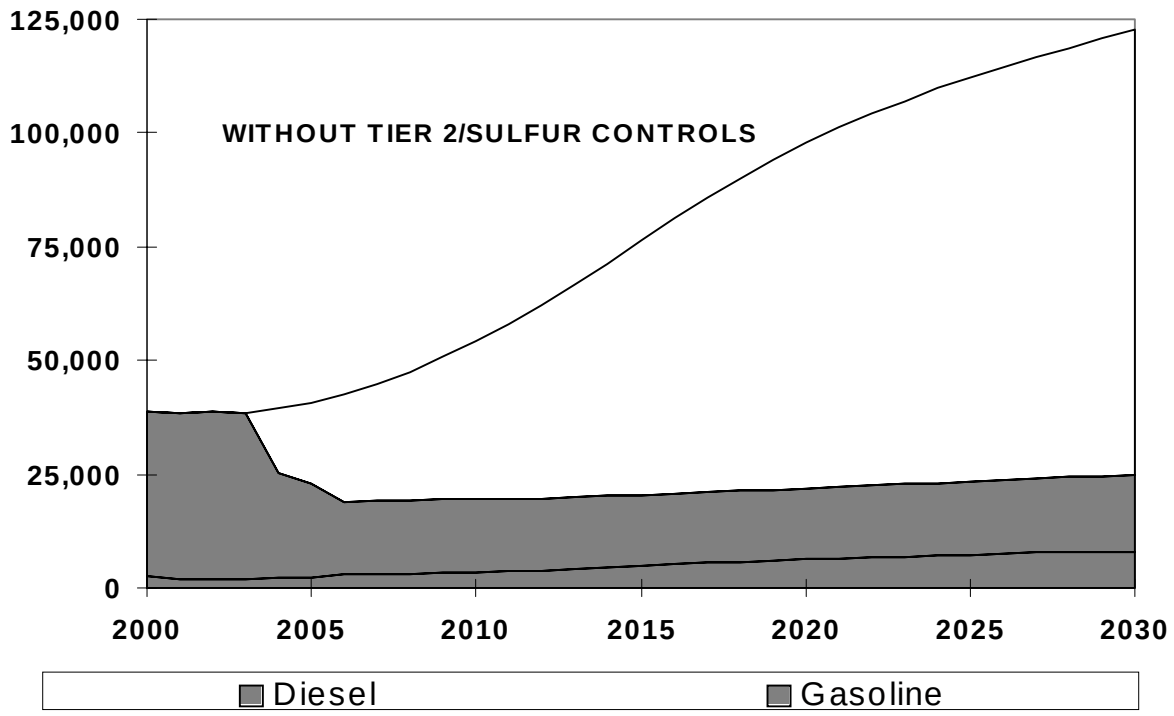

Figure III.A-16. 47-State Light-Duty Direct Exhaust PM_{10} Emissions With Tier 2/Sulfur - Increased Diesel Sales (Annual Tons)

B. Ozone: Baseline Nonattainment and Program Impacts

1. General Description of the EPA Ozone Modeling Used In This Rulemaking

A series of air quality modeling simulations were completed to a) support determination of the need for additional emissions reductions in order to meet the ozone NAAQS, b) assess the impact of the Tier 2/Sulfur rule on future ozone levels, and c) provide projected air quality information to support the benefits/cost analysis. The model simulations were performed for five emissions scenarios: a 1996 base year, a 2007 baseline projection, a 2007 projection with Tier 2/Sulfur controls, a 2030 baseline projection, and a 2030 projection with Tier 2/Sulfur controls. These scenarios and the underlying emissions inventories associated with each are described in Section III. A.

In conjunction with current air quality data, as explained below, the model output from the 2007 and 2030 baselines was used to identify areas expected to exceed the ozone NAAQS in 2007 and 2030. (These areas became candidates for being determined to be residual exceedance areas which will require additional emission reductions to attain and maintain the ozone NAAQS. As described in Section B.2, the impacts of the Tier 2/Sulfur controls were determined by comparing the model results in the future year control runs against the NLEV/high sulfur baseline simulations of the same year. The procedures for using the air quality modeling results in the benefits/costs analysis are described in Section IV. The remainder of this section provides a summary of the ozone modeling methodologies used to support this rulemaking. Additional details are provided in the Tier 2 Final Rule Air Quality Modeling Technical Support Document.

The structure of this section is as follows:

- Subsection 1.a. describes in general terms the ozone modeling that was used to determine the need for, and estimate the effects of, Tier 2/Sulfur controls.

- Subsection 1.b. describes the method used to determine residual non-attainment areas.

a. Modeling Methodology

A variable-grid version of the Urban Airshed Model (UAM-V) was utilized to estimate base and future-year ozone concentrations over the continental U.S. for the various emissions scenarios. UAM-V simulates the numerous physical and chemical processes involved in the formation, transport, and destruction of ozone. This model is commonly used for purposes of determining attainment/non-attainment as well as estimating the ozone reductions expected to occur from a reduction in emitted pollutants. The following sections provide an overview of the ozone modeling completed as part of this rulemaking. More detailed information is included in the Tier 2 Air Quality Modeling Technical Support Document (TSD).

Modeling domains

Two separate modeling domains were utilized in the Tier 2/Sulfur analyses. The first covered that portion of the U.S. east of west longitude 99 degrees. The second covered the remainder of the U.S. west of west longitude 99 degrees. The model resolution was 36 km over the outer portions of each domain and 12 km in the inner portion of the grids. The model grids for the eastern U.S. modeling were portioned into nine vertical layers with a surface layer depth of 50 meters and a top level well above the typical mixed layer height (4000 meters). The model grids for the western U.S. modeling were portioned into eleven vertical layers with a surface layer depth of 50 meters and a top level of 4800 meters.

A recent modeling study (LADCO, 1999) considered the sensitivity of regional modeling strategies to grid resolution. This study showed that the spatial pattern and magnitude of the ozone changes at 4 km in response to emissions reductions were slightly more pronounced, but generally similar to the modeled changes at 12 km in the Lake Michigan area. The OTAG[10] modeling application also investigated the effects of grid resolution on national/regional control strategies (e.g., Tier 2/Sulfur). The OTAG Final Report concluded that: a) peak simulated ozone is generally higher with more highly resolved grids, b) spatial concentration patterns are comparable between the fine and the coarse grid, and c) NOx reductions produce widespread ozone decreases and occasional limited ozone increases with either the fine or the coarse grid (although the increases tend to be larger in magnitude when finer-scale grids are used). More detail on the effect of grid size upon model results is provided in the response to comments and the TSD for this rule.

Modeling episodes

Three multi-day meteorological scenarios during the summer of 1995 were used in the model simulations over the eastern U.S.: 12-24 June, 5-15 July, and 7-21 August. These periods featured ozone exceedances at various times over most areas of the eastern U.S.[11]. In general, these episodes do not represent extreme ozone events but, instead, are generally representative of ozone levels near local design values[12]. Five simulations were completed for the June and July

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[10] The OTAG modeling project is used as a benchmark for the Tier 2/Sulfur modeling because it is the most extensive regional ozone modeling application completed to date in terms of days modeled, areas covered, and efforts of the air pollution modeling community to obtain sound model performance.

[11] Each modeling episode contains three days for which the modeling results are not considered. These days are simulated to minimize the dependence of the modeling results on uncertain initial conditions.

[12] The fourth highest daily maximum 1-hour average ozone concentration measured over a three-year period at a given monitor is the design value. Design values are used to determine the attainment status of a given region.

episodes (1996 base, 2007 baseline, 2007 control, 2030 baseline, 2030 control). Three simulations were completed for the August episode (1996 base, 2007 baseline, 2007 control).

Two episodes were modeled for the western U.S. domain: 5-15 July 1996 and 18-31 July 1996. Again, these 19 days contained design value level ozone exceedances over most of the western U.S. allowing for an assessment of emission controls in polluted, but not infrequent, conditions. The primary purpose of simulating the western episodes was to provide data for the benefits/cost analysis for 2030. Thus, no 2007 simulations were made for the West.

Non-emissions modeling inputs

The meteorological data required for input into UAM-V (wind, temperature, vertical mixing, etc.) were developed by a separate meteorological model, the Regional Atmospheric Modeling System (RAMS) for the eastern U.S. 1995 episodes, and the Fifth-Generation National Center for Atmospheric Research (NCAR) / Penn State University (PSU) Mesoscale Model (MM5) for the western U.S. 1996 episodes. These models provided needed data at every grid cell on an hourly basis. These meteorological modeling results were evaluated against observed weather conditions before being input into UAM-V and it was concluded that the model fields were adequate representations of the historical meteorology.

The modeling assumed background pollutant levels at the top and along the periphery of the domain. Additionally, initial conditions were assumed to be relatively clean as well. Given the ramp-up days and the expansive domains, it is expected that these assumptions will not affect the modeling results, except in areas near the boundary (e.g., Dallas-Fort Worth TX). The other non-emission UAM-V inputs (land use, photolysis rates, etc.) were developed using procedures employed in the OTAG regional modeling. The development of model inputs is discussed in greater detail in the Tier 2 Air Quality Technical Support Document.

Model performance evaluation

The purpose of the Tier 2/Sulfur base year modeling was to reproduce the atmospheric processes resulting in the observed ozone concentrations over these domains and episodes. One of the fundamental assumptions in ozone modeling is that a model which closely replicates observed ozone in the base year can be used to support future-year policymaking.

As with previous regional photochemical modeling studies, the accuracy of the Tier 2/Sulfur model base year simulations of historical ozone patterns varies by day and by location over this large modeling domain. From a qualitative standpoint, there appears to be considerable similarity on most days between the observed and simulated ozone patterns. Additionally, where possible to discern, the model appears to follow the regional-scale ozone trends fairly closely.

The values of two primary measures of model performance, mean normalized bias and

mean normalized gross error, indicate that the Tier 2/Sulfur modeling over the eastern U.S. is generally as good or better than the grid modeling done for OTAG[13], as shown in Table III.B-1. As OTAG did not perform any modeling for the West, no comparison back to OTAG is possible for the Tier 2 western U.S. model performance. Mean normalized bias is defined as the average difference between model predictions and observations (paired in space and time) normalized by the observations. Mean gross error is defined as the average absolute difference between model predictions and observations, paired in space and time, normalized by the observations. EPA guidance on local ozone attainment demonstration modeling (not the purpose of the Tier 2 modeling) suggests biases be less than 5-15 percent and error be less than 30-35 percent.

Table III.B-1. Comparison of eastern U.S. regional model performance statistics between the Ozone Transport Assessment Group (OTAG) modeling used to support the NO_X SIP call and the Tier 2/Sulfur modeling. The units are percentages.

Mean Normalized Bias	*OTAG 1988 Episode*	*OTAG 1991 Episode*	*OTAG 1993 Episode*	*OTAG 1995 Episode*	*Tier 2 June 95 Episode*	*Tier 2 July 95 Episode*	*Tier 2 August 95 Episode*
Domain	-8	-4	+1	+4	-10	-6 (-4)[14]	+2
Midwest	-15	-8	-8	-5	-11	-13 (-8)	+7
Northeast	-3	-6	-8	+8	-17	-9 (-9)	-9
Southeast	+2	+15	+21	+9	-4	+4 (+5)	+7
Southwest	-6	+6	+2	+12	+2	+8 (+8)	+6

Mean Normalized Gross Error	*OTAG 1988 Episode*	*OTAG 1991 Episode*	*OTAG 1993 Episode*	*OTAG 1995 Episode*	*Tier 2 June 95 Episode*	*Tier 2 July 95 Episode*	*Tier 2 August 95 Episode*
Domain	28	25	27	25	24	24 (24)	23
Midwest	27	26	25	24	24	26 (25)	22
Northeast	29	23	23	26	27	22 (21)	24
Southeast	28	25	32	27	20	24 (24)	22
Southwest	22	24	23	29	24	27 (26)	24

In general, the model underestimates ozone for the June and July eastern episodes in 1995

[13] Again, the OTAG application is used as a relative benchmark for model performance because it is the most detailed modeling to date over this region.

[14] Values in parentheses are for the 10-15th only. These dates correspond with OTAG episode days.

and, especially, both western episodes in 1996. The under prediction bias in the western U.S. modeling averages about 40 percent. The model is slightly biased toward overestimation in the August 1995 eastern episode. Although the overall tendency is to underestimate the observed ozone, there are several instances in which overestimations occurred. The net effect is expected to be an underestimate of the total extent of future-year exceedances, although some individual areas may be overstated.

Application of the modeling results

As discussed in the preamble and in other sections of this document, the grid modeling is being utilized to support the need for the Tier 2/Sulfur rulemaking and to determine the effects of the emissions reductions on ozone air quality, with results reported at the level of CMSAs and MSAs, as described in Section III.B.3, below. Section VII of this document discusses how these modeling results are used in the cost benefit analysis.

b. Determining Need for Additional Emissions Reductions

Table III.B-1 of the Tier 2/Sulfur preamble lists those metropolitan areas which were determined to require additional emission reductions in order to attain and maintain the 1-hour ozone NAAQS. This determination was made for all areas with current design values greater than or equal to 125 ppb and with modeling evidence that exceedances will persist into the future[15]. The following sections provide the details inherent in both parts of this determination.

Air quality design values

An ozone design value is the concentration that determines whether a monitoring site meets the NAAQS for ozone. Because of the way they are defined, design values are determined based on three consecutive-year monitoring periods. 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. 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 part per billion (ppb). Due to the precision with which the standards are expressed (0.12 parts per million (ppm) for the 1-hour, a violation of the 1-hour standard is defined as a design value greater than or equal to 125 ppb.

For a county, the design value is the highest design value from among all the monitors with valid design values within that county. If a county does not contain an ozone monitor, it does not have a design value. For most of our analyses, county design values are consolidated where possible into design values for consolidated metropolitan statistical areas (CMSA) or

[15] Modeling evidence from non-EPA analyses were also considered, as described in Section III.B.3, below.

metropolitan statistical areas (MSA). The design value for a metropolitan area is the highest design value among the included counties. Counties that are not in metropolitan areas are treated separately. For the purposes of defining the current design value of a given area, the higher of the 1995-1997 and 1996-1998 design values were chosen to provide greater confidence in identifying areas likely to have an ozone problem in the future. The 1995-1997 and 1996-1998 design values are listed in the Tier 2 Air Quality Modeling Technical Support Document.

Method for projecting future exceedances

The exceedance method was used for interpreting the future-year modeling results to determine where nonattainment is expected to occur in the 2007 and 2030 Base Cases[16]. As part of this method the modeling grid cells are first assigned to individual areas. The daily maximum 1-hour ozone values predicted in grid cells assigned to an area are then checked to identify whether there are any predictions >=125 ppb. Areas with current measured violations of the one-hour ozone standard, one or more model-predicted exceedances, and no conflicting modeling evidence to the contrary are projected to have a nonattainment problem in the future. This procedure is further described in the Tier 2 Air Quality Modeling Technical Support Document.

2. Ozone Reductions Expected from this Rule

The large reductions in emissions of ozone precursors from today's standards will be very beneficial to federal and State efforts to lower ozone levels and bring about attainment with the current one-hour ozone standards. The air quality modeling for the final rule shows that improvements in ozone levels are expected to occur throughout the country because of the Tier 2/Gasoline Sulfur program.[17] EPA found that the program significantly lowers model-predicted exceedances of the ozone standard. In 2007 the number of exceedances in CMSA/MSAs is forecasted to decline by nearly one-tenth and in 2030, when full turnover of the vehicle fleet has occurred, the program lowers such exceedances by almost one-third. In these same areas, the total amount of ozone above the NAAQS is forecasted to decline by about 15 percent in 2007 and by more than one-third in 2030. In the vast majority of areas, the air quality modeling predicts that the program will lower peak summer ozone concentrations for both 2007 and 2030. The reduction in daily maximum ozone is nearly 2 ppb, on average in 2007 and over 5 ppb, on average in 2030. These reductions contribute to EPA's assessment that the program will provide the large set of public health and environmental benefits summarized in Section VII. The forecasted impacts of the program on ozone in 2007 and 2030 are further described in the Tier 2 Air Quality Modeling Technical Support Document.

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[16] 2030 is the relevant baseline scenario for the western U.S. domain

[17] EPA assessment of air quality changes for 2007 and 2030 focused on 37 States in the East because these States cover most of the areas with 1-hour nonattainment problems.

During the public comment period on the proposed rule, EPA received several comments that expressed concern about potential increases in ozone that might occur as a result of this rule. As indicated above, the air quality modeling results indicate an overall reduction in ozone levels in 2007 and 2030 during the various episodes modeled. In addition to ozone reductions, a few areas had predicted ozone increases in portions of the area during parts of the episodes modeled. In most of these cases, the overall decrease led EPA to conclude that there will be a net reduction in ozone levels in these areas due to the Tier 2/Sulfur program. In the very small number of exceptions to this, the Agency did find benefit from reduction of peak ozone levels. Based upon a careful examination of this issue, including EPA's modeling results as well consideration of the modeling and analyses submitted by commenters, it is clear that the significant ozone reductions from this rule outweigh the limited ozone increases that may occur. Additional details on this issue are provided in the Response to Comments Document and in the Tier 2 Air Quality Modeling Technical Support Document.

Collectively, EPA believes these results indicate that it will be much easier for States to provide EPA assurances that their State Implementation Plans will attain and maintain compliance with the one-hour ozone standards. In the limited number of cases mentioned above, EPA will work with States who will be conducting more detailed local modeling of their specific local programs that they have designed to provide attainment. Notably, there are also other upcoming federal measures to lower ozone precursors will aid these efforts. If the State modeling of local programs shows a need, the Agency will work with states to plan further actions to produce attainment with the NAAQS in order to protect the public's health and the environment. Further details on EPA's modeling results can be found in the response to comments and technical support documents.

3. Ozone Modeling and Analysis in 1-Hour State Implementation Plan Submittals and Other Local Ozone Modeling

a. Overview

We have reviewed and recently proposed action on SIP submissions from 14 states covering 10 serious and severe 1-hour ozone nonattainment areas. We received these submissions as part of the three-phase SIP process allowed by EPA guidance memos or as part of a request for an attainment date extension. These submissions also provided ozone modeling results for two attainment areas in a downwind state. These submissions contain local ozone modeling which we considered along with the results of the EPA ozone modeling described above. We have also considered ozone modeling submitted as part of an attainment date extension request for Beaumont-Port Arthur, TX, but have not yet taken action on that request. We have also reviewed a status report on the results of modeling being conducted in anticipation of submittal to EPA as part of an extension request for Dallas, TX. Finally, we have considered information in the most recent SIP submittal from California for the South Coast Air Basin. Table III.B-2 lists the areas involved, our overall conclusion as to whether the modeling

demonstrates attainment without reductions that would be considered “further reductions” under CAA section 202(i), and whether the area is included in our recent proposals for actions on SIP submittals. The Federal Register notices for these recent proposals appeared together on December 16, 1999, beginning at 64 FR 70318. This section discusses the background for the submissions and our conclusions from them.

The local modeling analyses generally cover a modeling domain encompassing one or a few closely spaced nonattainment areas and a limited upwind area. Because of this limited domain, states have been able to use grid cells of 4 or 5 kilometers on a side, in keeping with EPA guidance for such modeling. This fine grid size is an important factor in how much weight we have given to this set of evidence. The future attainment date examined differs from state to state depending on its current (or proposed extended) attainment deadline. In the state modeling, ozone episode days were selected by the respective states based on days with high ozone in the local domain being modeled. In all cases, the selection of episode days met our guidance. The local modeling also makes use of more information on the local emission inventory and control program than is practicable to include in broad scale modeling by EPA as described above.

The SIP submissions for these 10 nonattainment areas contain many legally required elements in addition to the attainment demonstrations. After considering the attainment demonstrations and these other elements, we have proposed appropriate action on each of these submissions. In many cases, we have proposed alternative actions on our part, based on whether the state submits additional SIP elements which we have described as necessary. We also explained what each state m
ust provide us in order to allow us to take final approval or conditional approval action.

More specific descriptions of the ozone modeling contained in the SIPs, for areas where we have recently proposed action on a submittal, and more explanation of our evaluation of it can be obtained in the individual Federal Register notices and in the technical support document prepared for each action.

Table III.B-2. Nonattainment Areas For Which EPA Has Recently Proposed Action On SIP Submissions Containing 1-hour Ozone Attainment Demonstrations or Otherwise Has Considered Results of Local Ozone Modeling

Nonattainment Area (Major Metro Area)	*Affected States*	*Attainment Date*	*Demonstrates Attainment Without "Further Reductions"*	*Proposed for Action in December 16, 1999 Federal Register (64 FR 70318)*
Western Massachusetts (Springfield)	MA	2003 (Requested Extension)	Yes	Yes
Greater Connecticut (Hartford and other MSAs)	CT	2007 (Requested Extension)	Yes	Yes
New York City	NY, CT, NJ	2007	No	Yes
Philadelphia	PA, NJ, DE, MD	2005	No	Yes
Baltimore	MD	2005	No	Yes
Washington, D.C.	MD, VA, D.C.	2005 (Requested Extension)	No	Yes
Atlanta	GA	2003 (Requested Extension)	No	Yes
Houston	TX	2007	No	Yes
Chicago	IL, IN	2007	Yes	Yes
Milwaukee	WI	2007	Yes	Yes
Benton Harbor	MI	Not Applicable	Yes	No
Grand Rapids	MI	Not Applicable	Yes	No
Dallas	TX	2007	No	No

Nonattainment Area (Major Metro Area)	*Affected States*	*Attainment Date*	*Demonstrates Attainment Without "Further Reductions"*	*Proposed for Action in December 16, 1999 Federal Register (64 FR 70318)*
Beaumont-Port Arthur	TX	2007 (Requested Extension)	No	Yes
South Coast Air Basin	CA	2010	No	No

b. CAA Requirements and EPA Policy

The CAA, as amended in 1990, required EPA to designate as nonattainment any area that was violating the 1-hour ozone standard, generally based on air quality monitoring data from the three-year period from 1987-1989. CAA § 107(d)(4); 56 FR 56694 (Nov. 6, 1991). The CAA further classified these areas, based on the area's design value, as marginal, moderate, serious, severe or extreme. Marginal areas were suffering the least significant air pollution problems while the areas classified as severe and extreme had the most significant air pollution problems.

The control requirements and dates by which attainment needs to be achieved vary with the area's classification. Marginal areas are subject to the fewest mandated control requirements and have the earliest attainment date. Severe and extreme areas are subject to more stringent planning requirements but are provided more time to attain the standard. Serious areas were required to attain the 1-hour standard by November 15, 1999 and severe areas are required to attain by November 15, 2005 or November 15, 2007.

Under section 182(c)(2) and (d) of the CAA, serious and severe areas were required to submit demonstrations of how they would attain the 1-hour standard and how they would achieve reductions in VOCs and NOx emissions of 9 percent for each three-year period until the attainment year (rate-of-progress or ROP) by November 15, 1994.

In general, an attainment demonstration SIP includes a modeling analysis component showing how the area will achieve the standard by its attainment date and the control measures necessary to achieve those reductions. Another component of the attainment demonstration SIP is a motor vehicle emissions budget for transportation conformity purposes. Transportation conformity is a process for ensuring that States consider the effects of emissions associated with new or improved federally-funded roadways on attainment of the standard. As described in section 176(c)(2)(A), attainment demonstrations necessarily include the estimates of motor vehicle emissions that are consistent with attainment, which then act as a budget or ceiling for the purposes of determining whether transportation plans and projects conform to the attainment SIP.

Notwithstanding significant efforts by the States, in 1995 EPA recognized that many States in the eastern half of the United States could not meet the November 1994 time frame for submitting an attainment demonstration SIP because emissions of NOx and VOCs in upwind States (and the ozone formed by these emissions) affected these nonattainment areas and the full impact of this effect had not yet been determined. This phenomenon is called ozone transport.

On March 2, 1995, Mary D. Nichols, EPA's then Assistant Administrator for Air and Radiation, issued a memorandum to EPA's Regional Administrators acknowledging the efforts made by States but noting the remaining difficulties in making attainment demonstration SIP

submittals.[8] Recognizing the problems created by ozone transport, the March 2, 1995 memorandum called for a collaborative process among the States in the eastern half of the country to evaluate and address transport of ozone and its precursors. This memorandum led to the formation of the Ozone Transport Assessment Group (OTAG)[9] and provided for the States to submit the attainment demonstration SIPs based on the expected time frames for OTAG to complete its evaluation of ozone transport.

In June 1997, OTAG concluded and provided EPA with recommendations regarding ozone transport. The OTAG generally concluded that transport of ozone and the precursor NOx is significant and should be reduced regionally to enable States in the eastern half of the country to attain the ozone NAAQS.

In recognition of the length of the OTAG process, in a December 29, 1997 memorandum, Richard Wilson, EPA's then Acting Assistant Administrator for Air and Radiation, provided until April 1998 for States to submit for attainment demonstration SIPs and clarified that, by April 1998, States with serious and higher classified nonattainment areas additionally needed to submit (1) evidence that the applicable control measures in subpart 2 of part D of title I of the CAA were adopted and implemented or were on an expeditious course to being adopted and implemented; (2) a list of measures needed to meet the remaining ROP emissions reduction requirement and to reach attainment; (3) for severe areas only, a commitment to adopt the control measures necessary for attainment and ROP plans through the attainment year by the end of 2000; (4) a commitment to implement the SIP control programs in a timely manner and to meet ROP emissions reductions and attainment; and (5) evidence of a public hearing on the State submittal.[10]

Building upon the OTAG recommendations and technical analyses, in November 1997, EPA proposed action addressing the ozone transport problem. In its proposal, the EPA found that current SIPs in 22 States and the District of Columbia (23 jurisdictions) were insufficient to provide for attainment and maintenance of the 1-hour standard because they did not regulate NOx emissions that significantly contribute to ozone transport. 62 FR 60318 (Nov. 7, 1997). The EPA finalized that rule in September 1998, calling on the 23 jurisdictions to revise their SIPs to require NOx emissions reductions within the State to a level consistent with a NOx emissions budget identified in the final rule. 63 FR 57356 (Oct. 27, 1998). This final rule is commonly referred to as the NOx SIP Call or the Regional Ozone Transport Rule.

On July 16, 1998, EPA's then Acting Assistant Administrator, Richard Wilson, issued a guidance memorandum intended to provide further relief to areas affected by ozone transport.[11] The memorandum recognized that many moderate and serious areas are affected by transported pollution from either an upwind area in the same State with a higher classification and later attainment date, and/or from an upwind area in another State that is significantly contributing to the downwind area's nonattainment problem. The policy recognized that some downwind areas may be unable to meet their own attainment dates, despite doing all that was required in their

local area, because an upwind area may not have adopted and implemented all of the controls that would benefit the downwind area through control of transported ozone before the downwind area's attainment date. Thus, the policy provided that upon a successful demonstration that an upwind area has interfered with attainment and that the downwind area is adopting all measures required for its local area for attainment but for this interference, EPA may grant an extension of the downwind area's attainment date. Local area measures would include all of the measures within the modeling domain that were relied on for purposes of the modeled attainment demonstration. Once an area receives an extension of its attainment date based on transport, the area would no longer be subject to reclassification to a higher classification and subject to additional requirements for failure to attain by its original attainment date provided it was doing all that was necessary locally. The policy provides that the area must meet four criteria to receive an attainment date extension. In summary, the area must: (1) be identified as a downwind area affected by transport from either an upwind area in the same State with a later attainment date or an upwind area in another State that significantly contributes to downwind nonattainment; (2) submit an approvable attainment demonstration with any necessary, adopted local measures and with an attainment date that reflects when the upwind reductions will occur; (3) adopt all local measures required under the area's current classification and any additional measures necessary to demonstrate attainment; and (4) provide that it will implement all adopted measures as expeditiously as practicable, but no later than the date by which the upwind reductions needed for attainment will be achieved.

The States generally submitted the SIPs between April and October of 1998; some States are still submitting additional revisions. Under the CAA, EPA is required to approve or disapprove a State's submission no later than 18 months following submission. (The statute provides up to 6 months for a completeness determination and an additional 12 months for approval or disapproval.)

c. Local Ozone Modeling in SIP Submissions

The EPA provides that States may rely on a modeled attainment demonstration supplemented with additional evidence to demonstrate attainment. In order to have a complete modeling demonstration submission, States have submitted the required modeling analysis and identified any additional evidence that EPA should consider in evaluating whether the area will attain the standard.

For purposes of demonstrating attainment, the CAA requires serious and severe areas to use photochemical grid modeling or an analytical method EPA determines to be as effective. The EPA has issued guidance on the air quality modeling that is used to demonstrate attainment with the 1-hour ozone NAAQS.[12] The photochemical grid model is set up using meteorological conditions conducive to the formation of ozone. Emissions for a base year are used to evaluate the model's ability to reproduce actual monitored air quality values and to predict air quality changes in the attainment year due to the emission changes which include growth up to and

controls implemented by the attainment year. A modeling domain is chosen that encompasses the nonattainment area. Attainment is demonstrated when all predicted concentrations inside the modeling domain are at or below the NAAQS or at an acceptable upper limit above the NAAQS permitted under certain conditions by EPA's guidance. When the predicted concentrations are above the NAAQS, an optional weight of evidence determination which incorporates but not is limited to other analyses such as air quality and emissions trends may be used to address uncertainty inherent in the application of photochemical grid models.

The EPA guidance identifies the features of a modeling analysis that are essential to obtain credible results. First, the State must develop and implement a modeling protocol. The modeling protocol describes the methods and procedures to be used in conducting the modeling analyses and provides for policy oversight and technical review by individuals responsible for developing or assessing the attainment demonstration (State and local agencies, EPA Regional offices, the regulated community, and public interest groups). Second, for purposes of developing the information to put into the model, the State must select air pollution days, i.e., days in the past with bad air quality, that are representative of the ozone pollution problem for the nonattainment area. Third, the State needs to identify the appropriate dimensions of the area to be modeled, i.e., the domain size. The domain should be larger than the designated nonattainment area to reduce uncertainty in the boundary conditions and should include large upwind sources just outside the nonattainment area. In general, the domain is considered the local area where control measures are most beneficial to bring the area into attainment. Fourth, the State needs to determine the grid resolution. The horizontal and vertical resolutions in the model affect the dispersion and transport of emission plumes. Artificially large grid cells (too few vertical layers and horizontal grids) may dilute concentrations and may not properly consider impacts of complex terrain, complex meteorology, and land/water interfaces. Fifth, the State needs to generate meteorological that describe atmospheric conditions and emissions inputs. Finally, the State needs to verify the model is properly simulating the chemistry and atmospheric conditions through diagnostic analyses and model performance tests. Once these steps are satisfactorily completed, the model is ready to be used to generate air quality estimates to support an attainment demonstration.

The modeled attainment test compares model predicted 1-hour daily maximum concentrations in all grid cells for the attainment year to the level of the NAAQS. A predicted concentration above 0.124 ppm ozone indicates that the area is expected to exceed the standard in the attainment year and a prediction below 0.124 ppm indicates that the area is expected to attain the standard. This type of test is often referred to as an exceedance test. The EPA's guidance recommends that States use either of two modeled attainment or exceedance tests for the 1-hour ozone NAAQS: a deterministic test or a statistical test.

The deterministic test requires the State to compare predicted 1-hour daily maximum

ozone concentrations for each modeled day[18] to the attainment level of 0.124 ppm. If none of the predictions exceed 0.124 ppm, the test is passed.

The statistical test takes into account the fact that the form of the 1-hour ozone standard allows exceedances. If, over a three-year period, the area has an average of one or fewer exceedances per year, the area is not violating the standard. Thus, if the State models a very extreme day, the statistical test provides that a prediction above 0.124 ppm up to a certain upper limit may be consistent with attainment of the standard. (The form of the 1-hour standard allows for up to three readings above the standard over a three-year period before an area is considered to be in violation.)

The acceptable upper limit above 0.124 ppm is determined by examining the size of exceedances at monitoring sites which *meet or attain* the 1-hour NAAQS. For example, a monitoring site for which the four highest 1-hour average concentrations over a three-year period are 0.136 ppm, 0.130 ppm, 0.128 ppm and 0.122 ppm is attaining the standard. To identify an acceptable upper limit, the statistical likelihood of observing ozone air quality exceedances of the standard of various concentrations is equated to severity of the modeled day. The upper limit generally represents the maximum ozone concentration level observed at a location on a single day and it would be the only level above the standard that would be expected to occur no more than an average of once a year over a three-year period. Therefore, if the maximum ozone concentration predicted by the model is below the acceptable upper limit, in this case 0.136 ppm, then EPA might conclude that the modeled attainment test is passed. Generally, exceedances well above 0.124 ppm are very unusual at monitoring sites meeting the NAAQS. Thus, these upper limits are rarely significantly higher than the attainment level of 0.124 ppm.

When the modeling does not conclusively demonstrate that the area will attain, additional analyses may be presented to help determine whether the area will attain the standard. As with other predictive tools, there are inherent uncertainties associated with modeling and its results. For example, there are uncertainties in some of the modeling inputs, such as the meteorological and emissions data bases for individual days and in the methodology used to assess the severity of an exceedance at individual sites. The EPA's guidance recognizes these limitations, and provides a means for considering other evidence to help assess whether attainment of the NAAQS is likely. The process by which this is done is called a weight of evidence (WOE) determination.

Under a WOE determination, the State can rely on and EPA will consider factors such as other modeled attainment tests, e.g., a rollback analysis; other modeled outputs, e.g., changes in the predicted frequency and pervasiveness of exceedances and predicted changes in the design value; actual observed air quality trends; estimated emissions trends; analyses of air quality

[18]The initial, "ramp-up" days for each episode are excluded from this determination.

monitored data; the responsiveness of the model predictions to further controls; and, whether there are additional control measures that are or will be approved into the SIP but were not included in the modeling analysis. This list is not an exclusive list of factors that may be considered and these factors could vary from case to case. The EPA's guidance contains no limit on how close a modeled attainment test must be to passing to conclude that other evidence besides an attainment test is sufficiently compelling to suggest attainment. However, the further a modeled attainment test is from being passed, the more compelling the WOE needs to be.

Special explanation is necessary on the issue of how the NOx SIP Call/Regional Ozone Transport Rule has been handled by states in their local ozone modeling. For purposes of CAA section 202(i) we consider the emission reductions that will be achieved by the NOx SIP Call/Regional Ozone Transport Rule to be previous emission reductions rather than "further" reductions, since the 22 affected states and the District of Columbia are currently under an enforceable requirement to obtain these reductions. In most of the local ozone modeling in these SIP revisions, upwind NOx reductions have been assumed to occur through implementation of the the NOx SIP Call/Regional Ozone Transport Rule in some or all of the states subject to that rule, even though all states' rules to implement those reductions have not yet been adopted. Where upwind and local implementation of the NOx SIP Call is assumed, our conclusion that the modeling shows that an area cannot attain the NAAQS means that it cannot attain even with the prior implementation of the NOx SIP Call, and thus the area requires further emission reductions under section 202(i).[19]

d. Conclusions from the Local Modeling in SIP Submittals

All of the states have made use of the weight of evidence concept in their attainment demonstrations. EPA has proposed to find that some of the demonstrations are adequate, while for others additional reductions are needed to attain. There is an important distinction between our proposed finding on these SIPs and the determination required by CAA section 202(i). We are in some cases proposing to approve demonstrations that depend on emission reductions from measures that the state has not yet adopted and has not yet made a legally enforceable commitment to adopt and implement. Such emission reductions are "further" reductions under CAA section 202(i). In some cases, therefore, we are considering an area to need further reductions in order to attain and maintain and also proposing to approve its attainment demonstration. Before we take final and unconditional action on an attainment demonstration in such a case, the state will have to adopt all the necessary rules or make enforceable commitments to adopt them.

[19] Our recent proposals on the SIPs explain how we propose to approach the approval of 1-hour attainment SIPs themselves with respect to the NOx SIP Call. To summarize, we have proposed to approve a SIP which assumes implementation of the NOx SIP Call provided that the state is committed to implementing the NOx reductions within the in-state portion of the modeling domain of the subject nonattainment area. Reductions outside the domain and in other states may be assumed even if a commitment is currently lacking for those areas.

These state-specific findings are not final and we are not making them final via the Tier 2 rulemaking. In our final actions on these SIP revisions we may deviate from our proposal for one or more areas, based on the full record of the rulemaking for each, including any comments received after today. However, we have used the ozone attainment assessments as described summarized below in making our Tier 2 determination on the need for additional emission reductions in these areas.

As result of EPA's review of the states' SIP submittals, EPA believes that the ozone modeling submitted by the applicable states for the Chicago, IL; Milwaukee, WI; Greater CT (Hartford and New London metropolitan areas); and Western MA areas demonstrate attainment through the control measures contained in the submitted attainment strategy. We expect that Illinois, Wisconsin, and Indiana will submit further SIP revisions for Chicago and Milwaukee prior to our taking final action on our recent proposals regarding the submissions they made earlier. These new revisions will be based on a new round of modeling conducted by the Lake Michigan Air Directors Consortium (LADCO) on behalf of the states. While we have not received this modeling, we have received a progress report on it.[13]

While Michigan was not required to submit attainment demonstrations for the Benton Harbor and Grand Rapids-Muskegon areas, the ozone modeling submitted and weight of evidence analysis performed for the attainment demonstrations submitted in 1998 for Chicago and Milwaukee indicates that these two areas will also be in attainment in 2007 based only on emission reductions which come from measures which are already adopted and legally enforceable.

For the New York Metro area, Philadelphia, Baltimore, District of Columbia, and Houston nonattainment areas, the EPA has proposed to determine that additional emission reduction beyond those provided by the SIP submission are necessary for attainment. A portion of that reduction will be achieved by EPA's Tier 2/Sulfur program. In the case of Washington DC, our analysis indicates that the Tier 2/Sulfur program will provide all of the additional emission reductions needed to attain.

Atlanta's statutory attainment date as a serious 1-hour ozone nonattainment area was November 1999, which it has not met. Georgia has requested an attainment date extension for Atlanta to November 15, 2003 and has proposed an emission control program to achieve attainment by that date. The EPA has proposed to assign Atlanta an attainment date of November 2003 based on a successful demonstration by the State that the control strategy described in the SIP will achieve attainment by this date. However, many of the measures in that strategy are not yet adopted or fully committed, and are therefore "further" reductions under 202(i). It is clear from the amount of emission reductions from these measures that the nonattainment status of Atlanta would extend into the 2004 and later period if only "previous" emission reductions were considered. The modeling for Atlanta assumed implementation of the NOx SIP Call outside the local modeling domain, but lesser NOx reductions within the domain.

This is an issue, since the full NOx reductions from the SIP call are considered "previous" in connection with the Tier 2 rulemaking. However, the difference in NOx reduction within the modeling domain is small, and it is apparent that even if the full NOx reductions from the SIP call had been assumed attainment would still be impossible without reductions from measures which are "further" reductions for purposes of the Tier 2 determinations.

The specific reasons for reaching these conclusions are explained in the individual Federal Register notices.

e. Other Local Ozone Modeling

We have received ozone modeling for the Beaumont-Port Arthur nonattainment area.[14] Beaumont-Port Arthur is a moderate ozone nonattainment area which failed to attain by its November 15, 1996 deadline. Presently, the state of Texas is seeking our approval for a demonstration that Beaumont-Port Arthur is impacted by ozone transport from the Houston area, in order to support a request that we extend its attainment deadline to 2007 which would be the same as the deadline for Houston. We proposed action on this request on April 16, 1999 (64 FR 18864) and extended the comment period on June 3, 1999 (64 FR 29822). The modeling analysis indicates nonattainment in 2007 even under an emissions scenario that includes reductions that must be considered "further emission reductions" under CAA section 202(i).

We have also recently become aware of recent modeling by the state of Texas for the Dallas-Fort Worth metropolitan area.[15] Dallas has failed to meet its 1999 deadline for attainment Texas has made known its intent to seek an attainment date extension for this area. We have recently indicated to Texas that we will propose to approve its request for an attainment date extension to 2007, provided that the state can meet several necessary conditions one of which is to demonstrate attainment by that date. The state is conducting modeling analysis to identify its options for reaching attainment in Dallas by 2007. This modeling has been made public, and summaries of it have been put in the docket for this rulemaking. The modeling results to date indicate that even with the emission reductions from the Tier 2/Sulfur program, Dallas will be in nonattainment in 2007. This clearly demonstrates further reductions in emissions under CAA section 202(i) are needed to attain and maintain in this area.

We have not received any recent ozone modeling from California, because California submitted and we approved the SIPs for nonattainment areas in California some time ago, before our proposal for the Tier 2/Gasoline Sulfur program. However, the air quality situation and a recent SIP revision for one area in California support the conclusion that there is an overall need for further reductions in order to attain and maintain.

It is appropriate for us to consider the need for further emission reductions in order for areas in California to attain and maintain. California contains many of the most ozone-impacted areas in the nation. According to California, about 7 to 10 percent of all car and light truck travel

in California takes place in vehicles originally sold outside of California. Nine areas in California currently designated as nonattainment (and two counties currently designated as being in attainment) with a population of approximately 30 million have 1996-1998 design values above the 1-hour ozone NAAQS. Seven of the nonattainment areas have approved SIPs, including demonstrations of attainment for their required dates. The approved demonstrations did not depend on any reductions in emissions from more stringent standards for cars sold outside California, having been prepared prior to our proposal for these standards.

However, the state of California has recently filed an update to its State Implementation Plan for the South Coast Air Basin that expressly claims that the Tier 2 program will lead to four tons of reduced NOx emissions per day in the South Coast area in 2010, and includes this reduction in the attainment strategy for the area. [16] The four tons per day NOx reductions cited represents only a small fraction of the emission reductions needed in the South Coast to attain the NAAQS.

The state is developing yet another revision to the South Coast plan, which we understand will also depend in part on the emission reductions from Tier 2 vehicles originally sold out of state. We expect that California will be submitting one or more similar revisions including emission reductions from Tier 2 standards for some other areas, since it appears that some serious classification nonattainment areas in California with an attainment deadline of 1999 have not met that date. These areas are San Diego and the San Joaquin Valley. San Joaquin has had too many exceedances to be eligible for an extension other than through reclassification to severe or through an attainment extension based on overwhelming transport from an area with a later attainment date, while San Diego appears to be eligible for a 1-year attainment date extension under the provisions of CAA section 181(a)(5). We have not yet received an indication of California's intention in this regard, or any modeling which assesses whether these areas can attain before 2004 relying only on baseline measures with respect to CAA section 202(i)

Attainment of the 1-hour standard in the South Coast Air Basin, Southeast Desert, Sacramento, and Ventura nonattainment areas by their future attainment dates (2010 for the South Coast, 2007 for Southeast Desert, and 2005 for Sacramento and Ventura) remains the goal of California and EPA, but will be a challenging task. The difficulty of the task is reflected in ongoing litigation and settlement negotiations over both the design and the implementation of the attainment plans in the South Coast, for example. We believe that there is a possibility that some of these areas would not attain on schedule if we were not adopting the new standards for cars and light trucks, and the sulfur limits for gasoline sold outside of California.

f. Need for Further Reductions in Emissions in Order to Attain and Maintain

After considering the results of the exceedance method applied to the ozone concentrations predicted by the EPA ozone modeling described in Sections III.B.1,2, and 3, and

the conclusions from our review of the local ozone modeling described above, we determined which areas are certain or highly likely to require further reductions to attain and maintain, under the meaning of CAA section 202(i). Table III.B-1 in the preamble lists these areas.

We first considered all areas with predicted 2007 nonattainment according to the exceedance method applied to the EPA ozone modeling.

Areas which did not have a 1-hour ozone design value above the NAAQS in at least one of the 1995 to 1997 and 1996 to 1998 periods are not considered to be certain or highly likely to need further reductions, regardless of predictions of exceedances in our modeling. However, there were six areas predicted in the EPA modeling to have exceedances in 2007 which had design values of 90 to 100 percent of the NAAQS in at least one of these two periods. We consider these to have moderate risk of failing to attain and maintain without further emission reductions because meteorological conditions may be more severe in the future. These are Biloxi, Cleveland, Detroit, New Orleans, Pensacola, and Tampa.

Next, for Chicago, Milwaukee, and Greater Connecticut (Hartford and New London) we considered the SIP's successful demonstration of attainment relying only on baseline measures to be a sufficient reason not to consider these areas to be certain or highly likely to need further reductions. However, because of modeling uncertainties and the fact that these SIPs did not consider attainment and maintenance beyond the attainment date, we consider these areas to have a significant individual risk of failing to attain and maintain. Benton Harbor and Grand Rapids-Muskegon are included in this characterization also.

Because the SIP modeling analysis and the EPA exceedance method agreed on the nonattainment prospects for Houston, New York, Philadelphia, Baltimore, Atlanta, and Washington DC , excluding measures which would provide "further" reductions, we consider these to be certain or highly likely to require further emission reductions in order to attain and maintain the 1-hour ozone NAAQS.

Because the EPA modeling for Dallas did not successfully reproduce exceedances which actually occurred in 1995 we considered it at best inconclusive. The local modeling supports our conclusion that Dallas is certain or highly likely to need further reductions to attain and maintain.

Because the episode days in the EPA modeling did not include any on which Beaumont-Port Arthur experiences exceedances, yet exceedances have been observed, we considered the EPA modeling at best inconclusive. The local modeling led us to conclude that Beaumont-Port Arthur is certain or highly likely to need further reductions to attain and maintain. We included the Los Angeles-Riverside-San Bernardino CMSA (South Coast Air Basin) in this category as well, based on its reliance on Tier 2 reductions in its most recent SIP submittal.

C. Particulate Matter and Visibility/Regional Haze

1. Particulate Matter

a. Background on Particulate Matter

Particulate matter (PM) represents a broad class of chemically and physically diverse substances that exist as discrete particles (liquid droplets or solids) over a wide range of sizes. The NAAQS that regulates PM addresses only PM with a diameter less than 10 microns, or PM_{10}. The coarse fraction of PM_{10} are those particles which have a diameter in the range of 2.5 to 10 microns, and the fine fraction being those particles which have a diameter less than 2.5 microns, or $PM_{2.5}$. These particles and droplets are produced as a direct result of human activity and natural processes, and they are also formed as secondary particles from the atmospheric transformation of emissions of SOx, NOx, ammonia, and VOCs.

Natural sources of particles in the coarse fraction of PM_{10} include windblown dust, salt from dried sea spray, fires, biogenic emanation (e.g., pollen from plants, fungal spores), and volcanoes. Fugitive dust and crustal material (geogenic materials) comprise approximately 80 percent of the coarse fraction of the PM_{10} inventory as estimated by methods in use today.[20] Manmade sources of these coarser particles arise predominantly from combustion of fossil fuel by large and small industrial sources (including power generating plants, manufacturing plants, quarries, and kilns), wind erosion from crop land, roads, and construction, dust from industrial and agricultural grinding and handling operations, metals processing, and burning of firewood and solid waste. Coarse-fraction PM_{10} remains suspended in the atmosphere a relatively short period of time.

Most of the emission sources listed for coarse particles also have a substantial fine particle fraction. Their share of the $PM_{2.5}$ inventory is reduced somewhat, however, because of the role of other sources that give rise to primarily $PM_{2.5}$. The other sources of $PM_{2.5}$ include carbon-based particles emitted directly from gasoline and diesel internal combustion engines, and a large component of secondary sulfate-based particles (formed from SOx and ammonia), nitrate-based particles (formed from NOx and ammonia), and carbonaceous secondary particles (formed through transformation of VOC emissions). $PM_{2.5}$ from fugitive dust and crustal sources (geogenic materials) comprise approximately one-half of the directly emitted $PM_{2.5}$ inventory, substantially less than their share of coarse PM emissions. The presence and magnitude of

[20] There is evidence from ambient studies that emissions of these materials may be overestimated and/or that once emitted they have less of an influence on monitored PM concentrations than this inventory share would suggest.

crustal $PM_{2.5}$ in the ambient air is much lower even than suggested by this smaller inventory share, due to the additional presence of secondary PM from non-crustal sources and the removal of a large portion of crustal emissions close to their source. This near-source removal is a result of the lack of inherent thermal buoyancy, low release height, and interaction with their surroundings (impaction and filtration by vegetation).[17]

Secondary PM is dominated by sulfate particles in the eastern U.S. and parts of the western U.S., with nitrate particles and carbonaceous particles dominant in some western areas. Mobile sources can reasonably be estimated to contribute to ambient secondary nitrate and sulfate PM in proportion to their contribution to total NOx and SOx emissions. (EPA 1998, p. 44-45**)**

The sources, ambient concentration, and chemical and physical properties of PM_{10} vary greatly with time, region, meteorology, and source category. A first step in developing a plan to attain the PM_{10} NAAQS is to disaggregate ambient PM_{10} into the basic categories of sulfate, nitrate, carbonaceous, and crustal, and then determine the major contributors to each category based on knowledge of local and upwind emission sources. Following this approach, SIP strategies to reduce ambient PM concentrations have generally focused on controlling fugitive dust from natural soil and soil disturbed by human activity, paving dirt roads and controlling of soil on paved roads, reducing emissions from residential wood combustion, and controlling major stationary sources of PM_{10} where applicable. The control programs to reduce stationary, area, and mobile source emissions of sulfur dioxide, oxides of nitrogen, and volatile organic compounds in order to achieve attainment with the sulfur dioxide and ozone NAAQS also have contributed to reductions in the fine fraction of PM_{10} concentrations. In addition, the EPA standards for PM emissions from highway and nonroad engines are contributing to reducing PM_{10} concentrations. As result of all these efforts, in the last ten years, there has been a downward trend in PM_{10} concentrations, with a leveling off in the later years. (EPA 1998, p. 38)

Scientific studies have linked particulate matter (alone or in combination with other air pollutants) with a series of health effects.[18] Coarse particles can accumulate in the respiratory system and aggravate health problems such as asthma. Particles in motor vehicle exhaust emissions and the particles formed by the transformation of motor vehicle gaseous emissions tend to be in the fine particle range. 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. PM also causes damage to materials and soiling. It is a major cause of substantial visibility impairment in many parts of the U.S.

These effects are discussed further in EPA's “Staff Paper” and “Air Quality Criteria

Document" for particulate matter.[19]

There is additional concern regarding the health effects of PM from diesel vehicles, apart from the health effects which were considered in setting the NAAQS for PM_{10} and $PM_{2.5.}$ Diesel PM contains small quantities of chemical species that are known carcinogens, and diesel PM as a whole has been implicated in occupational epidemiology studies. We have considered these studies, and EPA's Office of Research and Development has recently submitted to a committee of our Science Advisory Board a draft assessment document which contains a proposed conclusion that diesel exhaust is a highly likely human cancer hazard and is a potential cause of other nonmalignant respiratory effects. The scientific advisory committee has met to discuss this document, and we are awaiting written review comments from the committee. We expect to submit a further revision of the document to the advisory committee before we make the document final.

b. PM_{10} Role of Cars and Light Trucks

Section A of this Chapter presents the estimates of PM emissions that were used for this rulemaking. PM emissions from mobile sources were estimated with newly developed models. PM emissions from other source categories were those from the most recent National Emissions Trends inventory process. Estimates of emissions were prepared at the county level, and then aggregated to higher levels for purposes of presentation.

The contribution of cars and light trucks to ambient PM_{10} concentrations can be assessed in simple fashion by comparing the estimates of direct PM_{10} emissions and of PM_{10} precursors emissions. This approach is subject to the uncertainties in those emission estimates, which can be large for many types of natural and stationary sources, and to uncertainties attributable to disregard for the locations and temporal patterns of emissions. An alternative approach to assessing role is to begin with measurements of the quantity and chemical identity of PM_{10} material collected on ambient filters, and apportion that material to sources based on the chemical identity of their emissions. The organic portion of PM_{10} can be analyzed for dozens of specific tracer compounds, allowing it to be apportioned with more sophistication. It is necessary to use estimates of inventory shares to apportion a single chemical class which has no tracer back to source type, for example sulfate PM_{10}.

Because of the current interest in $PM_{2.5,}$ most recent ambient-based source apportionment studies have focused on $PM_{2.5}$. Since virtually all of the PM_{10} attributable to cars and light trucks is also $PM_{2.5,}$ estimates of the mass concentration of $PM_{2.5}$ due to cars and trucks from these studies can be treated as estimates of PM_{10} as well. The 1997 Air Quality Trends Report presents a summary assessment based on studies across the country. Most of these studies identified PM composition only down to the nitrate/sulfate/crustal/carbonaceous level, requiring apportionment within each to be based on emission inventory estimates. In contrast, a recent

study in Denver made use of detailed analysis of the organic compounds within the carbonaceous fraction.

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. [20] 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.C-1.

Table III.C-1. 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.C-2.

Table III.C-2. 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.C-3. 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.C-3.

Table III.C-3. 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%

These results shown here within each $PM_{2.5}$ chemical fraction may be typical of urban areas, while the ratios between the chemical fractions may vary by area. Virtually all direct and secondary PM from gasoline vehicles is $PM_{2.5}$. The percentage contribution of gasoline vehicles to PM_{10} concentrations would be lower than for $PM_{2.5}$, after accounting for the crustal material PM and coarse-fraction PM from all sources.

A summary of several studies of the PM contribution, including the NFRAQS study just summarized, is given in Table III.C-4. The table also shows the researchers' estimate of the absolute contribution of gasoline vehicles to ambient PM.. This ranges to as high as about 8 $\mu g/m^{3.}$ The annual PM_{10} NAAQS is 50 $\mu g/m^3$ and the 24-hour NAAQS is 150 $\mu g/m^3$. On a percentage basis, gasoline vehicles can therefore contribute up to about 5 to 15 percent of the ambient loading allowed by the PM_{10} NAAQS. These findings for the most part apply to urban areas. In rural areas with less vehicle travel and/or better dispersion conditions the contribution would be less.

Source apportionment studies of the type summarized here have also addressed the contribution of diesel vehicles to ambient PM, but at the present time virtually all diesel PM is from vehicle classes other than cars and light trucks. The draft Health Assessment Document for Diesel Emissions contains a table similar to Table III.C-4 but for diesel PM contributions to ambient PM concentrations. This table is reproduced here as Table III.C-9, and discussed later in the context of the possibility of increased sales of diesel cars and light trucks.

Table III.C-4. Gasoline Vehicle/Engine Contribution to Ambient PM - from source apportionment reports

Author (Reference)	*Year of Sampling, No. days*	*Location Type*	*Source Profile Used*	*Location*	*Total PM2.5 (stdev), $\mu g/m^3$*	*Gas PM2.5 (stdev), $\mu g/m^3$*
Friedlander, 1973 [21]	1969, 1 day	Urban	EC, OC total, Elements	Pasadena	nr	8.2% of aerosol mass**
Gartrell and Friedlander, 1974 [22]	Sept/Oct 1972 1 day each site		EC, OC total, Elements, Major Ions	Pasadena Pomona Riverside Fresno San Jose	64 (7) 180 (20) 125 (14) 207 (23) 189 (21)	5.1 (0.15) 7.2 (0.3) 3.9 (0.15) 2.2 (0.1) 8.3 (0.33)
Schauer et al., 1996 Southern California [23]	1982, 60 days (one every sixth day)	Urban Urban Suburban Urban	OC Species, EC, Elements	West LA Pasadena Rubidoux Downtown LA	24.5 (2.0) 28.2 (1.9) 42.1 (3.3) 32.5 (2.8)	1.44 (0.16) 1.63 (0.20) 0.34 (0.05) 2.12 (0.23)
Lowenthal et al., 1992 [24]	1989, 59 days (one every sixth day)		EC, OC total, Elements, Major Ions	Santa Barbara, CA	36.5*	4.0 (2.2)*
Wittorff,1994 [25]	Spring, 1993, 3 days	Urban Bus Stop	EC, OC total, Elements, Major Ions	Manhattan, NY	35.8-83.0*	4.2 (avg) 7% of total PM on average
NFRAQS, 1998	Winter, 1996-97, 60 days	Urban Suburban	OC Species, EC, Elements, Major ions	Welby, CO Brighton, CO	16.7 12.4	6.51 (39%) 3.35 (27%)

*PM10, **TSP? OC: Organic Carbon EC: Elemental Carbon
† Not available Major Ions: nitrate, sulfate, chloride and in some cases ammonium, sodium, potassium
nr=not reported

c. Current PM_{10} Nonattainment

PM_{10} attainment status for the period 1996-1998 was developed through an analysis of data obtained from the Aerometric Information Retrieval System (AIRS) on October18, 1999. The attainment determination was based on the concepts outlined for the pre-existing National Ambient Air Quality Standards (NAAQS), and represent an exceedance-based form of the standard. [26] The PM_{10} NAAQS has a requirement that an area conducting 1 in 6 day sampling increase sampling frequency to daily frequency upon recording a violation. If this procedure is not followed, then an "estimate" of the number of exceedances expected is calculated for that year. Some areas considered nonattainment in this recent analysis have fewer than four actual monitored 24-hour exceedances. The analysis was not subjected to a review by the EPA Regional Offices, who have an important role in verifying and validating these data. The analysis therefore represents an upper bound of the number of areas that could potentially be in violation of the 1987 PM_{10} NAAQS.

The most recent PM_{10} monitoring data indicates that 15 designated PM_{10} nonattainment counties, with a population of almost 9 million in 1996, violated the PM_{10} NAAQS in the period 1996-1998. The areas that are violating do so because of exceedances of the 24-hour PM_{10} NAAQS. No areas had monitored violations of the annual standard in this period. Table III.C-5 lists the 15 counties. The table also indicates the classification for each area and the status of our review of the State Implementation Plan. SIP status was obtained from an EPA data base based on Federal Register actions. Maricopa County, AZ, did have an approved SIP as a moderate PM_{10} nonattainment area. It has been reclassified as a serious area, and has not received approval for serious area SIP requirements.

Although we do not believe that we are limited to considering only designated nonattainment areas in implementing CAA section 202(i), we have focused on the designated areas in the case of PM_{10}. An official designation of PM_{10} nonattainment indicates the existence of a confirmed PM_{10} problem that is more than a result of a one-time monitoring upset or a results of PM_{10} exceedances attributable to natural events. In addition to these designated nonattainment areas, there are 15 unclassified counties in 12 geographically spread out states, with a 1996 population of over 4 million, for which the state has reported PM_{10} monitoring data for this period indicating a PM_{10} NAAQS violation. We have not yet excluded the possibility that a one-time monitoring upset or a natural event(s) is responsible for the monitored violations in 1996-1998 in the 15 unclassified counties. We adopted a policy in 1996 that allows areas whose PM_{10} exceedances are attributable to natural events to remain unclassified if the state is taking all reasonable measures to safeguard public health regardless of the source of PM_{10} emissions. The policy was reiterated after the PM NAAQS were revised. [27] Areas that remain unclassified areas are not required to submit attainment plans, but we work with each of these areas to understand the nature of the PM_{10} problem and to determine what best can be done to reduce it. The Tier 2/Gasoline Sulfur program will reduce PM_{10} concentrations in these 15 unclassified counties, because all have car and light truck travel that contributes to PM_{10} and

precursor emissions loadings. This reduction will assist these areas in reducing their PM_{10} nonattainment problem, if a problem is confirmed upon closer examination of each local situation.

Boise, ID, had also been classified as a PM_{10} nonattainment area at one time and was monitored to have a PM_{10} NAAQS violation in 1996-1998. However, the pre-existing PM_{10} NAAQS does not presently apply in Boise, ID, because in the period between our revision of the old PM_{10} NAAQS and the Court's decision to vacate the revised PM_{10} NAAQS, we determined that Boise was in attainment with the old PM_{10} NAAQS and that it therefore no longer applied in that area.

Table III.C-5. Fifteen PM_{10} Nonattainment Areas Violating the PM_{10} NAAQS in 1996-1998

Area	*Classification*	*SIP Approved?*	*1996 Population (millions)*
Clark Co., NV	Serious	No	0.93
El Paso, TX	Moderate	Yes	0.67
Gila, AZ	Moderate	No	0.05
Imperial Co., CA	Moderate	No	0.14
Inyo Co., CA	Moderate	No	0.02
Kern Co., CA	Serious	No	0.62
Mono Co., CA	Moderate	No	0.01
Kings Co., CA	Serious	No	0.11
Maricopa Co., AZ	Serious	No	2.61
Power Co., ID	Moderate	No	0.01
Riverside Co., CA	Serious	No	1.41
San Bernardino Co., CA	Serious	No	1.59
Santa Cruz Co., AZ	Moderate	No	0.04
Tulare Co., CA	Serious	No	0.35
Walla Walla Co., WA	Moderate	Yes	0.05
		TOTAL POPULATION	8.61

d. Future Nonattainment

Because the types and sources of PM_{10} are complex and vary from area to area, the best projections of future PM_{10} concentrations are the local emission inventory and air quality modeling analyses that states have developed or are still in the process of developing for their PM_{10} attainment plans. We do employ a modeling approach, known as the source-receptor matrix approach, for relating emission reductions to PM_{10} reductions on a national scale. This

approach is one of our established air quality models for purposes of quantifying the health and welfare related economic benefits of PM reductions from major regulatory actions. One application of this modeling approach was for the Regulatory Impact Analysis for the establishment of the new PM NAAQS.[28] This model is also the basis for the estimates of PM_{10} (and $PM_{2.5}$) concentrations reductions we have used to estimate the economic benefits of the Tier 2/Gasoline Sulfur program in 2030. Its use for this purpose is described in the final RIA for the Tier 2/Gasosline Sulfur rule. In both applications, we modeled an emissions scenario corresponding to controls currently in place or committed to by states. As such, this scenario is an appropriate baseline for determining if further reductions in emissions are needed in order to attain and maintain the PM_{10} NAAQS.

In the RIA for the establishment of the PM NAAQS, we projected that in 2010 there will be 45 counties not in attainment with the original PM_{10} NAAQS . We cited these modeling results in our proposal for the Tier 2/Gasoline Sulfur program and in our first supplemental notice. After reviewing public comments on our presentation of these modeling results, we have concluded that while the source-receptor matrix approach is a suitable model for estimating PM concentration reductions for economic benefits estimation, it is not a tool we can use with high confidence for predicting that individual areas that are now in attainment will become nonattainment in the future. However, we believe the source-receptor matrix approach is appropriate for, and is a suitable tool for, determining that a current designated nonattainment area has a high risk of remaining in PM_{10} nonattainment at a future date. Therefore, we have cross-matched the results for 2030 from our final RIA for Tier 2 and the list of current PM_{10} nonattainment areas with monitored violations in 1996 to 1998 shown in Table III.C-5.

Based on this modeling, we conclude that the 8 classified nonattainment areas shown in Table III.C-6 have a high risk of failing to attain and maintain without further emission reductions. These areas have a population of nearly 8 million. Included in the group are the counties that are part of the Los Angeles, Phoenix, and Las Vegas metropolitan areas, where traffic from cars and light trucks is substantial. California areas will benefit from the Tier 2/Gasoline Sulfur program because of travel within California by vehicles originally sold outside the state, and by reduced poisoning of catalysts from fuel purchased outside of California.

We used the more recent modeling for 2030 rather than the earlier modeling for 2010, because the modeling for 2030 incorporates more recent estimates of emissions inventories. Our emission estimates in our final RIA indicate that PM_{10} emissions under the baseline scenario increase steadily between 1996 and 2030, for 47 states combined and for four specific cities, suggesting that areas in nonattainment in both 1996-1998 and 2030 will be in nonattainment in the intermediate years as well assuming no further emission reductions. A factor tending to make Table III.C-6 shorter is that we have not relied on the source-receptor matrix model's prediction of 24-hour nonattainment, as those predictions on an individual area basis are less reliable than the predictions of annual average nonattainment.

Table III.C-6. Eight areas with a high risk of failing to attain and maintain the PM_{10} NAAQS without further reductions in emissions.

Area	*1996 Population (millions)*
Clark Co., NV	0.93
Imperial Co., CA	0.14
Kern Co., CA	0.62
Kings Co., CA	0.11
Maricopa Co., AZ	2.61
Riverside Co., CA	1.41
San Bernardino Co., CA	1.59
Tulare Co., CA	0.35
TOTAL POPULATION	7.76

Taken together and considering their number, size, and geographic distribution, these 8 areas are sufficient to establish the case that additional reductions are needed in order to attain and maintain the PM_{10} NAAQS. This determination provides additional support for the NOx and VOC standards and for the limits on gasoline sulfur, which are also fully supported on ozone attainment and health effects considerations. The sulfate particulate, sulfur dioxide, NOx, and VOC emission reductions from the Tier 2/Gasoline Sulfur program will help the 8 areas in Table III.C-2 to attain and maintain the PM_{10} NAAQS. The new PM standards for gasoline and diesel vehicles is also supported by this PM_{10} determination. We are also establishing the new PM standard today to avoid the possibility that PM_{10} concentrations in these and other areas do not actually get worse due to an increase in sales of diesel vehicles, which could create a need for further reductions which would be larger and would affect more areas of the country.

Table III.C-6 is limited to designated PM_{10} nonattainment areas which both had monitored violations of the PM_{10} NAAQs in 1996-1998 and are predicted to be in nonattainment in 2030 in our PM_{10} air quality modeling. This gives us high confidence that these areas require further emission reductions to attain and maintain, but does not fully consider the possibility that there are other areas which are now meeting the PM_{10} NAAQS which have at least a significant probability of requiring further reductions to continue to maintain it. Our air quality modeling predicted 2030 violations of the annual average PM_{10} NAAQS in five additional counties that in either 1997 or 1998 had single-year annual average monitored PM_{10} levels of at least 90 percent of the NAAQS, but did not exceed the formal definition of the NAAQS over the three-year period ending in 1998. These areas were identified from the most recent published EPA Air Quality Trends Report (USEPA 1998) and from tables that have been prepared for inclusion in the next update of the Air Quality Trends report.[29] In two of these areas, New York Co., NY and Harris Co., TX, the average PM_{10} level in 1998 was above the 50 $\mu g/m^3$ value of the

NAAQS. These two areas are not included in the Table III.C-6 list of 15 areas with a high risk of failing to attain and maintain because lower PM_{10} levels in 1996 and 1997 caused their three-year average PM_{10} level to be lower than the NAAQS.

These five areas were listed based on their second high 24-hour concentration and annual average concentration in 1997 or 1998 only. Actual nonattainment determinations are made based on three years of data, and on estimates of expected exceedances of the 24-hour standard. The second-high 24-hour PM_{10} level in 1998 is only an approximate surrogate for the outcome of an expected exceedances calculation since other years of data and the frequency of monitor operation would also enter the calculation.

The five additional counties are shown in Table III.C-7. They have a combined population of almost 17 million, and a broad geographic spread. Unlike the situation for ozone, for which precursor emissions are generally declining over the next 10 years or so before beginning to increase, we estimate that emissions of PM_{10} will rise steadily unless new controls are implemented. The small margin of attainment which these areas currently enjoy will likely erode; the PM air quality modeling suggests that it will be reversed. We therefore consider these areas to each individually have a significant risk of failing to maintain the NAAQS without further emission reductions. There is a substantial risk that at least some of them would fail to maintain without further emission reductions. The emission reductions from the Tier 2/Gasoline Sulfur program will help to keep them in attainment.

Table III.C-7. Five areas with a significant risk of failing to attain and maintain the PM_{10} NAAQS without further reductions in emissions

Area	*1996 Population (millions)*
New York Co., NY	1.33
Cuyahoga Co., OH	1.39
Harris, Co., TX	3.10
San Diego Co., CA	2.67
Los Angeles Co., CA	8.11
TOTAL POPULATION	16.6

In addition to the counties already listed in Tables III.C-5 and III.C-7, there are other areas for which 1997 and 1998 data indicate that maintenance of the PM_{10} NAAQS is at risk, particularly if diesel sales of cars and light truck increase as discussed below. Table III.C-8 lists additional counties for which either 1997 or 1998 monitoring data, or both, indicated a second-high PM_{10} concentration for the single year within 10 percent of the PM_{10} 24-hour NAAQS or an annual average PM_{10} concentration within 10 percent of the annual average PM_{10} NAAQS. Our

Source-Receptor Matrix modeling of annual average PM_{10} concentrations in these areas did not indicate nonattainment in 2030, but the margin of attainment they currently enjoy is small. Only counties which are part of metropolitan statistical areas are listed in Table III.C-8, in order to focus on those in which traffic densities are high. Considering both the annual and 24-hour NAAQS, there were 13 areas within 10 percent of the standard.

Table III.C-8. Thirteen metropolitan statistical area counties with 1997 and/or 1998 ambient PM_{10} concentrations within 10 percent of the annual or 24-hour the PM_{10} NAAQS.*

	1996 Population (millions)
Areas within 10 percent of the annual PM_{10} NAAQS	
Lexington Co., SC	0.20
Union Co., TN	0.02
Washoe Co., NV	0.30
Madison Co., IL	0.26
Dona Ana Co., NM	0.16
El Paso Co., TX	0.68
Ellis Co., TX	0.97
Fresno Co., CA	0.74
Philadelphia Co., PA	1.47
Areas within 10 percent of the 24-hour PM_{10} NAAQS	
Lexington Co., SC	0.20
El Paso Co., TX	0.68
Union Co., TN	0.02
Mobile Co., AL	0.40
Dona Ana Co., NM	0.16
Lake Co., IN	0.48
Philadelphia Co., PA	1.47
Pennington Co., SD	0.09
Ventura Co., CA	0.71
TOTAL POPULATION OF ALL 13 AREAS	6.48

* These areas are listed based on their second high 24-hour concentration and annual average concentration in 1997, 1998, or both. Official nonattainment determinations are made based on three years of data, and on estimates of expected exceedances of the 24-hour standard.

e. Diesel PM

At the present time, virtually all cars and light trucks being sold are gasoline fueled. The ambient PM_{10} air quality data for 1996 to 1998 reflects that current situation, and the predictions of future PM_{10} air quality are based on an assumption that this will continue to be true. However, we are concerned over the possibility that diesels will become more prevalent in the car and light-duty truck fleet, since automotive companies have announced their desire to increase their sales of diesel cars and light trucks. As current diesel vehicles emit higher levels of PM_{10} than gasoline vehicles, a larger number of diesel vehicles could dramatically increase levels of exhaust PM_{10}, especially if more stringent standards are not in place. The new PM standards will ensure that an increase in the sales of diesel cars and light trucks will not increase PM emissions from cars and light trucks so substantially as to endanger PM_{10} attainment and maintenance on a more widespread basis. Given this potential, it is appropriate to establish the new PM standards now on the basis of the increase in sales of diesel vehicles being a reasonable possibility without such standards. Establishing the new PM standards now avoids the public health impact and industry disruption that could result if we waited until an increase in sales of diesels with high PM emissions had already occurred.

In order to assess the potential impact of increased diesel sales penetration on PM emissions, we analyzed the increase in PM_{10} emissions from cars and trucks under a scenario in which the use of diesel engines in cars and light trucks increases. We used projections developed by A.D. Little, Inc. as part of a study conducted for the American Petroleum Institute. The "Most Likely" case projected by A.D. Little forecasts that diesel engines' share of the light truck market will grow to 24 percent by the 2015 model year. Diesel engines' share of the car market would grow somewhat more slowly, reaching 9 percent by 2015. The A.D. Little forecasts did not address the period after 2015; we have assumed that diesel sales stabilize at the level reached in 2015, with the fraction of in-use vehicles with diesel engines continuing to increase through turnover. We believe these projections are more realistic than the scenario of even higher sales of diesels described in the notice for the proposed Tier 2/Gasoline Sulfur program, though the A.D. Little forecasts still show much higher percentages of diesel vehicles in the light-duty fleet than have ever existed historically in the U.S.

The A.D. Little "most likely" scenario of increased diesels would result in dramatic increases in direct PM_{10} emissions from cars and light trucks, if there were no change in these vehicles' PM standards. The increase in diesel exhaust PM_{10} emissions would more than overcome the reduction in direct PM_{10} attributable to the sulfur reduction in gasoline. With no change in the existing PM standards for cars and light trucks, our analysis of this scenario shows that direct PM_{10} emissions in 2020 would be approximately 98,000 tons per year, which is nearly two times the 50,000 tons projected if diesel sales do not increase. The increase in diesel PM would be somewhat larger than the 48,000 ton difference between these two values, since the

difference also reflects the lower amount of PM from gasoline vehicles due to fewer gasoline vehicles in operation. The portion of ambient PM_{10} concentrations attributable to cars and light trucks would climb steadily.

The added PM_{10} emissions from cars and trucks due to an increase in diesel sales without action to reduce PM_{10} from each diesel vehicle would exacerbate the PM_{10} nonattainment problems of the areas listed in Tables III.C-6 and III.C-7, for which our air quality modeling predicted future nonattainment even without an increase in diesel sales. Moreover, it might cause PM_{10} nonattainment in the additional areas listed in Table III.C-8. Increases in PM_{10} emissions from more diesel vehicles would put these areas in greater risk of violating the PM_{10} NAAQS, especially if growth in other sources is high or meteorological conditions are more adverse than in the 1996 to 1998 period.

We have considered two approaches to quantifying the increased risk of PM_{10} nonattainment that could results from the additional PM emissions from more diesel cars and trucks. First, Section D of this chapter presents estimates of the population exposure to diesel PM that would result from higher diesel sales, with and without the more stringent PM emission standards. Table III.D-9 and the text preceding it indicate that increased sales of cars and light trucks without a more stringent PM emission standard could increase personal exposure to diesel PM by about 0.2 $\mu g/m^3$. The exposure estimates in Section D estimates are based on an approach in which estimated personal exposures to carbon monoxide are adjusted based on ratios of emission inventories. They therefore incorporate the effect of personal movement among micro environments with more or less direct exposure to emissions and ambient air, and relate only indirectly to the monitored PM_{10} levels that determine attainment or nonattainment.

Our second approach to making a rough estimate of the possible contribution of diesel cars and light trucks to ambient PM_{10}, assuming the PM emission standard were not being made more stringent, was to first estimate the contribution of heavy-duty diesel vehicle PM to ambient PM_{10} for a historical period, and then adjust this by a PM emission inventory ratio of the quantity of diesel emissions associated with the historical contribution to ambient PM and the quantity that would be emitted from diesel cars and light trucks on a future date if sales of diesel cars and trucks did increase. The following paragraphs present an analysis along these lines.

The draft Health Assessment Document for Diesel Emissions includes a summary of the diesel PM findings of several source apportionment studies. The most commonly used receptor model for quantifying concentrations of diesel PM at a receptor site is the chemical mass balance model (CMB). Input to the CMB model includes PM measurements made at the receptor site as well as measurements made of each of the source types suspected to impact the site. Due to problems involving the elemental similarity between diesel and gasoline emission profiles and their co-emission in time and space, it is necessary to carefully quantify chemical molecular species which provide markers for separation of these sources (Lowenthal et al., 1992). Recent advances in chemical analytical techniques have facilitated the development of sophisticated

molecular source profiles including detailed speciation of organic compounds which allow the apportionment of PM to gasoline and diesel sources with increased certainty. Older studies which made use of only elemental source profiles have been published and are summarized here, but are subject to more uncertainty.

The CMB model has been used to assess the contribution of diesel PM to total PM mass in areas of California, Denver, CO, Phoenix, AZ, and Manhattan, NY (Table III.C-9). Diesel PM concentrations reported by Schauer et al. (1996) for data collected in 1982 ranged from 4.4 $\mu g/m^3$ in west Los Angeles to 11.6 $\mu g/m^3$ in Downtown Los Angeles. The average contribution of diesel PM to total PM mass ranged from 13 percent in Rubidoux to 36 percent in downtown Los Angeles. It should be noted that this model accounts for primary emissions of diesel PM only and the contribution of secondary aerosol formation (both acid and organic aerosols) is not included. In sites downwind from urban areas, such as Rubidoux in this study, secondary nitrate formation can account for a substantial fraction of the mass (25 percent of the fine mass measured in Rubidoux was attributed to secondary nitrate), a portion of which comes from diesel exhaust.[30]

Table III.C-9. Ambient Diesel PM Concentrations Reported from Chemical Mass Balance Modeling

Author	*Year of Sampling, No. days*	*Location*	*Location Type*	*Source Profile Used*	*Total PM2.5 (stdev), $\mu g/m^3$*	*Diesel PM2.5 (stdev), $\mu g/m^3$*
Schauer et al., 1996 Southern California	1982, 60 days (one every sixth day)	West LA Pasadena Rubidoux Downtown LA	Urban Urban Suburban Urban	OC Species, EC, Elements	24.5 (2.0) 28.2 (1.9) 42.1 (3.3) 32.5 (2.8)	4.4 (0.6) 5.3 (0.7) 5.4 (0.5) 11.6 (1.2)
Chow et al., 1991	Winter, 1989-90 †	Phoenix, AZ Area	Urban	†	†	4-22*
California EPA, 1998	1988-92, approx. 150 days	15 Air Basins	Rural-Urban	EC, OC total, Elements, Major Ions	†	0.2-3.6*
Wittorff, 1994	Spring, 1993, 3 days	Manhattan, NY	Urban Bus Stop	EC, OC total, Elements, Major Ions	35.8-83.0	13.2-46.7*
NFRAQS, 1998	Winter, 1996-97, 60 days	Welby, CO Brighton, CO	Urban Suburban	OC Species, EC, Elements, Major ions	16.7 12.4	1.7 1.2

*PM10
† Not available
OC: Organic Carbon EC: Elemental Carbon
Major Ions: nitrate, sulfate, chloride and in some cases ammonium, sodium, potassium

A wintertime study conducted in the Phoenix, AZ area by Chow et al.,[31] indicated that diesel PM levels on single days can range from 4 $\mu g/m^3$ in west, and central Phoenix, to 14 $\mu g/m^3$ in south Scottsdale and 22 $\mu g/m^3$ in central Phoenix. This apportionment, like the Schauer et al., (1996) data, reflects direct emissions only. These data relied on source profiles and ambient data collected prior to the introduction of technology to reduce PM emissions from diesel-powered vehicles. This study has not appeared in the peer reviewed literature.

A second CMB study reported ambient diesel PM concentrations for California and used ambient measurements from the San Joaquin Valley (1988-89), South Coast (1986), and San Jose (winters for 1991-92 and 1992-93).[32] The incorporation of sampling data from later dates provides information regarding exposures more relevant to current levels. The CMB in the California study (1998a) indicated that on an annual basis, basin-wide levels of direct diesel PM emissions may be as low as 0.2 $\mu g/m^3$ in the Great Basin Valleys and as high as 3.6 $\mu g/m^3$ in the South Coast basin.

The most recent study reporting diesel PM concentrations is from winter 1996-1997 sampling conducted in the Denver, CO area as part of the Northern Front Range Air Quality Study (NFRAQS, 1998). Ambient levels of diesel PM in the urban core site at Welby averaged 1.7 $\mu g/m^3$ over a 60-day winter period and a slightly lower average concentration of 1.2 $\mu g/m^3$ was measured at an urban downwind site in Brighton, CO. One of the major findings from this study was a substantial contribution of elemental carbon from gasoline-powered vehicles. At the Welby site, the contribution of diesel and gasoline emissions to elemental carbon measurements was 52 percent and 42 percent, respectively. At the Brighton site, the contribution of diesel and gasoline emissions to elemental carbon measurements was 71 percent and 26 percent, respectively. The findings from the NFRAQS study are compelling and suggest the need for further investigations of this type that specifically address high-emitting vehicles. Geographical and other site-specific parameters that influence PM concentrations, such as altitude, must be considered when extrapolating the NFRAQS findings to other locations

Limited data are available which allow a characterization of diesel PM concentrations in 'hot spots' such as near heavily traveled roadways, bus stations, train stations, and marinas. One 'hotspot' study conducted in Manhattan, NY reported diesel PM concentrations of 13.0 to 46.7 $\mu g/m^3$ during a three-day sampling period in the spring of 1993 (Wittorff,1994). This study attributed, on average, 50 percent of the PM to diesel exhaust. The diesel PM concentrations resulting from the source apportionment method used in this study require some caution. The CMB model overpredicted PM10 concentrations by an average 30 percent, suggesting that additional sources of the mass were not accounted for in the model. New advances in organic carbon speciation, as has been noted above, are necessary to most appropriately characterize gasoline and diesel PM sources to ambient PM measurements. The relevance of the Manhattan bus stop exposure for large urban populations provides strong motivation for further studies in the vicinity of such 'hotspots'. This study has not appeared in the peer reviewed literature.

In summary, recent source apportionment studies (California EPA, 1998; NFRAQS, 1998) indicate that ambient diesel PM concentrations averaged over 2-12 month periods for urban/suburban areas can range from approximately 1.2 $\mu g/m^3$ to 3.6 $\mu g/m^3$, while diesel PM concentrations in more rural/remote areas are generally less than 1.0 $\mu g/m^3$. In the vicinity of 'hot spots', or for short exposure times under episode-type conditions diesel PM concentrations are expected to be substantially higher than these levels, as high as 22 and 47 $\mu g/m^3$. However, a thorough and replicated characterization of these situations is not yet available. Two studies nearing completion by the South Coast Air Quality Management District will shed some light on near-highway concentrations of diesel PM.[33]

To quantify the potential contribution that diesel cars and light trucks may make to ambient PM10 concentrations, we have used the four numbers cited in the previous paragraph (1.2, 3.6, 22, and 47 $\mu g/m^3$) as starting points, recognizing that the latter two values have considerable uncertainty for reasons explained above. We assume that these estimated ambient concentrations are attributable to highway diesel vehicles, and specifically to heavy-duty vehicles because of the near-zero use of diesel engines in other classes in the time frames of these studies.[21]

Table III.C-10 summarizes this analysis, combining key findings from the studies just summaried with emissions estimates from the Tier 2 analysis, to predict increases in PM10 in 2030. A needed detail from the 47-state inventories described in Section A of this chapter is that 47-state PM emissions from all diesel vehicles in 1996 (the year of NFRAQS) was 160,109 tons. This figure must be adjusted to the time frame for each of the other three estimates of ambient diesel PM concentration. We have done this using the emissions trends given in the 1997 Emission Trends report, applying the ratio of two calendar year's 50-state emissions to the 47-state estimate for 1996.[34] The 2030 PM emissions from diesel cars and light trucks under the scenario of higher diesel car and light truck sales without more stringent PM emission standards would be 77,421 tons.

The final columns of Table III.C-10 suggest that with higher sales of diesel cars and light trucks, they could contribute between 0.6 to 20 $\mu g/m^3$ to PM_{10} concentrations. This would represent between one-half and 40 percent of the PM_{10} concentration allowed by the NAAQS, with the upper end of this range based on studies conducted in roadside situations with heavy traffic and using older and more simple approaches to source apportionment.

[21] Non-road diesel engines also operate in urban areas, and may actually have contributed somewhat to the ambient concentrations observed in the various studies. To the extent that they did, the estimates of the possible future contribution to ambient PM from diesel cars and light trucks would be overestimates.

Table III.C-10. Estimation of Potential Contribution of Diesel Cars and Light Trucks to Ambient PM_{10} Concentrations in 2030

Study Used as Starting Point	*Ambient PM10 from Diesels in Study $\mu g/m^3$*	*Assumed Year of Study*	*Highway Heavy-Duty Diesel PM10 Emissions at Time of Study (47-state annual tons) **	*2030 Light-Duty Diesel PM10 Emissions (47-state annual tons)***	*Estimate of 2030 Ambient PM10 from Light-Duty Diesels ($\mu g/m^3$)****	*Percentage of 24-hour PM10 NAAQS*	*Percentage of Annual PM10 NAAQS*
NFRAQS, 1998	1.2	1996	160,109	77,421	0.6	0.4 %	1.2 %
California EPA, 1998	3.6	1990	213,479	77,421	1.3	0.9 %	1.8 %
Chow et al., 1991	22	1990	213,479	77,421	8.0	5.3 %	16.0 %
Wittorff, 1994	47	1993	181,175	77,421	20.1	13.4 %	40.2 %

* Interpolated from EPA Emissions Trends Report.
** Derived from estimates in Section A of this chapter.
*** Concentration estimate from study multiplied by ratio of emissions estimates.

The standards included in today's actions will result in a steady decrease in total direct PM_{10} from cars and light trucks even if this increase in the use of diesel engines in these vehicles were to occur. If the A.D. Little scenario for increased diesel engines in light trucks were to occur, today's actions would reduce diesel PM_{10} from cars and light trucks by over 75 percent in 2020. Stated differently, by 2030 today's actions would reduce over 93,000 tons of the potential increase in PM_{10} emissions from passenger cars and light trucks. The result would be less direct PM_{10} than is emitted today, because the increase in diesel PM_{10} would be more than offset by the reduction in gasoline PM_{10}.

It should be noted that the analysis of the economic benefits of the Tier 2/Gasoline Sulfur program does not include any effects related to the possible increase in sales of diesel cars and light trucks or the to the control of the PM increase that would otherwise occur if the PM standard were not being revised.

Fortunately, the standards included in today's actions will result in a steady decrease in total direct PM_{10} from cars and light trucks even if this increase in the use of diesel engines in these vehicles were to occur. If the A.D. Little scenario for increased diesel engines in light trucks were to occur, today's actions would reduce diesel PM_{10} from cars and light trucks by over 75 percent in 2020. Stated differently, by 2030 today's actions would reduce over 93,000 tons of the potential increase in PM_{10} emissions from passenger cars and light trucks. The result would be less direct PM_{10} than is emitted today, because the increase in diesel PM_{10} would be more than offset by the reduction in gasoline PM_{10}.

We are establishing tighter PM standards for diesel vehicles because of the impact greater diesel PM emissions would have on PM_{10} attainment and public health and welfare if diesel sales increased in the future without the protection of the tighter standards. Because diesel vehicles will essentially be performing the same functions as the gasoline vehicles they will replace, it is appropriate for the new PM standards to also apply equally to gasoline and diesel vehicles. We expect that gasoline vehicles will need little or no redesign to meet the new PM standards when free of defects and properly operating. However, the new standards may achieve some reduction in real world PM emissions from gasoline vehicles by encouraging more durable designs. The new standards for PM will also prevent any changes in gasoline engine design which would increase PM emissions. These changes would otherwise be possible because of the current PM standard is so much higher than the current performance on the gasoline vehicles.

f. Reductions In Ambient PM

In general, we project that the Tier 2/Gasoline Sulfur program will reduce both direct and secondary PM from cars and light trucks substantially, regardless of the future market share for diesel engines in the light-duty fleet. The larger part of the reduction is due to large reductions in VOC, NOx, and SOx emissions, with corresponding reductions in secondary PM formation.

Low sulfur fuel will greatly reduce direct PM emissions and sulfate-based secondary PM formation from SOx emissions from gasoline vehicles, while tailpipe PM standards are projected to mitigate excess PM emissions from diesel vehicles, even at very aggressive rates of diesel vehicle sales growth. Substantial reductions in NOx emissions will carry over to reductions in indirect PM. These reductions will help reduce the number of areas with PM_{10} and $PM_{2.5}$ levels in excess of national standards, reduce the severity of PM nonattainment in other areas, and help areas facing PM maintenance challenges stay in attainment.

The magnitude of the PM reductions from today's actions in a given area depends on conditions such as the contribution of light-duty vehicles to the local PM, SOx, NOx, and VOC inventory; the contribution of light-duty vehicles to the PM, SOx, NOx, and VOC inventories in upwind areas; local and upwind ammonia inventories (involved in secondary PM formation); control measures being implemented on both local and upwind sources of PM and its precursors, and local meteorology. We have incorporated these factors into the air quality modeling used to develop the benefit/cost analysis presented in Chapter VII, which includes the economic benefits of the direct and secondary PM reductions expected to result from today's actions. The estimates of annual average ambient $PM_{2.5}$ reductions with full program implementation and phase-in in 2030 are presented in a contractor report that was part of the benefit/cost analysis. Reductions are given as an average for each state, and in the form of a shaded map. Reductions are larger in urban areas than rural, and larger in the east than in the sparsely populated areas of the west. The $PM_{2.5}$ reductions and PM_{10} reductions are essentially equal. State-wide average ambient PM reductions range from 0.04 $\mu g/m^3$ in Nevada, reflecting its large areas with low vehicle travel, to 0.45 $\mu g/m^3$ in Washington, DC. Much of the eastern half of the U.S. is estimated to have a reduction of at least 0.20 $\mu g/m^3$, with the largest reduction in any county being 1.25 $\mu g/m^3$.

2. Visibility/Regional Haze

Visibility is greatly affected by ambient $PM_{2.5}$ concentration, with $PM_{2.5}$ concentrations below the NAAQS being sufficient to impair visibility. The reductions in ambient $PM_{2.5}$ from the Tier 2/Gasoline Sulfur program will contribute to visibility improvements across the U.S. The geographical pattern of the improvement mirrors that of the $PM_{2.5}$ reductions. Visibility improvements have value to Americans in both recreational areas traditionally known for scenic vistas, and in the urban areas where people spend most of their time.

The Grand Canyon Visibility Transport Commission examined visibility impairment on the Colorado Plateau. Figures II-4 and II-5 in the Commission's contain estimates for the contribution of 11 different sources to the man-made visibility impairment at Hopi Point[35]. Figure II-4 is for annual average light extinction[22] and Figure II-5 for the worst days. Each

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

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. Emissions inventory estimates generally suggest a greater role for road dust than is suggested by studies of ambient PM. This discrepancy is thought to result from the generally shorter atmospheric residence time for road dust due to its greater size and lack of inherent thermal buoyancy, as well as its greater filtration by vegetation, than other sources of PM. Therefore, the contribution of road dust may be overstated in the estimates described in the preceding paragraph. 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 the reductions in highway vehicle emissions from the Tier 2/Gasoline Sulfur program can contribute significantly to improved visibility on the Colorado Plateau.

The economic benefits analysis reported in Chapter VII included modeling to determine the degree of visibility improvement, and estimated the economic value of visibility improvements in both recreational and residential settings.

D. Air Toxics

This section summarizes our analysis of the impact of the final Tier 2 standards on emissions of and exposure to air toxics. Section D.1 reviews the effects of selected air toxics emissions on human health. Section D.2 describes our analysis of air toxics emissions and exposure and the effect that the proposed Diesel 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 potency estimates that have or could have significant emissions from light-duty as well as heavy-duty vehicles: 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. 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 methodology used to develop these estimates has recently undergone 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.[36] 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[23] 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.[37,38] 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[39] and increased proliferation of mouse bone marrow cells[40]. 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.[41]

The latest assessment by EPA places the excess risk of developing acute nonlymphocytic leukemia at 2.2×10^{-6} to $7.7 \times 10^{-6}/\mu g/m^3$ (EPA, 1998a). 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).

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[23] 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.

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, [42]). 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[24] ,a condition characterized by decreased numbers of circulating erythrocytes (red blood cells), leukocytes (white blood cells), and thrombocytes (blood platelets).[43,44] Individuals that develop pancytopenia and have continued exposure to benzene may develop aplastic anemia,[25] whereas others exhibit both pancytopenia and bone marrow hyperplasia (excessive cell formation), a condition that may indicate a preleukemic state.[45,46]The most sensitive noncancer effect observed in humans is the depression of absolute lymphocyte counts in the circulating blood[47]. 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 draft 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.[48] This RfC is currently being revised.

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 TOG, depending on control technology and fuel composition.

1-3-Butadiene was classified by EPA as a Group B2 (probable human) carcinogen in

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[24] 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.

[25] 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, orincreased synthesis of blood cell elements, followed by hypoplasia, or decreased synthesis. As the disease progresses, thebone marrow decreases functioning. This myeloplastic dysplasia (formation of abnormal tissue) without acute leukemiais known as preleukemia. The aplastic anemia can progress to AML (acute mylogenous leukemia).

1985.[49] This classification was based on evidence from two species of rodents and *** epidemiologic data. EPA recently prepared a draft assessment that would determine sufficient evidence exists to propose that 1,3-butadiene be classified as a known human carcinogen.[50] 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.[51] 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.

The unit risk estimates presented in EPA's draft risk assessment were not accepted by the SAB. The SAB panel recommended that EPA recalculate the lifetime cancer risk estimates based on the human data from Delzell et al. 1995[52] and revise EPA's original calculations to account for the highest exposure of "360 ppm-year" instead of "250+ ppm-year"and 70 years at risk instead of 85 years. Based on these recalculations[53] the MLE estimate of lifetime cancer risk from continuous 1,3-butadiene exposure is $2.21 \times 10^{-6}/\mu g/m^3$. This estimate implies that approximately 2 persons in one million exposed to 1 $\mu g/m^3$ 1,3-butadiene continuously for their lifetime (70 years in this case) would develop cancer as a result of their exposure.

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.[54] 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[55] 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 this 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.[56] In persons with bronchial asthma, the upper respiratory irritation caused by formaldehyde can precipitate an acute asthmatic attack, sometimes at concentrations below 5 ppm;[57] formaldehyde exposure may also cause bronchial asthma-like symptoms in nonasthmatics.[58,59] However, it is unclear whether asthmatics are more sensitive than nonasthmatics to formaldehyde's effects.[60]

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, [61]). 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 0.78×10^{-6} /µg/m^3. In other words, it is estimated that less than 1 person in one million exposed to 1 µg/m^3 acetaldehyde continuously for their lifetime (70 years) would develop cancer as a result of their exposure.

Non-cancer effects in studies with rats and mice showed acetaldehyde to be moderately toxic by the inhalation, oral, and intravenous routes.[62, 63 , 64] 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 µg/m^3 to avoid appreciable risk of these non-cancer health effects.[65]

e. Diesel Particulate Matter

Diesel exhaust includes components in the gas and particle phases. 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 areas of the human lung. Gaseous components of diesel exhaust include nitrates, sulfur compounds, organic compounds, carbon monoxide, carbon dioxide, water vapor, and excess air (nitrogen and oxygen). Among these gas-phase constituents, the components suspected to have carcinogenic potential are the organic compounds (including benzene, formaldehyde, acetaldehyde, 1,3-

butadiene). Current studies have not been designed to specifically discern a role for the gaseous compounds in contributing to diesel exhaust carcinogenicity, but it is likely that some portion can be attributed to gas phase organics.

While some of the cancer risk is likely associated with exposure to the gaseous components of diesel exhaust, studies conducted suggest that the particulate component plays a substantial role in carcinogenicity. Information that is currently available suggests that the particulate fraction of diesel exhaust is carcinogenic independent of the gaseous component. Specifically, (1) diesel particles (the elemental carbon core plus the adsorbed organics) induce lung cancer at high doses, and the particles, independent of the gaseous compounds, elicit an animal lung cancer response; (2) the presence of elemental carbon particles as well as the organic-laden diesel particles correlate with an adverse inflammatory effect in the respiratory system of animals, with some limited evidence in humans; (3) the extractible particle organics taken collectively produce cancer and adverse mutagenic toxicity in experimental test systems; and (4) many of the individual organic compounds adsorbed onto the particles are mutagenic or carcinogenic in their own right (EPA, 1999b). This information suggests that the particle may be playing a dual role in contributing to the carcinogenicity of diesel exhaust: both as a mechanism of delivery for many of the organics into the respiratory system, and the role of the elemental carbon core.

In two human studies on railroad workers and one on Teamster Union Truck Drivers and attendant personnel who were occupationally exposed to diesel exhaust (EPA 1999b), it was observed that long-term inhalation of diesel exhaust produced an excess risk of lung cancer. Taken together, these and other human studies show a positive association between diesel exhaust exposure and lung cancer. While some uncertainties remain about confounding from smoking and possible coincident exposures to other agents, the totality of human evidence provides a strong inference for a human lung cancer hazard. Inhalation studies in rats show a lung cancer response at high doses, though the rat model is not deemed a satisfactory test system for indicating a low exposure hazard for humans. Results from inhalation studies in mice range from equivocal to suggestive but are not compelling (EPA 1999b). Lung implantation animal studies do show the carcinogenic reactivity of diesel particulates and the extracted organics. Extensive mutagenicity and genotoxicity studies show that the particle organics and the gaseous fractions are reactive and it is also evident that a number of the organic constituents present on the particles and in the gases are carcinogenic in their own right, though not necessarily in the lung (EPA 1999b). EPA's draft Diesel Health Assessment also identifies several types of adverse chronic respiratory effects including respiratory tract irritation/inflammation, changes in lung function, and a suggestion of adverse immunological changes as concerns for long term exposure to diesel exhaust. The evidence for chronic respiratory effects comes mainly from animal studies (the rat being the most studied), given the limited availability of human studies. The evidence for both cancer and chronic respiratory effects comes from the studies involving occupational exposures and or high exposure animal studies. The Agency's draft assessment (EPA, 1999b) stated that diesel exhaust is a highly likely human lung cancer hazard, but that the

data are currently unsuitable to make a confident quantitative statement of risk. The draft assessment also states that this risk is applicable to ambient exposures and that the risk may be in the range of regulatory interest (greater than one in a million over a lifetime). In addition, EPA believes that 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 chronic respiratory hazards.[66]

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, ARB's evaluation. Based on human epidemiology studies, the ARB's estimate of the range of a lifetime upper confidence limit unit cancer risk from continuous diesel exhaust particulate exposure ranges from 1.3×10^{-4} to 2.4×10^{-3} $\mu g/m^3$ (lifetime- $\mu g/m^3)^{-1}$. The geometric mean unit risk obtained from these end points of the range is 6×10^{-4} (lifetime- $\mu g/m^3)^{-1}$. In other words, it is estimated that approximately 130 to 2400 persons in one million Californians exposed to 1 $\mu g/m^3$ diesel exhaust particulate continuously for their lifetime (70 years) would develop cancer as a result of their exposure.

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, though the health concerns from exposure ambient PM vs diesel have differences as well as similarities. As diesel particulates make up more and more of the ambient PM mixture, the health concerns would overlap to a larger extent. Compared to a typical ambient PM mixture from many sources, diesel exhaust particles probably have a higher percentage of small particles which also have a higher surface area laden with adsorbed organics.

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[67,68] 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 nine urban areas and the results were extrapolated nationwide. Results from these analyses were summarized in the draft regulatory impact analysis for the proposal for this rulemaking. These analyses have been updated and extended for the final rule.[69] First, additional areas were modeled to encompass a

broader selection of I/M programs, fuel parameters, and temperature regimes. This enabled us to develop more accurate nationwide extrapolations. Second, model inputs were revised to reflect more recent information on emission rates, and to reflect the standards being promulgated in the final rule. 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 for the final rule. Subsection D.2.a. discusses the emission modeling conducted for mobile source gaseous air toxics (including both exhaust and nonexhaust air toxics) and diesel PM. Subsection D.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 D.2.c. describes our analysis of air toxics exposure for our baseline scenario. Subsection D.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 cars and 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 total organic gas (TOG) estimates. The TOG basic emission rates used in this modeling incorporated the available elements for MOBILE6 used to develop the VOC inventory for this rule. 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.

Toxic emissions were modeled for 10 urban areas and 16 geographic regions. These urban areas and geographic regions are presented in Table III.D-1. They were selected to encompass a broad range of I/M programs, fuel parameters, and temperature regimes. The intent of the selection process was to best characterize the different combinations needed to perform accurate nationwide toxic emissions estimates. Each U. S. county was then mapped to a modeled area or region. This approach was also used to develop the inventory estimates in the 1996 National Toxics Inventory.

Modeling for these areas was done on a seasonal basis. Information on fuel properties for 1990 and 1996 was obtained from surveys conducted by the National Institute for Petroleum and Energy Research (NIPER) and the American Automobile Manufacturers Association (AAMA). Fuel parameters for 2007 and 2020 were projected from 1996 baseline values using information from a February 26, 1999 report from Mathpro to the American Petroleum Institute. Data from the EPA Emission Trends Database and other agency sources were used to develop appropriate local modeling parameters for inspection maintenance programs, Stage II refueling controls, fuel RVP, average ambient temperature, and other inputs.

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.[70] This difference is especially significant for 1,3-butadiene; its toxic/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. The target fuel is simply the fuel of concern in the modeling analysis. 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.

Table III.D-1. Areas Included in Toxic Emissions Modeling

Chicago, IL	Atlanta, GA	Florida
Denver, CO	Western WA/ OR	Northeast States – non-I/M and non-RFG
Houston, TX	Northern CA	Northeast States - I/M and non-RFG
Minneapolis, MN	Southern CA	Northeast States - non-I/M and RFG
New York, NY	ID/ MT/ WY	Ohio Valley – non-I/M and non-RFG
Philadelphia, PA	UT/ NM/NV	Ohio Valley – I/M and non-RFG
Phoenix, AZ	West TX	Ohio Valley – I/M and RFG
Spokane, WA	ND/ SD/ NB/ IA/ KS/ Western MO	Northern MI/ WI
St. Louis, MO	AR/ MS/ AL/ SC/ Northern LA	

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 high emitting 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.D-2. 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.D-2. 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.D-1, below.

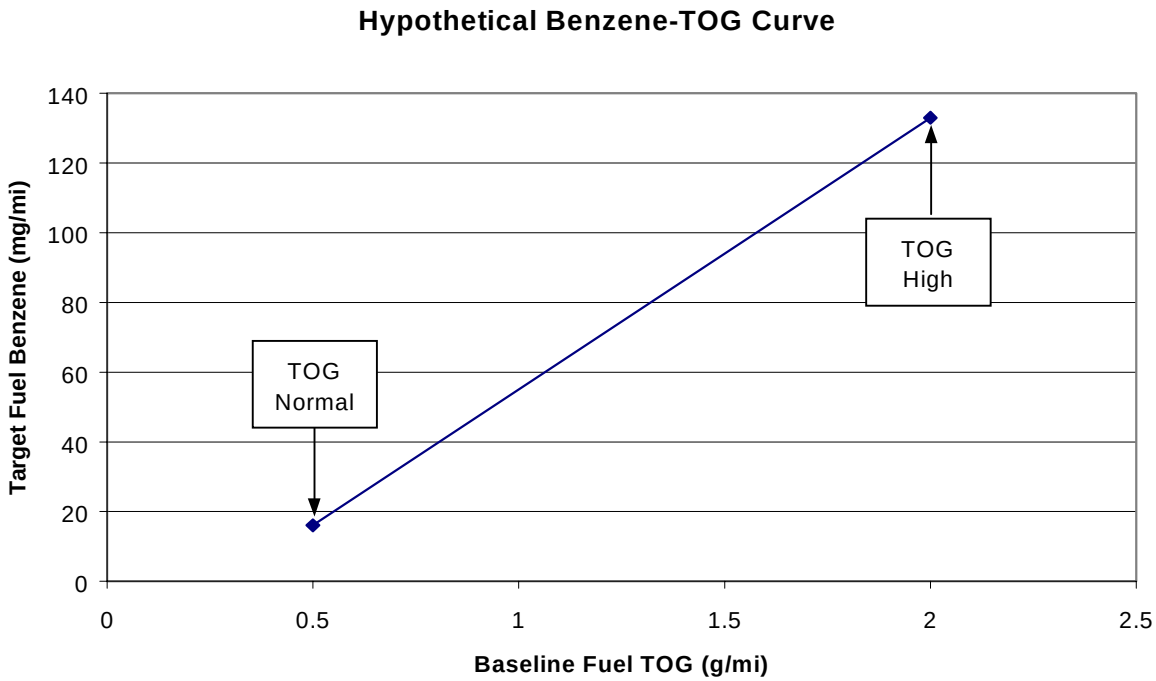

Figure III.D-1. Example Plot of Target Fuel Benzene Versus Baseline Fuel TOG under FTP Conditions

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 VOC emission rates below the Tier 0 normal emitter rate, for example, the toxic fraction stays constant at the toxic fraction for Tier 0 normal emitters). In 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 regardless of the VOC emission level.

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[71,72,73] 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 EPA (1999d). 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

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.

Diesel PM emission estimates are not presented in this section of the RIA since the impact of this rulemaking on the diesel PM inventory is discussed in Section III.A.4. It should be noted, however, that the diesel PM exposure estimates presented herein were based on inventory numbers developed in a slightly different manner than the ones in Section III.A.4. To develop these inventory estimates, we modeled emission factors in 26 areas explicitly and then mapped the remaining U. S. counties to these modeled areas, as described in Section III.D.2.a.i. The resulting emission factors for each county were multiplied by VMT estimates from EPA's Trends database to obtain total mass emissions estimates. The 2007 and 2020 light-duty diesel PM emission estimates obtained using this approach were within about 15 percent of the estimates presented in III.A.4 for all scenarios modeled.

b. Nationwide Toxic Emissions Estimates – Baseline Scenario

Toxic emission factor estimates for each county in the United States were developed by mapping them to one of the modeled areas (EPA, 1999d). The resulting county level emission factors were multiplied by VMT estimates from EPA's Emission Trends database to come up with nationwide emissions in tons. Forty-seven state estimates for gaseous toxics under baseline scenarios in 1990, 1996, 2007, and 2020 are given in Table III.D-3;[26] the diesel particulate estimates can be found in or inferred from Table III.A-11 for current diesel penetration rates and Table III.A-15 for increased diesel penetration rates. 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.

[26]Diesel PM inventory estimates are presented elsewhere in the Regulatory Impact Analysis.

Table III.D-3. 47 State Highway Vehicle Toxic Emissions (tons) In 1990, 1996, 2007, and 2020, for Baseline Scenarios.

Toxic	*CY 1990*	*CY 1996*	*CY2007*	*CY2020*
Benzene	228,000	156,000	89,000	81,000
Acetaldehyde	37,000	25,000	14,000	14,000
Formaldehyde	126,000	72,000	34,000	34,000
1,3-Butadiene	33,000	21,000	12,000	12,000

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.[74, 75] Data from 10 urban areas were used. These areas were Atlanta, GA, Denver, CO, Houston, TX, Minneapolis, MN, New York, NY, Philadelphia, PA, Phoenix, AZ, Spokane, WA, and St. Louis, MO. HAPEM-MS3 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.[76, 77] Nationwide urban CO exposure from on-road motor vehicles was estimated by first calculating a population-weighted average CO exposure for the ten 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. In the baseline scenario, we did not assume any increased penetration of diesel engines into the light-duty fleet. 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.[78] These factors account for the difference in reactivity between relatively inert CO, which is being used as the tracer for toxics exposure, and 1,3-butadiene. 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.D-4 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.D-4. Average 47 State Highway Vehicle Toxic Exposure (µg/m^3) In 1990, 1996, 2007, and 2020, for Baseline Scenarios.

Toxic	*CY 1990*	*CY 1996*	*CY2007*	*CY2020*
Benzene	0.99	0.68	0.39	0.35
Acetaldehyde	0.16	0.11	0.06	0.06
Formaldehyde	0.54	0.32	0.15	0.15
1,3-Butadiene	0.11	0.07	0.04	0.04
Diesel PM	0.78	0.44	0.25	0.27

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.[79] 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 47 State highway diesel PM_{10} 1996 exposure estimate of 0.44 $\mu g/m^3$ in Table III.D-4. One significant reason for the difference is that the California estimate is for diesel PM_{10} from all sources, including nonroad, while the estimate in Table III.D-4 is only for highway vehicles. Other reasons may be 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 30 ppm sulfur standard.
- NLEV, 30 ppm sulfur, and Tier 2 tailpipe standards
- NLEV, 30 ppm sulfur, Tier 2 tailpipe standards, and increased diesel penetration

Estimates of the impact of VOC reductions from Tier 2 tailpipe standards for the full useful life of the vehicle, combined with a 30 ppm sulfur standard, on toxics emissions and exposure, are provided in Tables III.D-6 through III.D-9.

The current updated assessment also evaluated the potential increase in diesel PM emissions and exposure due to increased use of diesel engines in cars and 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 cars and light trucks. Some manufacturers have announced capital investments to build such engines. The impact of this increase in light of Tier 2 standards were evaluated. For our projections through 2015, we assumed the most likely level of increased diesel penetration modeled in a draft report prepared by Arthur D. Little, Inc. for the American Petroleum Institute.[80] For years subsequent to 2015, we assumed that diesel engines' share of vehicle sales would continue to grow at the rate projected for 2010 through 2015 in the Arthur D. Little most likely scenario.

This assumption differs from that used to project the potential impact of greater diesel sales on PM emissions from cars and light trucks found in Section A.4.b of this chapter, where diesel engines' share of car and light truck sales were held constant at 2015 levels for subsequent years. The difference in these projections stems from their different purposes. The projections in Section A.4.b represent our efforts to project the impact of a likely diesel engine sales scenario on PM emissions. The projections used for the diesel PM analysis described in this section are

designed to illustrate the potential for greater diesel engine use in cars and light trucks to increase the health risks associated with diesel PM; they represent a more speculative scenario and should be used to evaluate the potential (rather than the most likely) impact of greater diesel engine use on the unique health risks associated with diesel PM. The sales penetration rates for this cautionary scenario are presented in Table III.D-5.

Table III.D-5. Percentage of sales fleet expected to be diesel in each respective year under "most likely" scenario, as estimated in A. D. Little, Inc. report.

Vehicle Class	*2000*	*2005*	*2010*	*2015*	*2020*
LDV	0	0	2	9	16
LDT1	1	3	17	22	27
LDT2	0	0	12	17	22
LDT3	2	13	23	30	37
LDT4	3	14	23	31	39

The impact of such increased diesel penetration on exposure to diesel PM are provided in Tables III.D-8 and III.D-9. Based on the exposure estimates for 2020 under Tier 2 controls, the potential 47 State cancer risk from diesel particulate matter would increase by about 8 percent under this scenario. Beyond 2020, the health risks would be even greater for two reasons. First, the proportion of cars and light trucks equipped with diesel engines would continue to increase as the older, gasoline-powered cars and light trucks are replaced by a mix of gasoline and diesel cars and light trucks. Second, continued growth in the total number of miles driven would increase diesel PM emissions. It should be noted that without Tier 2 controls, we estimate that the increased presence of diesel-powered cars and light trucks on the nation's roads could increase the potential cancer risks associated with PM emissions from all diesel-powered highway vehicles (including heavy-duty diesel trucks, diesel buses, and light-duty diesel vehicles) by approximately 80 percent as of 2020. This estimate is based on an inventory of about 69,000 tons of diesel PM from all highway vehicles in 2020 without increased diesel penetration, versus about 125,000 tons with increased diesel penetration. The 80 percent increase in inventory likely would translate into a similar increase in cancer risk.

Table III.D- 6. 47 State Highway Vehicle Toxic Emissions (tons) in 2007, for Various Scenarios

Toxic	*No New Controls Scenario*	*30 ppm Sulfur Scenario*	*Tier 2 Standard w/30 ppm Sulfur Scenario*	*Tier 2 Standard, 30 ppm Gasoline Sulfur, & Increased Diesel Sales Scenario*
Benzene	89,000	82,000	80,000	78,000
Acetaldehyde	14,000	13,000	13,000	13,000
Formaldehyde	34,000	33,000	32,000	33,000
1,3-Butadiene	12,000	11,000	11,000	10,000

Table III.D-7. 47 State Highway Vehicle Toxic Emissions (tons) in 2020, for Various Scenarios

Toxic	*No New Controls Scenario*	*30 ppm Sulfur Scenario*	*Tier 2 Standard w/30 ppm Sulfur Scenario*	*Tier 2 Standard, 30 ppm Gasoline Sulfur, & Increased Diesel Sales Scenario*
Benzene	81,000	74,000	63,000	55,000
Acetaldehyde	14,000	13,000	12,000	12,000
Formaldehyde	34,000	33,000	30,000	30,000
1,3-Butadiene	12,000	11,000	10,000	9,000

Table III.D-8. Average 47 State Highway Vehicle Toxic Exposures for the Entire Population (µg/m^3) in 2007, for Various Scenarios

Toxic	*No New Controls Scenario*	*30 ppm Sulfur Scenario*	*Tier 2 Standard w/30 ppm Sulfur Scenario*	*Tier 2 Standard, 30 ppm Gasoline Sulfur, & Increased Diesel Sales Scenario*
Benzene	0.39	0.39	0.35	0.34
Acetaldehyde	0.06	0.06	0.06	0.06
Formaldehyde	0.15	0.15	0.14	0.15
1,3-Butadiene	0.04	0.03	0.03	0.03
Diesel PM	0.25	0.25	0.25	0.28

Table III.D-9. Average 47 State Highway Vehicle Toxic Exposures for the Entire Population (µg/m^3) in 2020, for Various Scenarios

Toxic	*No New Controls Scenario*	*30 ppm Sulfur Scenario*	*Tier 2 Standard w/30 ppm Sulfur Scenario*	*Tier 2 Standard, 30 ppm Gasoline Sulfur, & Increased Diesel Sales Scenario*
Benzene	0.35	0.32	0.27	0.24
Acetaldehyde	0.06	0.06	0.05	0.05
Formaldehyde	0.15	0.14	0.13	0.13
1,3-Butadiene	0.04	0.03	0.03	0.03
Diesel PM	0.27	0.27	0.26	0.29

E. Carbon Monoxide

The standards being promulgated today will help reduce levels of carbon monoxide (CO). Twenty areas, with a combined population of 33 million, are designated as being in nonattainment with the CO NAAQS. An additional 24 areas with a combined population of 22 million are designated as CO maintenance areas. In 1997, 6 of 537 monitoring sites reported ambient CO levels in excess of the CO NAAQS.

As discussed in Section III.A, the Tier 2/Sulfur standards will require light trucks to meet more stringent CO standards. These more stringent standards will help extend the trend towards lower CO emissions from motor vehicles and thereby help the remaining CO nonattainment areas reach attainment while helping other areas remain in attainment with the CO NAAQS. The analysis of economic benefits and costs found in Section IV.D.-5. does not account for the economic benefits of the CO reductions expected to result from today's proposal.

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Chapter IV: Technological Feasibility

A. Feasibility of Tier 2 Exhaust Emission Standards for Vehicles

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, might 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. Perhaps most important of all, emission control calibrations continue to become more refined and sophisticated.

Table IV-1 below lists specific types of emission controls which EPA projects will be needed in order for the affected vehicles to meet the final Tier 2 standards. It is important to point out that all of the following technologies would not necessarily be needed to meet the 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 the need for increases in catalyst volume and precious metal loading, EPA believes that most, if not all, cars and trucks will use the specified emission control technique.

Table IV-1. Emission Control Hardware and Techniques Projected to Meet 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[1] 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. Some manufacturers use a mechanical back-pressure system that measure EGR flow (via delta pressure across an orifice) rather than inferring flow from the EGR pintle position. This system uses electronic control of the vacuum actuation and has very precise control. Many manufacturers are now using 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, in some cases, 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

[1] 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.

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. 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.

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 Pd/Rh, Pt/Rh 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. In 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 1100°C and, as a result, can be moved very close to the exhaust manifold to enhance catalyst light-off performance.

In addition to an increased reliance on Pd, 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 and 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.

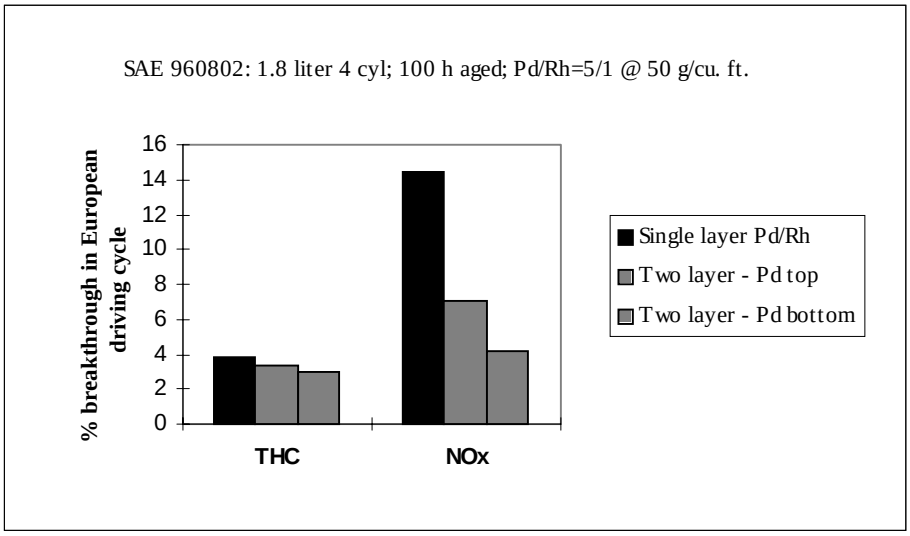

Figure IV-1. Impact of Coating Architecture on HC and NOx Emissions.

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 and 1200 cpsi catalysts has been progressing. Typical cell densities for conventional catalysts are 400 cpsi.

We have projected that in order to meet the 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 light and medium duty trucks only have ratios of 0.6 or less. We believe that in order to comply with Tier 2 standards, most vehicles 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 Tier 2 standards. Typical catalyst loadings 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 - 250 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 be 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 results 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.

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.

One manufacturer who incorporates a zeolite HC adsorber in its California SULEV vehicle found that an electrically heated catalyst was necessary after the adsorber because the zeolite acts as a heat sink and nearly negates the cold start advantage of the HC adsorber.

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 more quickly, 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 after the catalytic converters have been thermally aged to the equivalent of both the intermediate useful life (50,000 miles) and full useful life (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 Tier 2 standards at intermediate useful would be approximately 0.035 to 0.050 g/mi NMOG and 0.025 to 0.035 g/mi NOx. At full useful life, the design targets for the Tier 2 standards would be approximately 0.045-0.063 g/mi NMOG and 0.035-0.050 g/mi NOx at

full useful life.

With this in mind, we will present data from several sources that establish our Tier 2 standards to be feasible. The data ranges from certification emission levels to feasibility evaluation programs undertaken in the last year by EPA, ARB and MECA. Even though theARB and MECA 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 Tier 2 standards are the same as the LEV II standards. We will also present the results of an EPA test program that demonstrates the feasibility of the Tier 2 emissions standards for the largest sport utility vehicles and pickup trucks regulated under this final rule.

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 1999 model year 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 1999 Model Year 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 MY 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.

Table IV-4 provides a listing of 2000 model year 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. As for the 1999 data, 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. We assembled this list by reviewing 2000 model year certification data for engine families certified to nationwide Tier 1 standards, NLEV program standards, and the California program standards. At the time this document was published, approximately 90 percent of the 2000 model year certification data had been submitted.

Table IV-4. 2000 MY 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	Tiburon, Elantra	0.01 - 0.02+	0.05	LEV
Daimler Chrysler	Neon	0.01	0.05	ULEV
Ford	Mystique, Contour	0.01 - 0.04*	0.03 - 0.05	TLEV
Volvo	S80	0.01	0.05	LEV
Ford	Mystique	0.02 - 0.03+	0.03 - 0.04	Tier 1
Daimler Chrysler	Neon	0.02	0.04	ULEV
Mitsubishi	Eclipse, Gallant	0.02*+	0.02 - 0.04	LEV
Mitsubishi	Mirage	0.02 - 0.03*+	0.03 - 0.04	LEV
Daewoo	Lanos	0.02 - 0.07	0.06 - 0.07	LEV
SAAB	9-5	0.03	0.03	LEV
Daimler Chrysler	Stratus	0.03	0.06	LEV
Hyundai	Tiburon, Elantra	0.03 - 0.04*+	0.04 - 0.05	Tier 1
Ford	LS	0.03 -0.05	0.06 - 0.07	LEV

Volvo	S70, V70	0.03*	0.03 - 0.04	LEV
Toyota	Avalon, Lexus ES300	0.03 - 0.06	0.05	LEV
Jaguar	X200	0.03 - 0.05*	0.05 - 0.07	TLEV
Mazda	Protege	0.04+	0.03	LEV
Honda	Accord	0.04 - 0.06	0.04 - 0.05	LEV
Volvo	S80	0.04 - 0.06*	0.09	TLEV
Daimler Chrysler	SLK230 Kompressor, C230 Kompressor	0.04 - 0.05	0.04 - 0.05	TLEV
GM	Metro	0.04+	0.03	TLEV
GM	Park Avenue	0.04+	0.04	LEV
Honda	Accord	0.04 - 0.06	0.05 - 0.06	LEV
Mazda	Protoge	0.04	0.03	LEV
Volvo	S40	0.05 - 0.06*	0.06 - 0.07	LEV
Hyundai	Sonata	0.05	0.05	TLEV
Daimler Chrysler	ML320	0.05*	0.04 - 0.05	Tier 1
Nissan	Infiniti G20	0.06*	0.04	LEV
Kia	Sephia	0.06 - 0.07*	0.04 - 0.08	LEV
Honda	Accord	0.06 - 0.07*	0.06	LEV
Infiniti	I30	0.06	0.05	LEV
Ford	Contour, Cougar	0.06*	0.16	Tier 1
Toyota	Lexus GS300/GS400	0.06*	0.05 - 0.06	LEV
Volkswagen	Jetta	0.06*	0.06	LEV
Daewoo	Nubira, Lanos	0.06*	0.08	TLEV
Honda	Insight	0.06*	0.04	ULEV/LEV
Daewoo	Leganza, Nubira	0.07*	0.05 - 0.07	LEV
Honda	Accord	0.07*	0.03	ULEV
Daimler Chrysler	E430, S500	0.07*	0.02	LEV
BMW	X5	0.07	0.04	LEV
Nissan	Altima	0.07	0.06	LEV

SAAB	9-5	0.07	0.02 - 0.03	LEV
Hyundai	Accent/Brio	0.07*	0.03	LEV
LDT 1				
Toyota	Tacoma	0.01 - 0.02	0.05 - 0.07	LEV
Kia	Sportage	0.02 - 0.05	0.04 - 0.06	LEV
Ford	Ranger Pickup	0.04 - 0.07	0.09 - 0.18	Tier 1
Mazda	B2000	0.06*	0.05	Tier 1
Daimler Chrysler	Dakota Pickup	0.07	0.08	TLEV
LDT2				
Ford	F150 Pickup	0.03*	0.13 - 0.16	Tier 1
Ford	Ranger Pickup	0.04*	0.13 - 0.15	Tier 1
Mazda	B3000	0.04 - 0.05*	0.06 - 0.10	Tier 1
GM	Montana	0.05+	0.05 - 0.06	LEV
Daimler Chrysler	Grand Cherokee	0.05	0.10 - 0.11	LEV
Daimler Chrysler	Caravan	0.06	0.09	LEV
LDT3				
Ford	F150 Pickup	0.03 - 0.04	0.16 - 0.20	Tier 1
Daimler Chrysler	Durango	0.05	0.08	ULEV
Ford	F150 Pickup	0.05*	0.14 - 0.16	Tier 1
Daimler Chrysler	ML55	0.06 - 0.07	0.04 - 0.05	LEV
Land Rover	Range Rover, Discovery	0.07*	0.09 - 0.17	Tier 1
LDT4				
Ford	F250 Pickup	0.04 - 0.05	0.13 - 0.21	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 levels.

A review of the Tables above show 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 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 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 California LEV II and our 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 the equivalent of 50,000 miles 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 Tier 2 standard with a headroom of 23 percent. The actual test results are summarized in Table IV-5 below.

Table IV-5. 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. CARB Test Program

CARB tested five different 1997-98 model year production LEV LDV models. Two of the five models met the 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-6. CARB 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 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 Tier 2 NMOG and NOx emission standards. While these results are not with catalysts aged to

full useful 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 Tier 2 standards. Table IV-7 lists the modified passenger car emission results.

Table IV-7. 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-8 lists the baseline emission results for the two Expeditions.

Table IV-8. CARB 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. CARB 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-9 lists the emission results of the Expeditions with advanced catalyst systems.

Table IV-9. CARB 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

- *EPA Test Program*

Our test program was aimed at lowering the emissions of large 1999 LDT3 and LDT4 heavy-light-duty trucks to levels at or below those of the Tier 2 Standards at intermediate life (50,000 miles). All of the vehicles tested had large displacement (greater than 5.3 liter), high horsepower (230-270 hp) engines; four wheel drive; curb weights of 4,500 to 5500 pounds; and gross vehicle weights of greater than 6,000 lbs. Specifications of the trucks tested are included in table IV-10.

Table IV-10: EPA Test Vehicle Specifications

Trucks Tested	*Test Weight (lbs.)*	*Engine*	*Drivetrain*	*Intermediate Useful Life (50,000 mile) Certification Levels*		
				NMOG (g/mi)	*CO (g/mi)*	*NOx (g/mi)*
1999 Ford Expedition LEV	5876	5.3L V8, 230 bhp	4-speed Auto., 4-WD	0.09	1.7	.07
1999 GM Chevrolet Silverado LEV	4818	5.4 L V8, 270 bhp	4-speed Auto., 4-WD	0.11	2.4	0.3

A key element of the test was the alteration of engine calibration parameters of the powertrain control module (PCM), which included modification of spark timing, EGR, and fuel control. During testing at EPA-NVFEL, flash-reprogramming of the PCM, off-board ROM, and ROM emulation were used to accomplish PCM calibration changes. All of the catalysts/exhaust systems evaluated were thermally aged to an equivalent 50,000 miles using the vehicle manufacturers' specific catalyst aging cycle.

Specifications of some of the exhaust catalyst systems tested in this program can be found in table IV-11.

Table IV-11: Catalyst Specifications

		Ford Expedition		*GM Chevrolet Silverado*	
Catalyst Configuration		*EXP1 (stock OEM)*	*EXP3*	*SILV1 (stock OEM)*	*SILV2*
Total Catalyst Volume (L)		5.3	5.9	4.8	3.9
Total No. of Catalyst Bricks		6	6	4	6
Total Pd Loading (g)		17.2	26.4	4.6	69
Total Rh Loading (g)		0.82	4.18	0.28	4.94
Front Bricks	Volume (L)	0.69	0.69		0.345
	Pd Loading (g)	4.87	4.87		12.17
	Cell Density (cells/in^2)	400	400		600
	Wall Thickness (mil)	6	6		4
Middle Bricks	Volume (L)	1.06	1.26	1.2	0.695
	Pd Loading (g)	2.02	4.45	1.29	13.14
	Rh Loading (g)	0.22	1.12	0	1.45
	Cell Density (cells/in^2)	400	600	400	400
	Wall Thickness (mil)	6	4	6	6
Rear Bricks	Volume (L)	0.9	1.01	1.2	0.907
	Pd Loading (g)	1.72	3.88	1.02	9.18
	Rh Loading (g)	0.19	0.97	0.14	1.02
	Cell Density (cells/in^2)	400	600	400	400
	Wall Thickness (mil)	6	4	6	6

Only minor changes were made to the Chevrolet Silverado PCM calibration. These included:

- 4 to 6 degree spark timing retard under cold-start conditions to improve catalyst light-off times

- Earlier enablement of EGR after cold-start, using the original EGR map

The majority of the emissions improvement on the tested Silverado configurations are due to increased precious metal loading of the exhaust catalysts tested. No measurable differences in fuel economy were noted after the changes. Driveability was not affected. The final tested configuration of the Chevrolet Silverado achieved NOx emissions of 0.05 g/mi and NMHC emissions of 0.06 g/mi, meeting the Tier 2 standard.

The availability of ROM emulation for the Ford Expedition allowed considerable PCM calibration tuning to be performed both on the chassis dynamometer and while driving on the highway. The tested Expedition configurations relied considerably more on calibration tuning than the Silverado.

We found that more than 80 percent of the NOx and NMHC emissions from the Expedition occurred during the first 30 seconds after a cold start. Therefore, most of the calibration tuning focused on reducing NOx and NMHC emissions from the cold start portion, or “phase 1", of the light-duty FTP. Some of the calibration changes included:

- 15 to 20 degree spark timing retard under cold-start conditions to improve catalyst light-off times
- Minor spark timing retard to increase catalyst temperatures at lighter load, lower speed conditions
- Earlier enablement of EGR (enabled after ~30 seconds under typical FTP cold-start conditions)
- Increased EGR rates, particularly at part load conditions
- Extension of the EGR map to cover higher-speed, higher load driving conditions

The retarded spark timing initially after cold start resulted in increased front catalyst brick temperatures, which were increased from 425 °C to 550 °C at 30 seconds after cold start. Considerable EGR tuning approximately halved engine-out (pre-catalyst) NOx emissions. Maximum EGR rates did not exceed 14 percent, and were considerably less for most operating conditions. Engine-out CO was unchanged by the additional EGR. Engine-out HC was increased by 5 to 15 percent. The engine-out HC increase due to addtional EGR was more than offset by higher catalyst efficiency due to the higher PGM loading and volume of the underfloor catalyst, and due to the increased catalyst temperatures immediately after cold-start from the cold spark retard.

Cold start NOx performance was further improved by the use of low-mass, sealed-air-gap, tubular-steel exhaust manifolds. The prototype manifolds further increased front catalyst brick temperatures from 550 °C to 630 °C at 30 seconds after cold start. Catalyst brick temperatures did not exceed 850 °C for any of the tested configurations, even over the US06 cycle. The reliance on Pd and Pd/Rh formulations, and stabilized cerium oxide, allowed a safe margin with respect to catalyst brick temperatures. Catalyst manufacturers have indicated to us that current catalyst formulations can typically withstand temperatures of 950 °C to 1000 °C without

damage.

Considerable tuning of the PCM calibration was also used to minimize impacts of the calibration changes on driveability and fuel economy. The final calibrations achieved considerable improvements in emissions performance with no measurable impact on fuel economy and no perceptible change in driveability. The Expedition achieved NOx emissions of 0.04 g/mi and NMHC emissions 0.07 g/mi with the OEM cast exhaust manifolds, and 0.02 g/mi NOx, 0.07 g/mi NMHC with the sealed-air-gap exhaust manifolds. The final tested configurations easily met the Tier 2 NOx standard. The NMHC emissions meet the 50,000 mile standard. Use of close-loop controlled secondary-air-injection (similar to that used by SwRI for the MECA test program) would further reduce cold-start NMHC emissions with only a minor degradation in NOx performance.

In addition to testing at EPA, a virtually identical 1999 Ford Expedition was tested under an EPA contract at Southwest Research Institute (SwRI) using the ERIC system to facilitate calibration changes. The exhaust catalyst system tested was identical to the system tested by ARB with a 1998 Ford Expedition (see section iv). Data from a 1999 Chevrolet Silverado similar to the vehicle tested at NVFEL was provided by MECA. This vehicle was also tested at SwRI using the ERIC system to provide engine calibration changes. Emissions from the trucks tested at NVFEL and at SwRI for a number of the tested exhaust catalyst and engine calibration configurations are compared in figures IV-2 and IV-3. The trucks tested at SwRI achieved approximately the same low emissions levels as those tested at NVFEL, even though their mix of hardware and calibration changes were relatively different. The low emissions levels achieved essentially demonstrate the feasibility of the Tier 2 standards for heavy-light-duty trucks and the ability to achieve those standards using a variety of logical engineering paths.

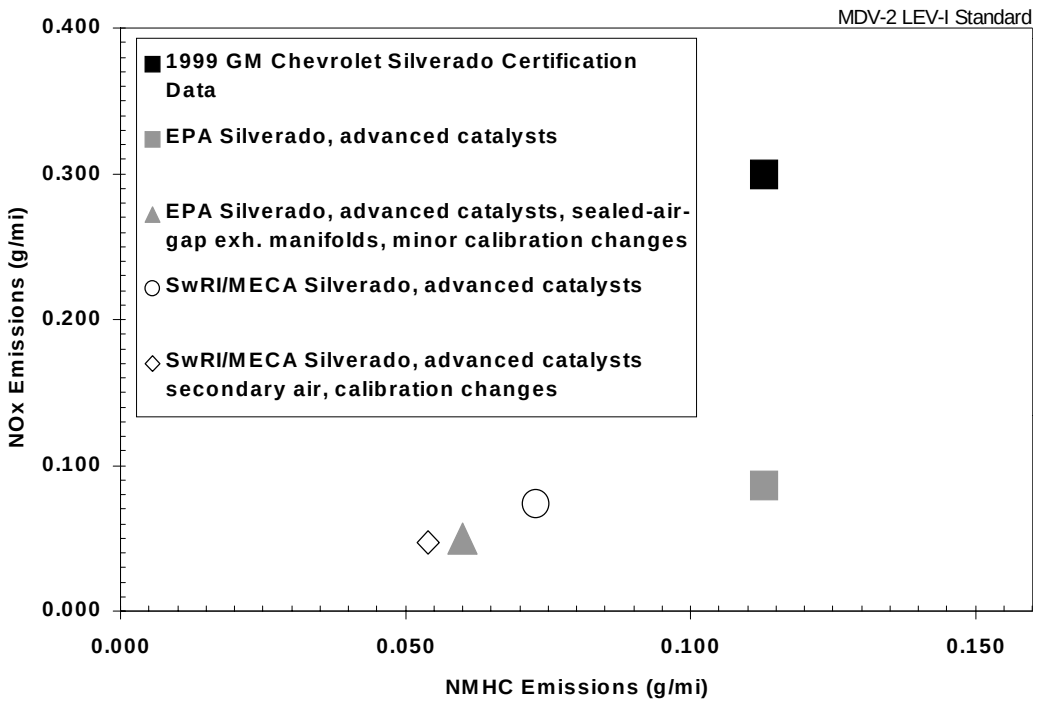

Figure IV-2: 50,000 mile equivalent NOx vs. NMHC levels for a number of hardware and engine calibration configurations tested with a 1999 GM Chevrolet Silverado Pickup (5.3L V8) originally certified to the LEV MDV-2 standard (0.4 g/mi NOx, 0.16 g/mi NMOG).

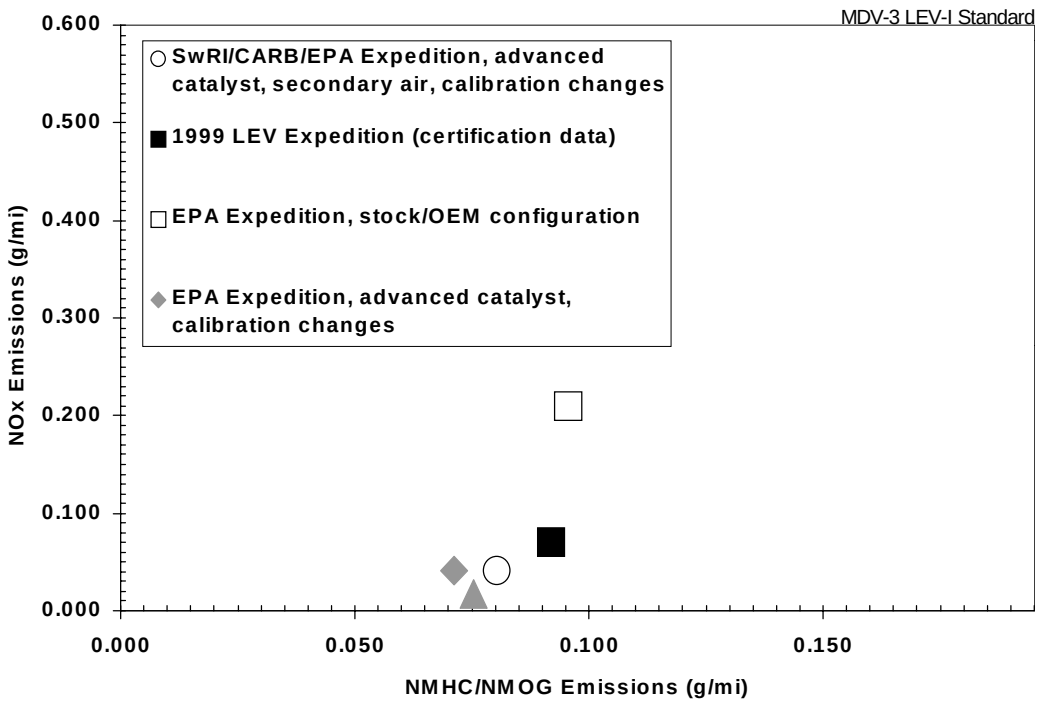

Figure IV-3: 50,000 mile equivalent NOx vs. NMHC emissions levels for a number of hardware and engine calibration configurations tested with a 1999 Ford Expedition (5.4L V8) originally certified to the LEV MDV-3 standard (0.6 g/mi NOx, 0.195 g/mi NMOG).

The technologies and emission control strategies that will be used for LDT3 and LDT4 vehicles should also apply directly to medium-duty passenger vehicles (MDPVs), which have a GVWR greater than 8,500 pounds. In our LDT technology demonstration program discussed above, we found that a combination of calibration changes and improvements to the catalyst system resulted in emission levels for NOx well below and NMHC/NMOG approximately at the Tier 2 intermediate useful life standards. The catalyst improvements consisted of increases in volume and precious metal loading, and higher cell-densities than those found in the original hardware. We are confident that the use of secondary-air-injection will greatly help cold-start hydrocarbon control, making the NMOG standards achievable.

The most significant difference between LDT4s and MDPVs is that MDPVs have a vehicle weight up to 800 pounds more than LDT4s. MDPVs will also be typically equipped with larger displacement engines. The potential impact of these differences is higher engine-out

emissions than LDT4s due to the larger engine displacement and greater load that the engine will be operated under due to the extra weight. However, neither of these preclude manufacturers from applying the same basic emission control technologies and strategies as used by LDVs and LDTs. The only difference will likely be the need for larger catalysts with higher precious metal loading than found in LDT4s. We are confident that MDPVs will be capable of meeting the Tier 2 standards.

We are currently testing a Ford Excursion as part of our LDT technology demonstration program. Preliminary baseline results with a green (i.e., "new") catalyst indicate that emission levels are higher than baseline emissions for the Ford Expedition. These results, although with a green catalyst, are well below our interim Tier 2 upper bin standards. In fact, the majority of these vehicles certified on the chassis dynamometer in California, have certification levels well below our interim upper bin standards. We have also tested the Excursion at loaded vehicle test weight (curb + 300 lb) and again at adjusted loaded vehicle weight (half payload) and found that the engine-out and tailpipe emission results for NMHC and NOx were the same for the two test weights. In other words, the additional weight (approximately 700 lbs) had no impact on emission performance. This suggests that challenge for MDPVs in meeting Tier 2 standards may not be as difficult as originally believed.

While this testing is still ongoing, we feel that the preliminary results are encouraging since they suggest that the additional weight for these vehicles may not be as significant as originally thought, and the difference in emission results between the Excursion and Expedition suggest that the strategies used on the Expedition can be successfully employed with the Excursion. Therefore, we believe that by using technologies and control strategies similar to what will be used by LDVs and LDTs, combined with larger catalysts, MDPVs will be able to meet our Tier 2 emission standards.

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 is 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. As part of the ongoing efforts in developing GDI technology, substantial progress is being made in the application of aftertreatment controls. While much remains to be done both in lowering engine-out emission levels and in aftertreatment development, we believe that the bin structure in the Tier 2 standards is sufficient to allow the introduction of GDI engines.

2. CO Emissions from Gasoline Fueled Vehicles

EPA is only requiring tighter CO emission standards for LDT2s, LDT3s, LDT4s and MDPVs. 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 LDT1s 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 Tier 2 CO emission standards should not be difficult given compliance with the Tier 2 NMOG standards. The control of both pollutants utilizes much of the same technology and the Tier 2 NMOG standards are the more stringent of the two sets of standards. In addition, the change in test weight from “adjusted loaded vehicle weight” to “loaded vehicle weight” will make it easier to meet the Tier 2 CO emission standards. The following table IV-12 summarizes CO emissions from vehicles certified to the LEV standards in California.

Table IV-12. 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 Tier 2 CO standard of 4.2 g/mi. While CO emissions from LDT3s and LDT4s are more than half the 4.2 g/mi standard, the current LEV standards for these vehicles is more than twice the 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 Tier 2 CO standard should not add any additional burden to manufacturers relative to compliance with the NMOG and NOx standards.

3. Formaldehyde Emissions from Gasoline Fueled Vehicles

EPA is only requiring tighter formaldehyde emission standards for LDT2s, LDT3s, LDT4s and MDPVs. 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 Tier 2 formaldehyde emission standards should not be difficult given compliance with the Tier 2 NMOG standards. The control of both pollutants utilizes the same technology and the Tier 2 NMOG standards are the more stringent of the two sets of standards. Table IV-13, below, summarizes formaldehyde emissions from vehicles certified to the LEV standards in California.

Table IV-13. 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 Tier 2 formaldehyde standard of 0.018 g/mi. Thus, compliance with the Tier 2 formaldehyde standard should not add any additional burden to manufacturers relative to compliance with the NMOG and NOx standards.

4. Evaporative Emissions

The Tier 2 standards 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 Tier 2 standards 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

As discussed earlier, the Tier 2 standards are intended to be "fuel neutral." In this document, we establish that the Tier 2 standards are technologically feasible and cost-effective for LDVs and LDTs overall. Under the principal of fuel neutrality, all cars and light trucks, including those using diesel engines, will be required to meet the Tier 2 standards. Contrary to some of the comments received on our proposal, given that the overwhelming majority of vehicles in these classes are gasoline-fueled, we do not believe it is appropriate to provide less stringent standards for diesel-fueled vehicles. Manufacturers of LDVs and LDTs today provide consumers with a wide choice of vehicles that are overwhelmingly gasoline-fueled. Less stringent standards for diesels would create provisions that could undermine the emission reductions expected from this program, especially given the expectation that some manufacturers are hoping to greatly increase their diesel sales.

As with gasoline engines, manufacturers of diesels have made abundant progress 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 actually met with only engine modifications. Indeed, emissions and performance of lighter diesel engine are rapidly approaching the characteristics of gasoline engines, while retaining the durability and fuel economy advantages that diesels enjoy. Against this background of continuing progress, we believe that the technological improvements that would be needed could be made in the time that would be available before diesels would have to meet the new Tier 2 standards.

Manufacturers may take advantage of the flexibilities in our Tier 2 emission standards to

delay the need for diesel LDVs and LDTs to meet the final Tier 2 levels until late in the phase-in period (as late as 2007 for LDVs/LLDTs and 2009 for HLDTs), giving manufacturers a relatively large amount of leadtime. In a recent public statement, Cummins Engine Company has indicated that the interim Tier 2 standards in effect for vehicles and trucks in the early years of the Tier 2 program are feasible for diesel equipped models through further development of currently available engine technology.[2] We also believe that standards can be met through the use of existing technologies, such as cooled EGR where it currently is not used, moderate amounts of fuel injection timing retard, and perhaps limited use of lean NOx catalysts and/or diesel oxidation catalysts, as well as particulate traps.

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 Tier 2 standards for these pollutants. Engine-out emissions continue to be reduced. The following are some examples of technologies and strategies that can be used to reduce engine-out emissions.

One of the most important control strategies for the reduction of engine-out NOx emissions is the the addition of cooled exhaust gas recirculation (cooled EGR). This method recirculates a portion of the exhaust back to the intake manifold where it is drawn into the combustion chamber. The resulting mixture of fresh air and exhaust products has a lower concentration of O_2 than fresh air alone. The lower concentration of O_2 in the combustion chamber results in lower O_2 partial pressure which lowers its propensity to oxidize N_2 to NO and NO_2 (NOx) during the combustion process.

More sophisticated electronic control systems will be necessary to control the EGR system. EGR control algorithms will require additional engine condition information, possibly including mass air flow, oxygen, NOx, or EGR valve position sensors. These inputs will be necessary to control the EGR rate via an EGR valve or possibly a variable geometry turbocharger (VGT). These turbochargers will also require a sophisticated control algorithm to take advantage of their transient response, EGR pumping, and air flow control characteristics. In addition, the turbomachinery used with EGR will likely be pushed near the limits of its capability, and the engine's electronic control module (ECM -- the engine's control computer) will need to ensure the limits of the hardware are not exceeded.

While reductions in "engine-out" emissions may continue to be made, increasing emphasis is being placed on various aftertreatment devices for diesels. We believe that the use of aftertreatment devices alone will allow diesels to comply with the Tier 2 standards for NOx and PM.

[2]"Cummins Sees Diesel Feasible for Early Years of Tier 2". Hart Diesel Fuel News, Sept. 20, 1999, p.2.

For NOx emissions, potential aftertreatment technologies include lean NOx catalysts, NOx adsorbers and selective catalytic reduction (SCR). Lean NOx catalysts are still under development, but generally appear capable of reducing NOx emissions by about 15-30 percent. This efficiency is not likely to be sufficient to enable compliance with the final Tier 2 standards, but it could be used to meet the interim standards that would begin in 2004.

NOx adsorbers appear capable of reaching efficiency levels as high as 90 percent. Efficiency in this range is likely to be sufficient to enable compliance with the proposed Tier 2 standards. NOx adsorbers temporarily store the NOx and thus the engine must be run periodically for a brief time with excess fuel, so that the stored NOx can be released and converted to nitrogen and oxygen using a conventional three-way catalyst, like that used on current gasoline vehicles.

There is currently a substantial amount of development work being directed at NOx adsorber technology. While there are technical hurdles to be overcome, progress is continuing and it is our judgement that the technology should be available by the time it would be needed for the final Tier 2 standards.

One serious concern with current NOx adsorbers is that they are quickly poisoned by sulfur in the fuel. Some manufacturers have strongly emphasized their belief that, in order to meet the final Tier 2 levels, low sulfur diesel fuel would also be required to mitigate or prevent this poisoning problem. In its comments on the NPRM, Navistar indicated that the Tier 2 standards may be achievable given low sulfur fuel and other programmatic changes such as those included in this Final Rule. Navistar has also been quoted publically as describing the Tier 2 standards as “challenging but achievable” given appropriate low sulfur fuel.[3]

One solution would be to reduce sulfur to very low levels. Another solution would be to reduce sulfur somewhere below current levels and develop a way to periodically remove the sulfur from the adsorber. In any event, this technique, if used, would also require low sulfur diesel fuel. We will be issuing a Notice of Proposed Rulemaking in the near future intended to reduce sulfur in highway diesel fuel on a parallel path with today’s final rule as a step to enable the technology most likely to be used to meet the Tier 2 standards.

SCR has been demonstrated commercially on stationary diesel engines and can reduce NOx emissions by 80-90 percent. This efficiency would be sufficient to enable compliance with the proposed Tier 2 standards. However, SCR requires that the chemical urea be injected into the exhaust before the catalyst to assist in the destruction of NOx. The urea must be injected at very precise rates, which is difficult to achieve with an on-highway engine, because of widely varying engine operating conditions. Otherwise, emissions of ammonia, which have a very objectionable

[3]Harts Diesel Fuel News, August 9, 1999, p4.

odor, can occur. Substantial amounts of urea are required, meaning that vehicle owners would have to replenish their vehicles' supply of urea frequently, possibly as often as every fill-up of fuel. As the engine and vehicle will operate satisfactorily without the urea (only NOx emissions would be affected), some mechanism would be needed to ensure that vehicle owners maintained their supply of urea. Otherwise, little NOx emission reduction would be expected in-use.

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 15-30 percent. By itself, the oxidation catalyst is not likely to be sufficient to enable compliance with the 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 a 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 Tier 2 PM standards.

In summary, we believe that the structure of our final program, including the available bins and phase-in periods, will allow the orderly development of clean diesel engine technologies. We believe that the interim standards are feasible for diesel LDV/LDTs, within the bin structure of this rule and without further reductions in diesel fuel sulfur levels. And, as indicated earlier, at least one major diesel engine manufacturer (Cummins) has publically agreed with this assessment. We further believe that in the long-term, the final standards will be within reach for diesel-fueled vehicles in combination with appropriate changes to diesel fuel to facilitate aftertreatment technologies. Manufacturers have argued that low sulfur diesel fuel will be required to permit diesels to meet the final Tier 2 standards, and we agree. Once again, at least one major manufacturer (Navistar) has indicated its belief that the final Tier 2 standards

may be achievable for diesel engines with low sulfur diesel fuel.

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, or cracked, and the embedded sulfur ends up in gasoline. Thus, the refinery units which convert the heavy parts of crude oil into gasoline are the units most responsible for putting sulfur into gasoline.

The fluidized catalytic cracker (FCC) unit is 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 streams produced in 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 (much of it is hydrotreated and processed further before blending 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 hydrocrackate, and isomerate. Oxygenates which are blended into gasoline usually have very little or no sulfur,

however, during shipping through pipelines, they can pick up some sulfur. The implementation of 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 simplistic conclusion which could be reached would be that refiners could simply shut down these units in their refineries 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 the volume of crude oil is composed of heavy compounds which have no end use, and thus is not usable without processing by these units. 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 amount of sulfur in gasoline for determining the most cost-effective sulfur removal methods for our cost analysis, and for developing the gasoline sulfur phase-in requirements. For the NPRM, we used a mixture of gasoline sulfur data from the American Petroleum Institute (API) and the National Petrochemical Refiners Association (NPRA) survey which was conducted during the Summer of 1996,[6] and 1995, 1996 and 1997 gasoline sulfur data from the RFG data base. To enable our cost analysis, we compiled the data by 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)

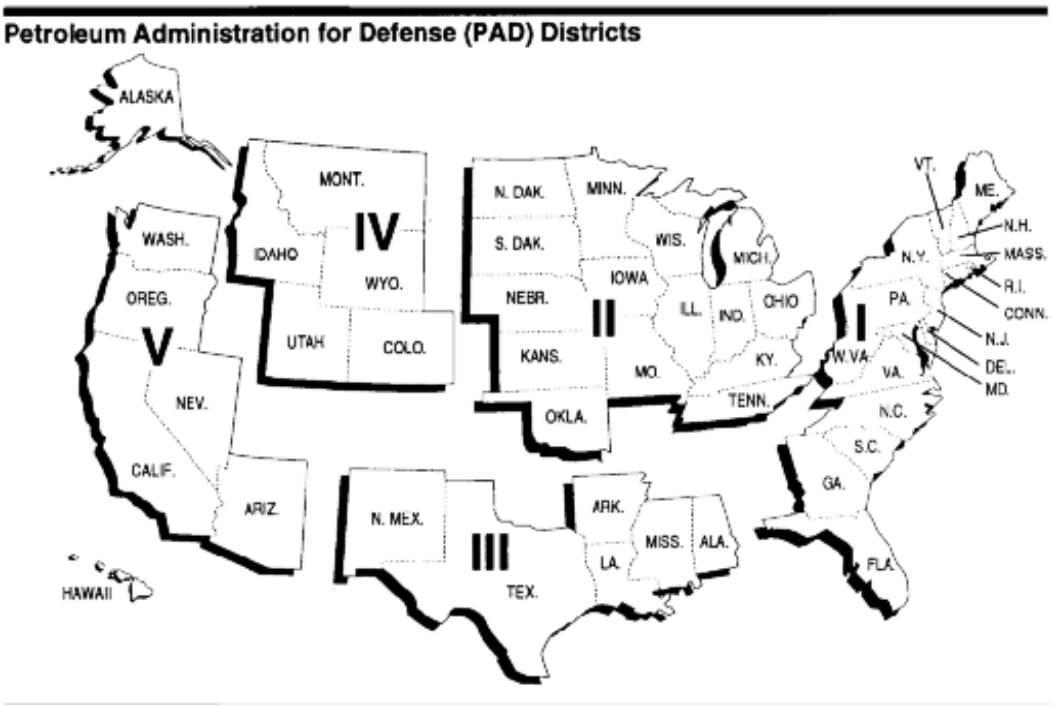

Figure IV-4. Map of U.S. Petroleum Administrative Districts for Defense

The API/NPRA study showed that the gasoline sulfur, outside of California, averaged 340 ppm during the Summer of 1996. 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. Another possible reason for the discrepancy is a difference in the specific refiners included in the two sets of data. Some refiners did not participate in the API/NPRA survey (especially in PADDs 1 and 5), while data handling complications precluded the inclusion of gasoline sulfur data from some refiners from being reported in the RFG data base. 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 in lieu of the API/NPRA survey information.

For the Final Rule, we analyzed the 1998 RFG fuel quality reports to determine the gasoline sulfur levels for 1998. The analysis revealed that during 1998 national gasoline sulfur levels were significantly lower than the sulfur levels in 1997 and previous years. The most likely

reason why the sulfur levels are lower in 1998 is related to the certification requirements for both RFG and conventional gasoline which changed in 1998. Prior to 1998, RFG was certified using the EPA Simple Model which only required that sulfur not increase relative to each refiner's 1990 baseline level. Regarding conventional gasoline, sulfur levels were simply prevented from increasing by more than 25 percent over the refiner's 1990 baseline level. Starting in 1998, refiners had to use the EPA Complex Model to certify both fuels, which included sulfur's impact on emissions from Tier 0 vehicles. RFG sulfur levels were also capped at 500 ppm starting in 1998. Finally, RFG NOx emission performance began to be determined relative to the Clean Air Act baseline fuel, which is much cleaner than many refiners' baseline levels.

Since the 1998 data is the best estimate of where refiners will start from in meeting the new sulfur standards, we recalculated our PADD and national average gasoline pool sulfur levels for estimating gasoline desulfurization cost and the phase-in of the low sulfur program based on the new data. Table IV-14 below summarizes the U.S. sulfur levels by PADD, and for the country as a whole used in the NPRM and for this analysis. Because California has its own low sulfur gasoline program, gasoline produced there was excluded from consideration in this analysis.

Table IV-14. Estimated Average Sulfur Levels by PADD and for the Nation.

	PADD 1	*PADD 2*	*PADD 3*	*PADD 4*	*PADD 5 OC**	*U.S. Avg.**
NPRM	215	338	307	265	506	305
FRM	189	276	288	282	301	268

* Outside of California

It is important to note that the gasoline sulfur values reported in Table IV-14 are estimates 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 Final Gasoline Sulfur Standards

The feasibility of meeting the final 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 final standard. The second way is to determine if refiners are already demonstrating that they can meet a low sulfur gasoline standard similar to that contained in this final rule. Evidence that a large number of refineries having various configurations are already meeting a stringent gasoline sulfur program is a more compelling example of feasibility since the technology is clearly already available if 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 in the U.S. today. Furthermore, the State of California has established tighter gasoline sulfur standards. The average sulfur standard is 15 ppm, with a 60 ppm cap, which takes effect starting January 1, 2003. The cap decreases to 30 ppm starting January 1, 2005.[10] 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 30 ppm sulfur.[11]

4. Meeting a Low Sulfur Gasoline Standard

a. Background

The methodology that refiners would use 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-5, 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

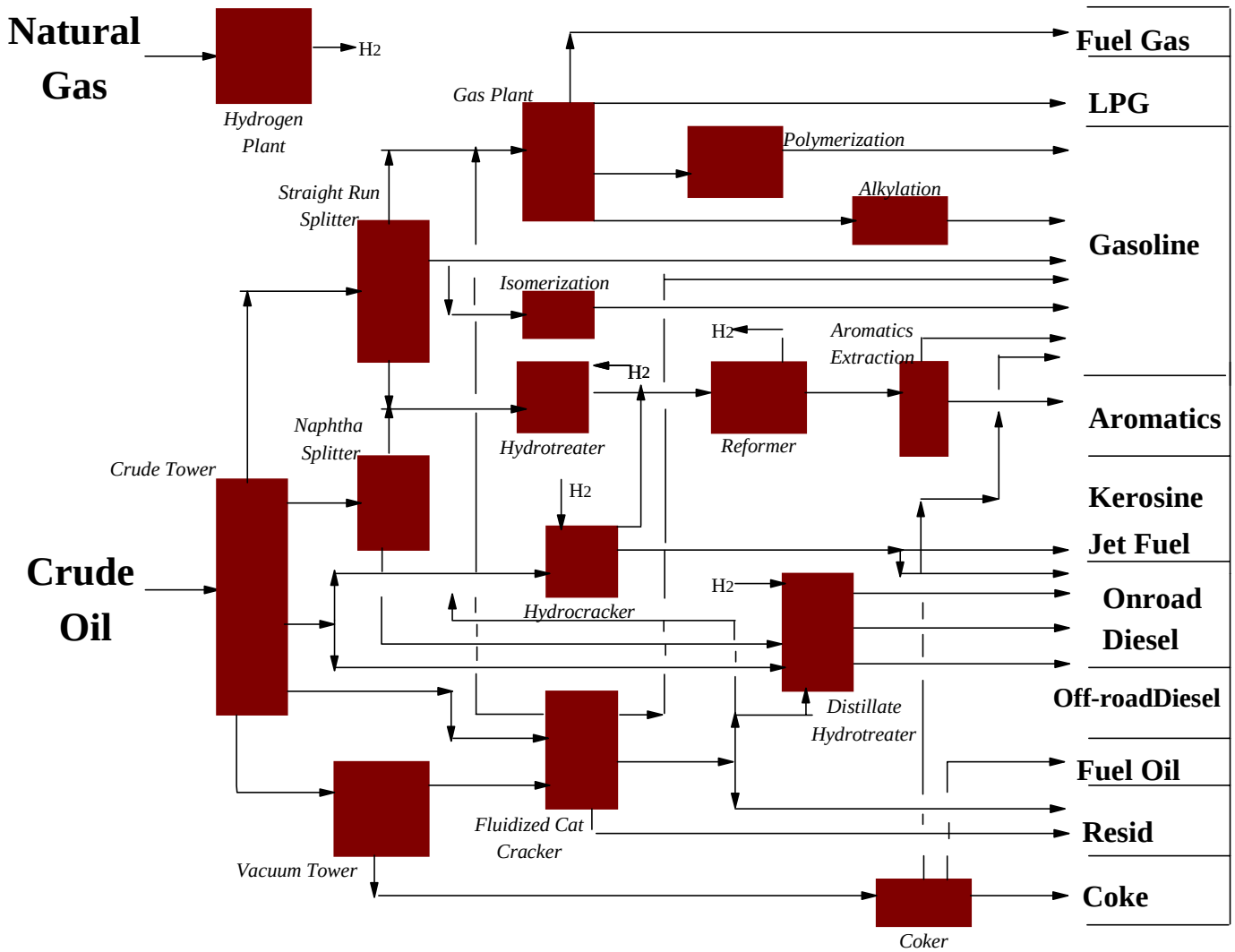

Figure IV-5. Diagram of a Typical Complex Refinery

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, 50 ppm) will probably not need to invest in expensive capital. These refineries have very low sulfur levels due to one or more of a number of possible reasons. For example, some of these refiners may not have certain refining units, such as a fluidized catalytic cracker (FCC) unit, or a coker, which convert heavy boiling stocks to gasoline (Figure IV-5 shows 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 average sulfur levels below 30 ppm would not have to do anything. On the other hand, those refineries with sulfur levels above 30 ppm but below some level, such as 50 ppm, could probably meet the standard employing operational changes only and avoid making capital investments. There are only 3 refineries in this category, representing a total of 2.8% of non-California gasoline production. One such refinery does not have a FCC unit. However, it does have a coker, which produces less gasoline volume than a FCC unit, but the sulfur level of this gasoline can be quite high. This refinery also has extensive hydrotreating capacity. The other two refineries in this situation have FCC units, but also have utilize FCC feed hydrotreating. Thus, all 3 refineries have the capability to desulfurize nearly all of the gasoline components being produced in their refineries. These refiners should be able to meet the 30 ppm sulfur standard by running existing desulfurization units more severely, or by increasing the volume of blendstock sent to these units. If necessary, more active desulfurizing catalysts could be utilized. Refiners also have FCC additives available to them which could allow them to reduce their FCC gasoline sulfur level by 15 to 35 percent, which should be more than sufficient for the two refineries with FCC units.[12] Two of these refineries have average sulfur levels of 40 ppm or less. Thus, they should be able to meet the 80 ppm cap with no change in average sulfur level. They could buy credits (or transfer them from other refineries in their corporation, in the case of multi-refinery refiners) to meet the 30 ppm average standard. Because of their low current sulfur levels, these refineries have until at least 2006, and possibly later in order to implement these strategies. Given the wide range of options available, these 3 refineries should be able to meet the 30 ppm standard without building a desulfurization unit.

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.

b. FCC Feed Hydrotreating

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 the highest profit-making products such as gasoline and diesel. While FCC feed hydrotreating provides these benefits which partially offsets the costs of adding this type of desulfurization, the costs are still high enough that many refiners would have a hard time justifying the installation of this sort of unit. For a medium to large refinery (i.e., 150,000-200,000 BPCD), the capital costs may exceed $100 million. Because of the higher temperatures and pressures involved, utility costs are expensive relative to other forms of hydrotreating explained below. Another justification for this approach is that it allows refiners to switch to a heavier, more sour crude oil. These crude oils are less expensive per barrel and can offset the increased utility cost of the FCC desulfurization unit, providing that the combination of reduced crude oil costs and higher product revenues justify the switch. Another benefit for using FCC feed hydrotreating is that the portion of the distillate pool which comes from the FCC unit would be hydrotreated as well. This distillate blendstock, termed light cycle oil, comprises a relatively small portion of the total distillate produced in the refinery (about 20 percent of on-road diesel comes from light cycle oil), like FCC naphtha, light cycle oil contributes a larger portion of the total sulfur which ends up in distillate. Thus, FCC hydrotreating would 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.

c. FCC Gasoline Hydrotreating

A less expensive alternative for reducing FCC gasoline sulfur levels 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 50 to 60 percent of the feed to the FCC unit ends up as gasoline. The unit is often smaller than that as refiners, which choose to use a fixed bed hydrotreater, could choose to only treat the heavier, higher sulfur portion of that stream with hydrotreating, and then treat the lighter fraction with catalytic extractive desulfurization. FCC gasoline hydrotreaters operate at lower temperatures and pressures than FCC feed hydrotreating which further reduces the capital and operating costs associated with this type of desulfurization equipment. For a medium to large refinery, the capital costs would be on the order of $50 million for a conventional hydrotreater.

One drawback of this desufurization methodology is that the octane value and/or some of the gasoline yield may be lost depending on the process used for desulfurization. Octane loss can occur by the saturation of high octane olefins which are produced by the FCC unit. Most of the olefins are contained in the lighter fraction of FCC naphtha. With increased olefin saturation comes increased hydrogen consumed. There can be a loss in the gasoline yield caused by mild cracking which breaks some of the gasoline components into smaller fractions which are too light for blending into gasoline. If there is octane loss, it must be made up by additional octane production by other units in the refinery or by oxygenate addition, and any 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 by technologies which were recently developed. These processes preserve much of the octane and gasoline yield because they were designed for treating gasoline blendstocks. Octane is preserved because their catalysts are specially designed to either avoid saturating olefins, or if the process does saturate olefins, it causes other reactions to occur which improves the octane of the gasoline lost through desulfurization. These processes may also operate at less severe conditions than conventional hydrotreaters which preserves yield compared to conventional hydrotreating processes. The less severe conditions lowers the capital and operating costs for this process. Typical capital cost for these newer desulfurization technologies ranges from $20 to $40 million for a medium to large sized refinery. The lower operating costs arise out of the reduced utility requirements (e.g., process heat, electricity), octane losses and hydrogen consumption. For example, because these processes are less severe, there is much less or no 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.

The lower capital and operating costs of these newer FCC gasoline hydrotreaters are important incentives for refiners to choose this desulfurization methodology over conventional FCC gasoline or FCC feed hydrotreating. That some refiners would use this newer desulfurization technology is reinforced by conversations with refiners and licensors of hydrotreating hardware. For this reason, we are assuming that many refiners will choose to use the more recently developed FCC gasoline hydrotreating technologies for meeting the gasoline sulfur standard.

For the NPRM we presumed that refiners would choose either of two of the more improved FCC gasoline desulfurization processes, CDTech or Mobil Oil Octgain 220. However, we received a number of comments from the oil industry that they generally require that refining processes be commercially demonstrated, for at least two years, before choosing to use these technologies. Since the CDTech and Mobil Oil have not been commercially demonstrated that length of time yet, we expanded our list of technolgies upon which we we are basing our rule to currently proven FCC gasoline desulfurization technologies. Furthermore, we learned of another class of FCC gasoline desulfurization technologies which are now commercially available.

These newest desulfurization technologies work by adsorption and work more efficiently than hydrotreating desulfurization technologies. We are including these technologies in our analysis as well.

i. Proven Desulfurization Technologies

We know of three commercially proven FCC gasoline desulfurization technologies. These are Mobil Oil Octgain 125, Exxon Scanfining, and IFP Prime G. These are all fixed bed desulfurization technologies, so they function similar to each other. These processes are called fixed bed because the catalyst resides in a fixed bed reactor.[13] The high sulfur gasoline blendstock is heated to a high temperature (on the order of 600 degrees Fahrenheit) and pumped to a high pressure, to maintain the stream as a liquid, and is combined with hydrogen before it enters the reactor. The reactions occur over the bed of the catalyst. While the petroleum is in contact with the catalyst in the reaction vessel, the sulfur is removed from the petroleum compounds and is converted to hydrogen sulfide. Also, depending on the process, some, most or all of the olefin compounds which are present in the cracked stream are saturated which increases the amount of octane lost and hydrogen consumed. The difference between these and conventional hydrotreating processes is that these technologies have a way for either minimizing the loss in octane or compensating for it, either by minimizing the loss of olefins, or by recovering the loss octane through octane producing reactions. The catalyst may cause yield loss through cracking of some of the petroleum compounds. After the reactor, the gaseous compounds, which include unreacted hydrogen, hydrogen sulfide, and any light end petroleum compounds which may have been produced in the reactor by cracking reactions, are separated from the liquid compounds. The hydrogen sulfide must be stripped out from the other compounds and then converted to elemental sulfur in a separate sulfur recovery unit, and the recovered sulfur is then sold. If there is enough hydrogen and it can be economically recovered, it is separated from the remaining hydrocarbon stream and recycled. Otherwise, it would probably be burned with the light hydrocarbons as fuel gas.

Each of these commercially proven desulfurization technologies are a little different. The Octgain 125 process saturates all the olefins, but recovers the lost octane through isomerization and alkylation.[14] It needs to be run at fairly severe conditions for it to recover octane, so this process is more appropriate for refiners with higher sulfur levels which requires severe hydrotreating to reach the sulfur target. While octane loss can be eliminated with the proper operating conditions, yield loss can be significant. It has been commercially demonstrated at Mobil's refinery in Joliet, Illinois.

Exxon's Scanfining process preserves octane by saturating very few olefins, however, at severe operating conditions for higher levels of desulfurization, octane loss can be high. The Scanfining catalyst causes very little yield loss. This process has been demonstrated for a total of over 4 years in two of Exxon's refineries.[15]

IFP's (Intitute Francais du Petrole) Prime G desulfurization process largely preserves olefins as its strategy for diminishing octane loss.[16 17] Like Scanfining, Prime G is less severe and cracks the petroleum compounds less resulting in less yield loss. Prime G has been commercially demonstrated for over 7 years in two U.S. refineries, and in an Asian refinery.

ii. Improved Gasoline Desulfurization Technology

Consistent with the NPRM, we are placing CDTech and Mobil Oil Octgain 220 processes in the same category called improved desulfurization technologies, and these technologies have not yet had significant commercial experience. Mobil Octgain will be discussed first since the process is similar to the commercially proven hydrotreating technologies discussed above. Like the commercially proven desulfurization technologies, the Mobil 220 process uses a fixed bed for its catalyst.[18] Octgain 220 preserves most of the olefins and recovers lost octane through isomerization reactions.[19 20] The less severe operating conditions also causes less yield loss, as the conditions are less favorable for causing cracking of the larger petroleum compounds to smaller compounds. For high levels of desulfurization, yield and octane loss increase significantly for this process so Mobil recommends that refiners use the 125 process for these desulfurization cases. Mobil loaded the 220 catalyst into their Joliet hydrotreater during March of 1999, so the process has some commercial experience. In addition, Mobil Oil has signed a license agreement with a refinery outside the U.S., so another Octgain unit will be installed soon.

The CDTECH process is significantly different from either conventional hydrotreating or Octgain, and it is a little more complex to describe. The CDTECH process utilizes catalytic distillation.[21 22 23] 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 most important portion of the CDTech desulfurization process is a set of two distillation columns loaded with desulfurization catalyst in a packed structure. The first vessel, called CDHydro, treats the lighter compounds of FCC gasoline and separates the heavier portion

of the FCC gasoline for treatment in the second column. The second column, called CDHDS, removes the sulfur from the heavier compounds of FCC gasoline. All of the FCC gasoline is fed to the CDHydro column. The 5 and 6 carbon petroleum compounds boil off and head up through the catalyst mounted in the column, along with hydrogen which is also injected in the bottom of the column. The reactions in this column are unique in that the sulfur in the column are not hydrotreated to hydrogen sulfide, but they instead are reacted with dienes in the feed to form thioethers. Their higher boiling temperature causes the thioethers to fall to the bottom of the column. They join the heavier petroleum compounds at the bottom of the column and are sent to the CDHDS column. Because the pressure and temperature of the first column is much lower than conventional hydrotreating, saturation of olefins is reduced to very low levels (according to CDTECH, the saturation which does occur is desirable to eliminate diolefins). Thus, little excess hydrogen is consumed. An option for the refiner is to put in an additional catalyst section in the CDHydro column to increase octane. This octane enhancing catalyst isomerizes some of the olefins which increases the octane of this stream by about three octane numbers, and few of the olefins are saturated to degrade this octane gain.

The seven-carbon and heavier petroleum compounds leave the bottom of the CDHydro unit and are fed into the CDHDS column. There, the heavier compounds head down the column, and the lighter compounds head up. Both sections of the CDHDS column have catalyst loaded into them which serve as hydrotreating reaction zones. Similar to how hydrogen is fed to the CDHydro column, hydrogen is fed to the bottom of the CDHDS column.

The temperature and pressure of the CDTech process columns are lower than fixed bed hydrotreating processes, particularly in the upper section of the distillation column, which is where most of the olefins end up. These operating conditions minimize yield and octane loss. While the CDTech process is very different from conventional hydrotreating, the catalyst used for removing the sulfur compounds is the same. Thus, if concerned about the reliability of the process, refiners can look at the track record of the catalyst in conventional hydrotreating to get an indication of its expected life, and then adjust that expectation based on the milder conditions involved. One important different between the CDTech process and conventional hydrotreating is that CDTech mounts its catalyst in a unique support system, while conventional catalyst is simply dumped into the fixed bed reactor. Although the CDTech desulfurization process is different from conventional hydrotreating processes, the use of a distillation column as the basis for the process is very familiar to refiners. Every refinery has distillation in its refinery, thus, refiners are very skilled in its application.

CDTech has numerous CDHydro units in operation, but CDHDS units have not yet been installed in refineries. Thus, one portion of the CDTech process is commercially proven, while the other portion is not. A CDHDS unit is expected to be operational in the Motiva refinery in Port Arthur, Texas starting March of 2000. Additionally, a combined CDHydro/HDS unit is expected to be operational in North America in October of 2000, and another license aggrement has been signed for an installation in Europe. An installation of an HDS unit is planned for the

Transamerican refinery in Louisiana, however, that refinery is currently shutdown and the startup date of the refinery and the planned CDHDS unit is unclear.

The relative cost of the improved desulfurization technologies and the commercially proven technologies depends on the specific situation faced by a refiner. For most refiners, the more recent, improved desulfurization technologies are projected to be less expensive. However, as we point out above, Mobil Oil recommends that the Octgain 125 process be used for treating the FCC naphtha from heavy, high sulfur crude oils. In our analysis, we are estimating the desulfurization cost of average refineries meeting the gasoline sulfur standard, and Mobil Oil would probably recommend that their Octgain 220 process be used for this application. However, Scanfining and Prime G processes are well suited desulfurizing technologies for average refineries as well. Thus, when we use costs developed for improved technologies, these costs could be representative for some of the proven technologies as well.

iii. Adsorption Desulfurization Technologies

Black and Veatch Pritchard Inc. and Phillips Petroleum Co. have announced the commercial availability of adsorption desulfurization technologies (i.e., they are prepared to design and license this technology to refiners). We believe that similar adsorption technologies may be available soon from UOP and a major refiner as well. These technologies use the chemical process of adsorption, instead of hydrotreating, as the principal methodology for the removal of sulfur from gasoline. Adsorption has the benefit of operating at much lower pressure and temperatures, which lowers operating costs, and potentially can lower capital costs as well. Each of these desulfurization processes operates differently.

The Black and Veatch process, named IRVAD, adsorbs heteroatom-containing petroleum compounds, which are sulfur, nitrogen and oxygen containing petroleum compounds, onto their adsorption catalyst.[24] The catalyst is alumina-based and manufactured by Alcoa Industrial Chemicals. The catalyst is fluidized and continuesly removed and regenerated, using hydrogen, in a second column. The regenerated catalyst is then recycled back into the reactor vessel at the rate which it is being removed. In the regeneration column, the adsorbed heteroatom containing petroleum compounds, which is about 4 percent of the petroleum stream being treated, are removed from the catalyst. Since the hydrogen used in the regeneration column is for scavenging the petroleum compounds off of the catalyst and it is not reacting with the petroleum, hydrogen loss is considered by Black and Veatch to be negligable. According to Black and Veatch process operations information, the treated FCC gasoline is 2 octane numbers higher than the untreated FCC gasoline.

This high sulfur stream, which contains about 1 percent by weight of sulfur (10,000 ppm), must then be treated for reblending with gasoline. This stream cannot just be blended to offroad diesel since it contains many volatile petroleum compounds. Black and Veatch surmises that

most refiners would treat the stream in an existing diesel hydrotreater. After hydrotreating, the gasoline substream, which is now blended in with desulfurized diesel, would have to be separated either by the existing stripping column which hydrotreating processes have for separating the light ends produced in these facilities, or in a splitting column which may already be installed after the hydrotreater. If the stripping column is insufficient for the volume of gasoline which would have to be hydrotreated, and there is not an existing splitting column, then a splitting column would have to be added, or the stripping section would have to be enlarged. At the time that this document was being drafted, Black and Veatch had not yet signed a license agreement to install one of their units, although two refiners who own small refineries have given Black and Veatch verbal agreements that they will install IRVAD units in their refineries.

The adsorption process by Phillips, called S-Zorb, is similar to the Black and Veatch process in that two separate columns are needed and the catalyst is constantly moving from the reactor vessel to the regeneration column, and back again.[25] However, beyond that, the processes are very different. The untreated FCC naphtha and hydrogen are fed to the reaction vessel where the Phillips catalyst adsorbs the sulfur-containing petroleum compounds onto the catalyst. However, the catalyst also catalytically removes the sulfur from the petroleum compound so the petroleum compound which contained the sulfur never leaves the reaction vessel. Instead, the catalyst which begins to accumulate the removed sulfur, is transfered over to the regeneration column on a continual basis where the sulfur is removed from the catalyst using hydrogen as the scavenging compound. Then the hydrogen disulfude is converted to sulfur dioxide and sent to the sulfur recovery unit. Since, the petroleum compounds are desulfurized in the main reactor, there is no need to hydrotreat any high sulfur stream. However, because the process still relies upon catalytic processing in the presence of hydrogen, there is some saturation of olefins, with a commensurate reduction in octane. Currently, there are no S-Zorb units operating, however, Phillips is working rapidly to install a 6000 barrel per day unit at its Borger, Texas refinery, and plans to have it operating by the first quarter of 2001.

5. Expected Desulfurization Technology to be Used by Refiners

With the promulgation of the Federal sulfur control program, which begins to phase-in in 2004, 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 install capital to meet the sulfur standard. Arguably, refiners would try to minimize the cost to their business. As stated above, the adsoprtion gasoline desulfurization technologies seem to be the lowest cost technologies based on our analysis of average refineries in each PADD, followed by the improved desulfurization technologies, such as CDTECH and Mobil Oil Octgain. However, several 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 the lower cost adsorption and improved desulfurization technologies, to applying proven desulfurization technologies.

While there is a concern now on the part of some refiners about using the adsorption and improved, but not commercially tested desulfurization technologies, we believe that much of this concern will dissipate in the near future. All these processes are expected to be operating commercially in the next two years. Mobil Oil has already installed its Octgain 220 catalyst in the hydrotreater at its Joliet, Illinois refinery and is accruing commercial experience with that technology. CDTech has years of accumulated service with its CDHydro unit, but not with the CDHDS unit. The CDHDS unit and the adsorption technologies are expected to be installed in refineries in the year 2000 and 2001.

We have clear examples specific to these technologies that refiners do not need to observe a certain technology operating in a refinery before they will choose to use that technology. For example, no CDHDS units, nor complete CDHydro/CDHDS units, are up and operating, however, a handful of refiners have committed to installing the process in their refineries. Thus, these refiners have been willing to commit to that technology without observing it operating commercially in a refinery. We believe that it may be more difficult to commit to the adsorption technologies as easily, as they are somewhat different from conventional desulfurization technologies. For developing the cost of the desulfurization program, we need to project the types of desulfurization units which will be installed during the years that the gasoline sulfur program is phased-in. Our projections are summarized below in Table IV-15.

Table IV-15. Projected Use of Desulfurization Technology Types by Refiners During the Phase-in Period

Year	*Mix of Technology Types Used*
2004	1/2 Proven, 1/2 Improved
2005	3/4 Improved, 1/4 Adsorbent
2006	1/2 Improved, 1/2 Adsorbent
2007 & 2008	1/4 Improved, 3/4 Adsorbent

Prior to 2004, we project that new desulfurization units will fall into two broad categories: early units being installed by refiners who desire to generate credits and possibly use low sulfur as a marketing factor and demonstration units. We project that the former will primarily utilize proven technology (90 percent proven, 10 percent improved). On the other hand, the demonstration units will all utilize improved or adsorbent technology, as there is no need to demonstrate the proven technology. On a volumetric basis, we project a breakdown of

50 percent proven, 25 percent improved, and 25 percent adsorbent.

6. Feasibility for a Low Gasoline Sulfur Standard in 2004

The final gasoline sulfur control program provides a full four years before the first sulfur standard must be met starting on January 1, 2004. As discussed below, not all refiners will have to modify their operations on this date. Thus, more than four years leadtime is available for many refiners (i.e., those with low current sulfur levels). This is consistent with requests received from API and NPRA, as well as from a number of refiners, in their comments to the proposal, that at least four years be provided prior to the start date of the program.

The following table breaks down the steps involved in constructing new refining equipment and our projection of the time necessary for each step and the entire process. The reader is also referred to the Draft RIA for some additional detail in the development of these estimates.

Table IV-16. Leadtime Required Between Promulgation of the Final Rule and Implementation of the Gasoline Sulfur Standard (years)

	Naphtha/Gasoline Hydrotreating		*More Major Refinery Modification (e.g., FCC Feed Hydrotreating)*	
	Time for Individual Step	*Cumulative Time*	*Time for Individual Step*	*Cumulative Time*
Scoping Studies	0.5-1.0*	0.5	0.5-1.0*	0.5
Process Design	0.5	1.0	0.5-0.75	1.0-1.25
Permitting	0.25-1.0	1.25-2.0	0.25-1.0	1.25-2.0
Detailed Engineering	0.5-0.75	1.5-2.25	0.5-1.0	1.5-2.25
Field Construction	0.75-1.0	2.0-3.0	1.0-1.5	2.5-3.5
Start-up/Shakedown	0.25	2.25-3.25	0.25	2.75-3.75

* 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.).

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. For example, refiners have been sending samples of their FCC naphtha to the vendors of desulfurization technology for some time to determine exactly how well each technology will perform in their specific refinery. 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 not have been demonstrated in actual refinery applications by the end of 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. Thus, the fact that less than four years are actually needed to design and build gasoline desulfurization equipment once the technology is selected and some refiners do not need this equipment until 2005 or beyond allows refiners to observe the performance of these new, potentially lower cost technologies and make a more informed selection in a year or two. We believe that at a minimum, refiners should have 6 months after the final rule to assess their situation with respect to the final sulfur control program and select their technological solution.

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.

All of this equipment is already common to refineries. Aside from the new adsorption technologies, all gasoline desulfurzation units are 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.[26]

For example, CDTECH estimates that 10 - 12 weeks are needed for the basic process design of their equipment. Discussions with other contractors have indicated that 4-5 months is usually more than sufficient to complete the process design.

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, particularly SOx and toxics. However, FCC hydrotreating can increase NOx emissions relative to naphtha hydrotreating due to processing more hydrocarbons and the greater temperature and pressure involved. The emission reductions should ease permitting and compliance with future MACT standards for toxics, while the NOx emission increase would have to be addressed in ozone nonattainment areas subject to NOx offsets. We have allocated up to 3 months more for the process design of these more major modifications.

Regarding permitting, EPA has held a number of discussions with state/local permitting agencies, environmental organizations and refiners. EPA is committed to streamlining the process of obtaining permits. One step in this process would be to identify soon after the final rule the technologies that EPA believes would constitute Best Available Control Technology (BACT) and the Lowest Achievable Emission Rate (LAER). This would inform both states and refiners of the types of refinery emission control technology EPA believes would meet the BACT and LAER requirements The lower limit of 3 months is typical for obtaining a minor source permit. States such as Texas typically issue permits in four months on average, including major NSR permits. One year for a permit would represent a very protracted process which should be avoidable if refineries are working closely with the states to resolve any issues that may arise during the permitting process. Nonetheless, this time period was included above in order to identify the worse case situation which may occur. EPA's permit streamlining approaches should provide opportunities to shorten this time period even further.

Based on discussions with contractors, design and construction of naphtha hydrotreaters typically requires about 18 to 20 months, while about two years is required for more major equipment like FCC feed hydrotreaters. If all refiners attempted to construct their new equipment at the same time, limited capacity of vendors who manufacture the pressure vessels and compressors could extend these times to 24-30 and 36 months. However, as described in the next section, we have explicitly designed the sulfur control program to spread out construction. Thus, the manufacturing capability of these equipment vendors should not be over-taxed.

Several different fuel programs already in place suggest that a stringent gasoline desulfurization program can be phased-in in four or less years. 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.[27] Similarly, the Phase II California Reformulated Gasoline Program was promulgated in November 1991 and took effect about 4½

years after promulgation.[28] 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. 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.[29] 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 fixed bed gasoline desulfurization units, such as Octgain. Refiners' volume of onroad diesel fuel is generally less than their FCC gasoline volume. However, leadtime is generally not a strong function of unit capacity, at least for capacity differences of this magnitude.

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.

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.[30] 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. Under one set of provisions, the smallest refiners will be given until 2008 to meet the 30 ppm sulfur standard. Under another set of provisions, refiners supplying fuel to a number of western states will be given until 2007 to meet the 30 ppm standard. This provision most directly affects the relatively small refineries located in these western states. This additional leadtime should provide not only enough time for these small refiners to construct equipment, but to also allow these refiners more time to select the most advantageous desulfurization technology. This additional time for technology selection will help to compensate for the diseconomy of scale inherent with adding

equipment to a small refinery.

7. Phase In of Compliance with the Proposed Sulfur Standards and Early Credit Generation

As stated earlier in this chapter, the sulfur content of gasoline in 1998 averaged about 268 ppm, well above the eventual refinery average standard of 30 ppm. The vast majority of the sulfur in gasoline comes from a single gasoline blending component, FCC or cat naphtha. As projected above, for most refiners, removing enough sulfur from FCC naphtha to meet a 30 ppm standard on average will require the construction of a naphtha desulfurization unit.

There are two reasons to evaluate the timing of the construction of these desulfurization units. One, the type of desulfurization technology employed must be determined at the beginning of the design and construction process. A desulfurization unit whose design and construction begins prior to the time when a specific desulfurization technology is deemed to be commercially proven and ready for broad application will generally not be available for use in that specific refinery. As discussed above, we have identified three groups of desulfurization technology ranging from those already commercially proven to those which will generally not be available for use (not design and construction) until 2005. Therefore, if the applicable gasoline sulfur standards require a refinery to install a hydrotreating unit in 2004, a refiner may consider its options for desulfurization technology to be more limited than if he could delay the installation until 2005 or later.

The second reason to project the timing of new desulfurization units is to evaluate the ability of the design and construction industry to fulfill the needs of the refining industry. Here, the type of unit is less important (though not irrelevant), because all of the technologies use pressure vessels of some type, compressors and process heaters. The vendors which manufacture these items are limited in number, so the more refiners ordering this equipment at the same time, the longer the leadtime for delivery.

Projecting the timing of this new equipment consisted of a two step process. In the first step, EPA evaluated the sulfur levels of gasoline certified in 1997 and 1998 to estimate each refinery's average gasoline sulfur level in these two years. This was done separately for RFG and CG, as these two types of fuels are certified separately to different quality standards. There are 126 refineries in the U.S. that produced gasoline in 1998. This total includes 12 refineries located in California, which produce gasoline primarily for the state of California. As only a small portion of the gasoline produced by California refineries will be affected by this regulation, these refineries will be addressed separately below. The total of 126 also includes 14 refineries which are located in the 6 states which are included in the temporary geographical phase-in program and 17 refineries which fall under the small refiner provisions. These two sets of refineries are also addressed separately below.

The following table shows the number of refineries whose average sulfur levels fall into various ranges.

Table IV-17. Number of U.S. Refineries with 1998 Sulfur Averages Falling Into the Specified Range of Sulfur Content (ppm)

Sulfur Range	*≤100*	*101-200*	*201-300*	*301-400*	*401-500*	*>500*
Number of Refineries	22	29	28	12	5	14

As can be seen, refinery's current sulfur levels vary dramatically. This causes some refineries to deeply desulfurize FCC naphtha earlier under EPA's sulfur control program than others.

The current national average pool sulfur levels were 293 ppm and 207 ppm for CG and RFG, respectively, based on the CG and RFG batch certification reports. This is considerably lower than the 1997 CG and RFG sulfur levels of 314 and 282, respectively. This significant reduction in gasoline sulfur is likely due to the mandatory use of the Complex Model in the certification of both CG and RFG beginning in 1998. Prior to 1998, the Simple Model was used to certify RFG and sulfur levels were simply capped at 1990 levels. Prior to 1998, CG sulfur levels could be as much as 25 percent higher than 1990 levels. The Phase II RFG specifications begin in 2000. EPA projects that RFG sulfur levels will average roughly 150 ppm during the summer months. In their comments to the Tier 2/sulfur rule, several refiners and refining organizations indicated that refiners could meet the sulfur-related portion of the Phase II RFG requirements without reducing their refinery average sulfur levels. They indicated that they could shift sulfur from RFG to CG during the summer and reverse this shift during the winter. As noted above, 1998 RFG sulfur levels are only 57 ppm above this target. No further reduction in pool sulfur is expected to occur with Phase II RFG, only shifts in sulfur between CG and RFG

The second step in this process was to develop and apply criteria which indicate which refineries must install and apply desulfurization equipment under various sulfur standards. In any particular calendar year, refiners have to comply with up to three specifications: a per gallon standard, a corporate average standard and a refinery average standard. The first applies to every batch of gasoline introduced into the market. The second can be met by averaging across refineries within a corporation, and also through the trading of allotments across refiners. Thus, in essence, assuming allotments are actively traded, the corporate average standard essentially becomes a national average standard. Finally, the refinery average standard can be met on average by a refinery and through the trading of credits generated relative to this standard. In 2005 and 2006, the refinery average standard can also be met through the trading of early sulfur reduction credits (i.e., reductions in sulfur relative to a refinery's baseline generated prior to

2004). Criteria were developed to represent each of these three specifications.

The first set of criteria apply to a refinery's ability to comply with a per gallon cap. For sulfur levels of 100 ppm or more, EPA projects that a refinery will produce gasoline with an average sulfur level about two-thirds of the level of the per gallon cap. For example, a refinery is expected to average 200 ppm sulfur under a 300 ppm cap. There is no need to project an average sulfur level under the 80 ppm cap, as compliance with the average standard of 30 ppm should be sufficient for compliance with the cap (temporary equipment disruptions aside).

As indicated above, the corporate average standards are essentially national average standards, intended to ensure that, on average, the national pool of gasoline does not exceed certain sulfur levels. Thus, the primary criterion indicating compliance is the national average sulfur level. Again assuming actively traded allotments, the national average sulfur level need be just below the corporate average standard. However, it is unlikely that every refiner would market every allotment generated relative to the standard. Refiners will likely keep some allotments back from the market in order to provide themselves with a compliance cushion towards the standard. Also, there could be some inefficiencies in the market. For example, some refiners may be looking for allotments prior to other refiners deciding that they have excess allotments to sell. Later, when allotments become available, potential buyers have already decided to comply with the standards without the need for allotments. Thus, to be conservative, we projected that refiners would have the capability of producing fuel with a national average sulfur level 30 ppm below the applicable corporate average standard. This translates into the capability to produce national average sulfur levels of 90 ppm in 2004 and 60 ppm in 2005.[4]

Finally, criteria were developed to represent compliance with the refinery average standard of 30 ppm. In 2005, we assumed that refiners would use early credits to allow them to produce fuel complying with the corporate average standard of 90 ppm. In 2006 and later, we assumed that the refinery would have to average 30 ppm sulfur.

The third and final step was to determine when a refinery had to build a desulfurization unit in order to comply with one of the above criteria. First, when complying with the temporary cap of 300 ppm, as indicated above, a refinery is presumed to average 200 ppm sulfur or less.

[4] While refiners are projected to be able to produce gasoline at these levels, this does not necessarily mean that these sulfur levels will be achieved. We expect that most refiners will design their refineries to be capable of producing 30 ppm sulfur gasoline, as this is the long-term standard. However, prior to 2006, some refiners may utilize their equipment to produce gasoline at 30 ppm, while others will find that they can comply with the interim standards while using this equipment to produce gasoline with higher sulfur levels. For example, a refiner may produce 30 ppm gasoline for a portion of the year in order to generate allotments in case of operational difficulties later in the year. However, as the year progresses, these allotments will build up and the likelihood of a disruption will decrease. Therefore, they could operate this equipment at a lower sulfur removal efficiency in order to reduce costs.

We project that a refinery could reduce its maximum sulfur level (i.e., that which determines compliance with the per gallon cap) by 20 percent for a year or so in order to delay construction of new equipment. Therefore, refineries with average sulfur levels of 250 or less are projected to be able to delay construction of new desulfurization units under the 300 ppm cap. In addition, three refiners informed EPA that they had refineries with sulfur averages above 250 ppm which could meet the 300 ppm cap without major construction due to more unique circumstances (excess equipment on site, existing excess hydrodesulfurization capacity, etc.)

This 20 percent sulfur reduction due to operational modifications is based on an assessment of the capability of a number of sulfur reducing techniques available to refiners. First, refineries with FCC feed hydrotreating can usually increase the severity of their units to remove more sulfur from the FCC naphtha. Second, many refiners can switch or shift to a lower sulfur crude oil. Third, refiners can route some of their FCC naphtha to their reformer hydrotreater and reformer. Fourth, refiners can change their FCC catalyst to one which reduces the amount of sulfur in FCC naphtha. (Grace makes such a catalyst.) Finally, refiners can shift the heaviest (and most sulfur laden) portion of their FCC naphtha to the distillate pool. The cost associated with each of these techniques generally increases as one progresses down the list. The cost which a refiner would be willing to pay will depend on the value of delaying the selection and construction of new desulfurization equipment.

With regard to the final 30 ppm refinery average standard, we project that a refinery will need to construct a new desulfurization unit if its current average is greater than 50 ppm. As discussed in Section 4 above, refiners that currently have such a low sulfur level probably do not have an FCC unit, hydrotreat the FCC feed, or utilize low sulfur crude. In this situation, the refiner should be able to reduce their sulfur further through operational changes and avoid major capital investment.

The same basic criteria were applied to those refineries which are covered by the temporary geographical phase-in program and the small refiner provisions, with the exception that the standards which these refineries must meet differ to some degree from those which are generally applicable. For example, under the temporary geographical phase-in program, refiners must meet a 300 ppm cap and a 150 ppm refinery average standard in 2004. Since credits or allotments can be purchased and used in meeting the 150 ppm standard, the 300 ppm cap is the primary controlling standard. As discussed above, refineries currently with an average sulfur level of more than 250 ppm are projected to install a desulfurization unit in order to meet the 300 ppm cap, except for three refineries, as noted previously. These standards apply unchanged until 2007, when the 30 ppm average standard and 80 ppm cap take effect. As projected above for other refineries, all refineries with a current average sulfur level above 50 ppm are projected to install a desulfurization unit in order to meet the 2007 standards.

Refineries covered under the small refiner provisions which currently have an average sulfur level of 200 ppm or less only need to maintain that level until 2008. Those with current

average sulfur levels between 200 and 300 ppm will have to modestly reduce their sulfur levels, while those with higher sulfur levels will have to reduce their sulfur levels more significantly. Only five small refiners currently average more than 300 ppm sulfur. Given that these refiners will not have to meet the 30 ppm standard until 2008 (four years after the date of the initial standard), these five refiners have a significant incentive to delay the installation of naphtha desulfurization equipment until that time. Thus, we project that they will modify their refinery operations to the fullest degree possible to reduce sulfur and avoid constructing their final desulfurization equipment. This could involve the operational modifications described above. It could also involve more modest investment in new equipment, which would reduce sulfur modestly and immediately, while being useful in the long term, as well. An example of this would be the installation of a distillation column to separate light and heavy FCC gasoline and a Merox unit to remove sulfur from the light FCC naptha. Instead of projecting that all five will require a naphtha desulfurization unit in 2004, we only project that two will require units.

Regarding California refiners, we analyzed the gasoline sold by these refiners outside of California in 1997 and 1998. We also compared the volume of fuel sold outside of California to that sold inside of California by each refiner. With two exceptions, the non-California fuel produced by California refiners contains 50 ppm sulfur or less and represents a small fraction of total gasoline production. Thus, compliance with the Federal sulfur program should not require major new equipment at 10 of the 12 California refineries marketing gasoline outside of the state. One of the two remaining refineries certified non-California fuel in 1998, but did not do so in 1997. The 1998 non-California fuel averaged 91 ppm and represented 10-15 percent of their total gasoline production. Assuming that their California gasoline was at 30 ppm sulfur or lower, this refinery's overall average sulfur level was 36-39 ppm, well under our 50 ppm criterion mentioned above. Thus, this refinery should not require an additional desulfurization unit. The one remaining refinery appears to be selling a significant fraction of its fuel outside of California at an average sulfur level of about 150 ppm in 1998. We project that this refinery will add a desulfurization unit in 2006 in order to comply with the Federal sulfur control program.

We applied these criteria to the each refinery's 1997 and 1998 two-year average sulfur levels and projected both the number of new desulfurization units which would be required each year, as well as the national average sulfur level. In determining the national average sulfur level, we assumed that refineries with new desulfurization units would operate at 30 ppm sulfur on average year round. The results are shown in Table IV-18 below.

Table IV-18. Number of New Desulfurization Units Operating by January 1 of Indicated Year and National Pool Average Sulfur Levels Under the Final Sulfur Standards

	2003 and Earlier	*2004*	*2005*	*2006*	*2007*	*2008*
New Units	7-10	37-40	6	23-26	9	9
Sulfur (ppm)	---	67	60	31	30	30

As shown in Table IV-16, 7-10 desulfurization units are projected to be built and operating in 2003 or earlier. This is based on information received from both licensors of desulfurization technology and refiners. Included in these units are a CDTech unit at Motiva's Port Arthur refinery, a CDTech unit at another refinery not yet publicly identified, two Black and Veatch units at smaller refineries, one Phillips S-Zorb unit, and 2-5 additional units at major refineries desiring to reduce sulfur early. The two CDTech projects are expected to be operational in 2000, while the Black and Veatch and Phillips projects are expected to be operational in 2001 and 2002. The additional units are projected to be operational in 2002 and 2003.

These pre-2004 desulfurization units will also provide a source for early sulfur reduction credits. Based on the production volumes and sulfur levels of the refineries projected to receive these projects, we project that these new units will reduce national average sulfur levels by 1 ppm in 2001, 29 ppm in 2002, and 29-51 ppm in 2003. These projections are based on:

- Two refineries (representing about 1.0% of non-California gasoline production) installing CDTech and Octgain 220 desulfurization units in 2000 which reduces half of its gasoline to 30 ppm,
- Three refineries (representing about 1% of non-California gasoline production) installing absorbent desulfurization units in 2001 and 2002 to produce 30 ppm gasoline in order to demonstrate this technology,
- Two to five refineries (representing about 3-8% of non-California gasoline production) installing absorbent desulfurization units in later 2002 and 2003 to produce 30 ppm gasoline in order to generate early sulfur credits and allotments,
- The baseline sulfur levels for these refineries range from 130-700 ppm; on average, the baseline sulfur level is roughly 350-400 ppm.

On an annual national gasoline pool basis, these annual credits sum to a total of 59-81 ppm of credit. Ignoring the small increase in gasoline consumption annually, operating at 90 ppm in 2005 will require that refiners use 60 ppm of credits relative to the 30 ppm refinery average standard. The credits which can be used by small refiners beyond 2005 are very low, due

to their small production volumes and amount to less than 5 ppm. Thus, these early units will either provide all of the credits which are needed in 2005 and beyond, with roughly 15 ppm of credit to spare, or will fall less than 5 ppm short.

In addition to credits from new plants, refiners can generate credits operationally, as discussed above. Eliminating the 5 ppm shortfall would only require that annual average sulfur levels from 2000-2003 be reduced by 1 ppm on average. Routing heavy FCC gasoline to reforming hydrotreaters has far more potential to reduce sulfur than 1 ppm on average. Also, as mentioned above, sulfur levels in 1998 were significantly below those of 1997. Given that refinery's baselines will be based on their 1997-98 average, many of these refineries can generate credits if they can continue producing gasoline at their 1998 levels. This approach could generate more than 15 ppm of credit per year, well above that needed to complement credits generated from new desulfurization units, even if refiners did not trade all of the credits that they generated.

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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. Cost estimates have been prepared for all categories of vehicles, LDVs through LDT4. The cost estimates for medium-duty passenger vehicles (MDPVs) to meet Tier 2 exhaust and evaporative standards have been grouped with the costs for LDT4s.[1] We have taken this approach with MDPVs because they are grouped with HLDTs in the program for phase-in purposes and are required to meet essentially the same requirements as vehicles in the LDT4 category. 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.[2] 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

[1] EPA has categorized passenger vehicles (primarily SUVs and passenger vans) between 8,500 pounds and 10,000 pounds GVWR as MDPVs and has included them in the Tier 2 program.

[2] 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. The MDPVs are required to meet engine-based standards prior to 2004. The projected technologies likely to be used by manufacturers to meet the 2003 engine-based standards form the baseline for these vehicles.

discussions with manufacturers about trends in technology.

As described in detail below, we have projected costs for the final Tier 2 standards. We have not projected specific incremental costs for the interim standards contained in the Tier 2 program.[3] To account for the interim standards in the cost analysis, we have assumed that the manufacturers would opt to accelerate the phase-in of Tier 2 vehicles rather than redesign vehicles for the interim program. The Tier 2 program averaging flexibility allows manufacturers to take this approach. We believe this approach by the manufacturers is likely because it allows manufacturers to avoid significant R&D efforts to meet standards that are in effect for only a few model years.

The following analysis projects a relatively uniform emission control strategy for various LDV, LDT, and MDPV models. However, this should not suggest that a single combination of technologies would be used by all manufacturers. Selecting technology packages requires extensive engineering development work and EPA does not know future technology mixes and costs with certainty for each vehicle model. 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 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 certification levels are well below current standards, also suggesting this approach makes sense. We have made a best estimate of the combination of technologies that any manufacturer might use to meet the standards at an acceptable cost and these technologies form the basis of the cost estimates. In making our cost estimates, we have relied on our own technology assessment including the results of our in-house testing, described in Chapter IV. Since California, in their LEV II program, has adopted essentially the same standards and time-line as Tier 2, 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

[3] We have assumed for purposes of our cost analysis that manufacturers will choose the Tier 2 program option that brings all 2004 model year vehicles into the Tier 2 program. We believe manufacturers are very likely to select this option due to the program flexibility it provides.

analyses. Most manufacturer input is considered confidential business information and therefore is not described in detail.

As noted above, 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 about 0.156 g/mile or less. Vehicles have their emissions capped at 0.60 g/mile NOx and 0.23 g/mile NMHC prior to phase-in.[4] 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.

[4] Manufacturers may select an option that provides an NMOG standard of 0.280 g/mile for LDT4s and MDPVs for the 0.6 g/mile NOx bin. Manufacturers also may select an option that allows MDPVs to be placed in a bin with a NOx level of 0.9 g/mile and a NMOG level of 0.280 g/mile during the interim program. Further, the optional program provides that diesel vehicles in the MDPV category may be certified to heavy-duty engine-based standards prior to 2008. The optional standards are equivalent to those that apply in the California LEV I program in 2004-2006.

For the interim fleet average NOx standard, (average standard of 0.2 g/mile NOx with an NMHC standard of about 0.156 g/mile or less), 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. In other words, manufacturers would introduce Tier 2 vehicles early and use the averaging program to avoid redesigning vehicles to the interim standards. We believe this approach is reasonable considering manufacturers are likely to avoid significant R&D efforts to meet an interim standard that is in effect for only a few model years. Essentially, a few such interim 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. We have projected an accelerated phase-in of LDT3s and LDT4s, as noted above. For both phase-in periods (for LDVs, LDT1s, LDT2s, and for LDT3s, LDT4s, and MDPVs), 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/MDPVs 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 and 10-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, LDTs, and MDPVs will be equipped with advanced catalysts. Catalyst manufacturers are currently working with engine manufacturers on improved 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 $12.20 and $67.10 per vehicle. We derived the increased volume cost by taking the baseline cost of the catalyst per liter ($61/liter) and multiplying by the increase in catalyst volume.[5] 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 per vehicle cost from $2.36 for light-duty vehicles to $29.50 for LDTs and MDPVs with the largest displacement engines. The details of the underfloor catalyst cost estimates are provided in Table V -1.

[5] We have updated the baseline per liter catalyst cost and other catalyst costs from the NPRM to reflect changes in the spot prices of precious metals. The precious metals costs used in the cost analysis are shown 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)	Higher substrate cost (e) (dollars)	Total Increased Cost (dollars)
LDV	4-cylinder	2.0	1.8	2.0	12.20	0.000	0.000	0.085	0	0	2.35	2.44	16.99
	6-cylinder	3.2	2.8	3.2	24.40	0.000	0.000	0.138	0	0	3.86	3.90	32.16
	8-cylinder	4.5	4.0	4.5	30.50	0.000	0.000	0.194	0	0	5.43	5.49	41.42
LDT/ MDPV	4-cylinder	2.3	2.3	2.3	0.00	0.000	0.000	0.097	0	0	2.71	2.81	5.52
	6-cylinder	3.7	2.6	3.7	67.10	0.035	0.540	0.157	0.44	7.17	4.39	4.52	83.62
	8-cylinder	5.4	4.7	5.4	42.70	0.082	0.550	0.229	1.03	7.30	6.41	6.59	64.03
	8/10-cylinder	6.0	4.7	5.4	42.70	0.164	1.100	0.458	2.06	14.62	12.82	6.59	78.79

Precious Metal Costs

	$/troy ounce	$/gram
Pt	412	12.58
Pd	390	13.29
Rh	868	28.00

(a) Baseline catalyst cost is $61/liter. Increased catalyst volume costs are the increase in catalyst volume multiplied by $61/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, LDT4s, and MDPVs the use of close coupled catalysts is currently low relative to the other classes, especially for MDPVs. For Tier 2 LDT3s, LDT4s and MDPVs, 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 $107.54 and $131.44, 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 available for use in 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. We believe 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-powered air injection strategies for Tier 2 vehicles equipped with 6- and 8-cylinder engines. The air injection systems consist of an electric-powered 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. In some cases, manufacturers may be able to use the combined exhaust system improvements in lieu of adding close-coupled catalysts. However, we are not projecting an increase in the use of low thermal capacity manifolds due to the Tier 2 standards. For most vehicles, manufacturers using close-coupled catalysts are not likely to need the improved manifolds as well.

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, LDT4s and MDPVs, 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/ten 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 vehicles 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-2 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/MDPV ($)*
4-cylinder	24.99	13.16	8.16	N/A	N/A
6-cylinder	65.16	91.46	90.98	238.86	N/A
8-cylinder	75.42	N/A	70.97	171.99	171.99
larger 8/10-cylinder*	N/A	N/A	N/A	N/A	291.54
sales weighted	44.69	39.87	84.27	178.74	187.53

* Primarily used in MDPVs.

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	0	0.00	20.00	0	0	0.00	20.00	0	0	0.00
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	12.20	0	100	12.20	24.40	0	100	24.40	30.50	0	100	30.50
Increased catalyst loading (Rh)	2.35	0	100	2.35	3.86	0	100	3.86	5.43	0	100	5.43
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				24.99				65.16				75.42

(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 8-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-powered 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	0	0.00	20.00	0	0	0.00
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	0	0.00	4.00	0	0	0.00
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	67.10	0	100	67.10
Increased catalyst loading	2.35	0	100	2.35	3.86	0	100	3.86
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				13.16				91.46

(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, 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-powered 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	0	0.00	20.00	0	0	0.00	20.00	0	0	0.00
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	0	0.00	4.00	0	0	0.00	6.00	0	0	0.00
Low thermal capacity manifold	20.00	25	25	0.00	40.00	25	25	0.00	40.00	25	25	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	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	67.10	0	100	67.10	42.70	0	100	42.70
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)	2.35	0	100	2.35	3.86	0	100	3.86	5.43	0	100	5.43
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				8.16				90.98				70.97

(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 8-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-powered 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 Current LDT3s

	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	0	0.00	20.00	0	0	0.00
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	0	0.00	6.00	0	0	0.00
Leak-free exhaust system (e)	20.00	50	100	10.00	20.00	50	100	10.00
Low thermal capacity manifold	40.00	25	25	0.00	40.00	25	25	0.00
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	107.54	12	100	94.64	131.44	55	80	32.86
Dual underbody or main catalyst	160.00	0	0	0.00	160.00	40	40	0.00
Increased catalyst volume	67.10	0	100	67.10	42.70	0	100	42.70
Increased catalyst loading (Pt)	0.44	0	100	0.44	1.03	0	100	1.03
Increased catalyst loading (Pd)	7.17	0	100	7.17	7.30	0	100	7.30
Increased catalyst loading (Rh)	4.39	0	100	4.39	6.41	0	100	6.41
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				238.86				171.99

(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 8-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-powered 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 LDT4s and MDPVs Compared to Current Vehicles

	8-Cylinder (87%)				Larger 8 & 10-Cylinder (13%)			
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	0	0.00	20.00	0	0	0.00
Air-assisted fuel injection (a)	16.00	0	50	8.00	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)	6.00	0	0	0.00	6.00	0	0	0.00
Leak-free exhaust system (e)	20.00	50	100	10.00	20.00	50	100	10.00
Low thermal capacity manifold	40.00	25	25	0.00	40.00	25	25	0.00
Engine modifications (f)	15.00	0	100	15.00	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	60	60	0.00	80.00	60	60	0.00
Dual close-coupled catalyst	131.44	55	80	32.86	131.44	0	80	105.15
Dual underbody or main catalyst	160.00	40	40	0.00	160.00	40	40	0.00
Increased catalyst volume	42.70	0	100	42.70	42.70	0	100	42.70
Increased catalyst loading (Pt)	1.03	0	100	1.03	2.06	0	100	2.06
Increased catalyst loading (Pd)	7.30	0	100	7.30	14.62	0	100	14.62
Increased catalyst loading (Rh)	6.41	0	100	6.41	12.82	0	100	12.82
Improved double layer washcoat + 600 cpsi cell density	6.59	0	100	6.59	6.59	0	100	6.59
Secondary air injection (g)	65.00	0	50	32.50	65.00	0	100	65.00
Total Incremental Cost				171.99				291.54

(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 8-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-powered 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 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 new 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 finalizing. 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 percent 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 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 $2,400 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 evaporative standard for HLDTs (1.2 gpt) and MDPVs (1.4 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 proportionally 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 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 research 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, LDT4s and MDPVs. 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.[6] 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

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

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. This estimate does not account for the ability of manufacturers in some cases to carry-over certification data from California, which would lower certification costs.

We expect there to be a certification testing cost savings for HLDTs due to the change in test procedures for these vehicles. For Tier 2, HLDTs will be emissions tested at the same test weight as is required for the CAFE fuel economy test (i.e., loaded vehicle weight). Currently, HLDTs are emissions tested at a higher weight (adjusted loaded vehicle weight). This change in emissions test procedure will allow manufacturers to measure fuel economy and emissions during the same test, eliminating one of the FTP tests currently required. To be conservative, however, we have not reduced the certification cost estimate to reflect this likely cost savings.

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 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 (aggregate costs are described in the following section). 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/MDPVs 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/MDPV ($)*
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/MDPV ($)*
Variable	47.94	43.12	87.52	181.99	190.78
Fixed	22.03	19.47	19.26	19.61	21.18
Total	69.97	62.59	106.78	201.60	211.96

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 shown that as manufacturers gain experience in production, they are able to lower the per-unit cost of production. These effects are often described as the manufacturing learning curve.[6]

The learning curve is a well documented 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 of 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. Examples 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. 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.

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]. The distribution of these progress ratios is shown in Figure V-1. 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. The average progress ratio for the whole data set falls between 81 and 82 percent. Other studies (Alchian 1963, Argote and Epple 1990, Benkard 1999) appear to support the commonly used p value of 80 percent, i.e., each doubling of cumulative production reduces the former cost level by 20 percent.

The learning curve is not the same in all industries. For example, the effect of the learning curve seems to be less in the chemical industry and the nuclear power industry where a

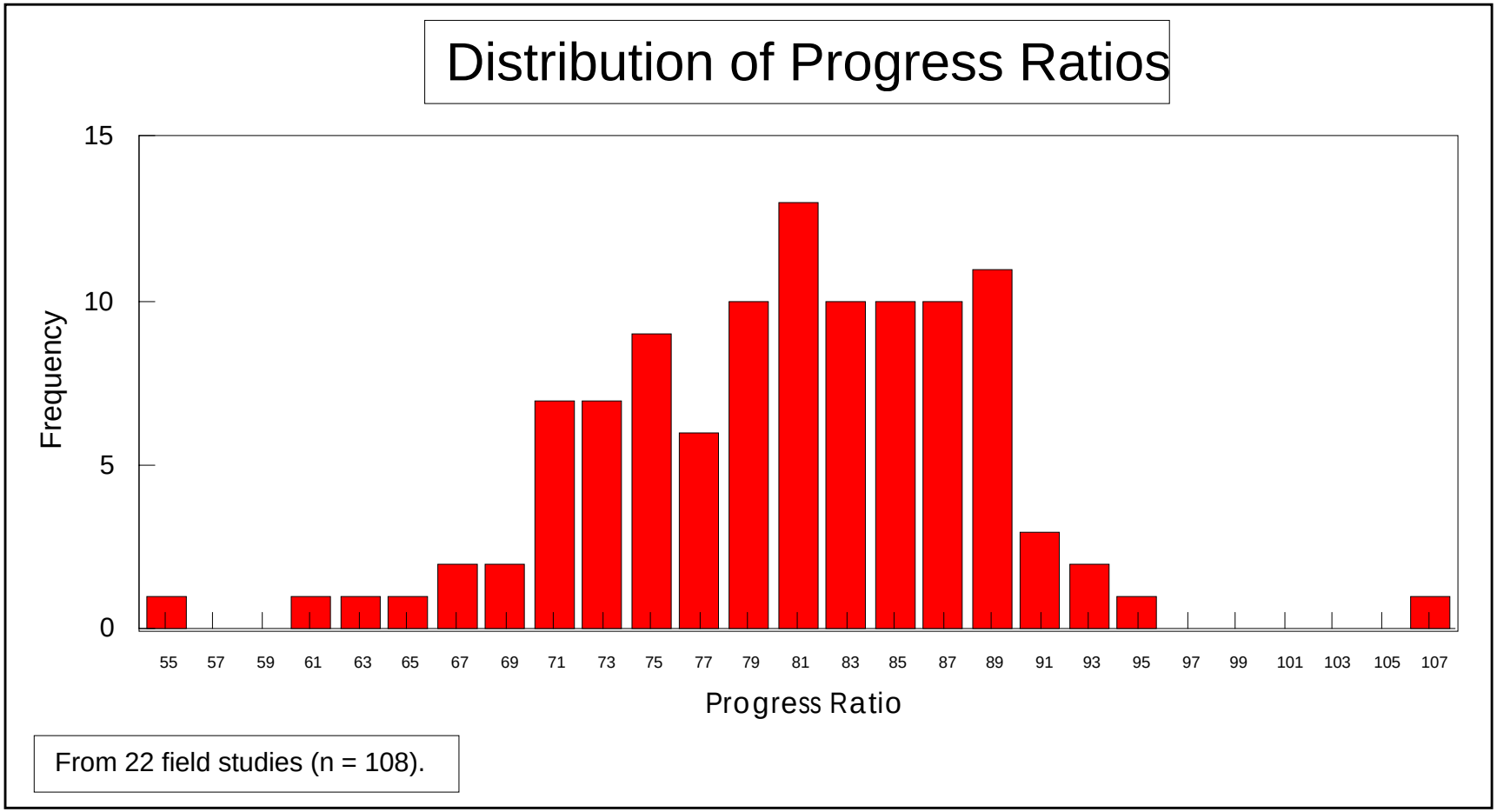

Figure V-1. Distribution of Progress Ratios
(Dutton and Thomas, 1984)

doubling of cumulative output is associated with 11% decrease in cost (Lieberman 1984, Zimmerman 1982). The effect of learning is more difficult to decipher in the computer chip industry (Gruber 1992).

We applied a p value of 80 percent in this analysis. Using one year as the base unit of production, the first doubling would occur at the start of the third model year of production. Beyond that time, 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, LDT4s, and MDPVs than for LDVs.

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

Production Year	*LDV ($)*	*LDT1 ($)*	*LDT2 ($)*	*LDT3 ($)*	*LDT4/MDPV ($)*
1st and 2nd year	69.97	62.59	106.78	201.60	211.96
3rd year: learning curve applied	64.23	58.38	99.12	180.69	189.96
6th year: fixed costs expire	42.20	38.91	79.86	161.08	168.78

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 vehicle standards. Manufacturers will most likely meet the standards through improvements to existing technologies. The costs of fuel quality improvements are provided in section B, below.

We do not anticipate that the improvements to technologies will affect fuel economy or in-use maintenance. We expect the standards to be met through improvements in current technologies rather than through the use of new technologies. We do not believe these improvements would adversely affect fuel economy or maintenance costs. Also, we have not observed fuel economy losses in our testing programs described in Chapter IV.

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 (incremental to ORVR), as well as the improved exhaust emissions control system.[7] 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/MDPV ($)*
1st and 2nd year	82.43	73.80	129.54	248.92	261.57
3rd year: learning curve applied	75.22	68.50	119.90	222.60	233.52
6th year: fixed costs expired	53.19	49.03	100.64	202.99	212.34

[7] 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.

The above analysis presents estimated vehicle costs for Tier 2 exhaust and evaporative emissions standards. In addition, we are finalizing On-board Diagnostics (OBD II) and On-board Refueling Vapor Recovery (ORVR) for MDPVs. Light-duty vehicles and light-duty trucks already must comply with these requirements. The OBD II and ORVR requirements were proposed as part of a Heavy-duty Engines and Vehicles Regulation (64 FR 58472) and the detailed cost analyses are presented in the RIA for that rulemaking (Docket A-98-32, Item II-B-01)

In summary, for OBD II, the vehicles will likely be equipped with additional and improved hardware such as additional oxygen sensors, solenoids for the evaporative system purge and leak check, and improved electronic control modules. We estimate the total cost to consumers for the system to be about $80 per vehicle. For the ORVR system, we estimate the cost to consumers to be about $10 per vehicle. Also, the ORVR system provides a fuel economy savings of about $6 over the lifetime of the vehicle. This savings occurs because refueling vapors are captured, and burned in the engine, rather than escaping to the atmosphere.

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, LDTs, and MDPVs. 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 $269 million in 2004 and peaking at $1,579 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 $1,351 million in 2014, after which the growth in vehicle population leads to increasing costs that reach $1,392 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	253,327	358,521	301,938	311,110
LDT1	0	98,943	73,026	75,245
LDT2	0	579,898	499,791	514,973
LDT3	9,544	339,109	306,125	315,425
LDT4/MDPV*	5,907	201,991	169,841	174,000
Total	268,778	1,578,462	1,350,721	1,391,753

*Includes costs for OBD II and ORVR requirements for MDPVs

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.[11] 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.[12] 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.[13] 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/MDPV[8]	541	663	747	762	793
Total	13,304	13,709	13,985	14,267	14,848

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 29 percent of vehicles overall would fall into the highest bin (0.60 g/mile NOx), 28 percent in the next highest bin (0.3 g/mile NOx) and the remaining 43 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.

[8] To account for sales of MDPVs, we estimated 1998 sales of 70,000 vehicles and projected growth at a rate of one-half percent per year. The MDPV sales projections were added to the yearly sales estimates for LDT4s.

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/MDPV* (%)*
2004	50	0	0	3	0
2005	100	0	0	9	0
2006	100	100	30	26	0
2007	100	100	100	68	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, LDT4s,and MDPVs starting with LDT3s in 2008. OBD II is required for MDPVs starting in 2004. The phase-in for ORVR for MDPVs is 40/80/100 percent in 2004-2006.

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 average 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 annualized nationwide costs by vehicle class for years 2004 through 2020. Table V-21(A) presents these cost figures summed for all vehicle categories. In addition, Table V-20 and V-21(A) include aggregate costs for MDPV OBDII and ORVR requirements.[9] Table 21(B) provides the non-annualized costs for the Tier 2 program.

[9] The net present value of the fuel savings over the life of the vehicle due to ORVR, estimated to be $5.50, has been subtracted from the system cost of $10.25 for purposes of estimating the aggregate costs.

Table V-16. Annual Nationwide Costs For Tier 2 LDVs

Calendar Year	*Fixed Cost ($)*	*Variable Cost ($)*	*Total Cost ($)*
2004	64,020,172	189,306,353	253,326,525
2005	128,040,345	367,257,308	495,297,653
2006	128,040,345	334,503,997	462,544,342
2007	128,040,345	303,014,320	431,054,665
2008	128,040,345	292,689,560	420,729,905
2009	64,020,172	294,501,019	358,521,192
2010	0	295,973,524	295,973,524
2011	0	297,453,392	297,453,392
2012	0	298,940,659	298,940,659
2013	0	300,435,362	300,435,362
2014	0	301,937,539	301,937,539
2015	0	303,447,227	303,447,227
2016	0	304,964,463	304,964,463
2017	0	306,489,285	306,489,285
2018	0	308,021,731	308,021,731
2019	0	309,561,840	309,561,840
2020	0	311,109,649	311,109,649
2021	0	312,665,198	312,665,198
2022	0	314,228,524	314,228,524
2023	0	315,799,666	315,799,666
2024	0	317,378,665	317,378,665
2025	0	318,965,558	318,965,558
2026	0	320,560,386	320,560,386
2027	0	322,163,188	322,163,188
2028	0	323,774,003	323,774,003
2029	0	325,392,874	325,392,874
2030	0	327,019,838	327,019,838
2031	0	328,654,937	328,654,937
2032	0	330,298,212	330,298,212
2033	0	331,949,703	331,949,703
2034	0	333,609,451	333,609,451

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	73,706,372	101,421,556
2007	27,715,184	76,145,235	103,860,420
2008	27,715,184	70,928,248	98,643,433
2009	27,715,184	71,227,705	98,942,890
2010	27,715,184	71,583,844	99,299,028
2011	0	71,941,763	71,941,763
2012	0	72,301,472	72,301,472
2013	0	72,662,979	72,662,979
2014	0	73,026,294	73,026,294
2015	0	73,391,426	73,391,426
2016	0	73,758,383	73,758,383
2017	0	74,127,175	74,127,175
2018	0	74,497,811	74,497,811
2019	0	74,870,300	74,870,300
2020	0	75,244,651	75,244,651
2021	0	75,620,874	75,620,874
2022	0	75,998,979	75,998,979
2023	0	76,378,974	76,378,974
2024	0	76,760,869	76,760,869
2025	0	77,144,673	77,144,673
2026	0	77,530,396	77,530,396
2027	0	77,918,048	77,918,048
2028	0	78,307,638	78,307,638
2029	0	78,699,177	78,699,177
2030	0	79,092,673	79,092,673
2031	0	79,488,136	79,488,136
2032	0	79,885,577	79,885,577
2033	0	80,285,004	80,285,004
2034	0	80,686,429	80,686,429

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	149,650,348	177,375,502
2007	92,417,180	515,340,381	607,757,561
2008	92,417,180	518,028,642	610,445,822
2009	92,417,180	487,480,951	579,898,131
2010	92,417,180	489,918,356	582,335,536
2011	64,692,026	492,367,948	557,059,974
2012	0	494,829,787	494,829,787
2013	0	497,303,936	497,303,936
2014	0	499,790,456	499,790,456
2015	0	502,289,408	502,289,408
2016	0	504,800,855	504,800,855
2017	0	507,324,860	507,324,860
2018	0	509,861,484	509,861,484
2019	0	512,410,791	512,410,791
2020	0	514,972,845	514,972,845
2021	0	517,547,710	517,547,710
2022	0	520,135,448	520,135,448
2023	0	522,736,125	522,736,125
2024	0	525,349,806	525,349,806
2025	0	527,976,555	527,976,555
2026	0	530,616,438	530,616,438
2027	0	533,269,520	533,269,520
2028	0	535,935,868	535,935,868
2029	0	538,615,547	538,615,547
2030	0	541,308,625	541,308,625
2031	0	544,015,168	544,015,168
2032	0	546,735,244	546,735,244
2033	0	549,468,920	549,468,920
2034	0	552,216,264	552,216,264

Table V-19. Annual Nationwide Costs For Tier 2 LDT3s

Calendar Year	*Fixed Cost ($)*	*Variable Cost ($)*	*Total Cost ($)*
2004	869,782	8,674,674	9,544,455
2005	2,609,345	26,928,407	29,537,753
2006	7,538,109	79,344,616	86,882,725
2007	19,715,055	213,951,882	233,666,936
2008	28,992,728	324,084,012	353,076,740
2009	28,122,946	310,986,090	339,109,036
2010	26,383,382	300,078,649	326,462,031
2011	21,454,618	301,579,042	323,033,661
2012	9,277,673	303,086,937	312,364,610
2013	0	304,602,372	304,602,372
2014	0	306,125,384	306,125,384
2015	0	307,656,011	307,656,011
2016	0	309,194,291	309,194,291
2017	0	310,740,262	310,740,262
2018	0	312,293,964	312,293,964
2019	0	313,855,433	313,855,433
2020	0	315,424,711	315,424,711
2021	0	317,001,834	317,001,834
2022	0	318,586,843	318,586,843
2023	0	320,179,778	320,179,778
2024	0	321,780,676	321,780,676
2025	0	323,389,580	323,389,580
2026	0	325,006,528	325,006,528
2027	0	326,631,560	326,631,560
2028	0	328,264,718	328,264,718
2029	0	329,906,042	329,906,042
2030	0	331,555,572	331,555,572
2031	0	333,213,350	333,213,350
2032	0	334,879,417	334,879,417
2033	0	336,553,814	336,553,814
2034	0	338,236,583	338,236,583

Table V-20. Annual Nationwide Costs For Tier 2 LDT4s and MDPVs

Calendar Year	*Tier 2 Fixed Costs ($)*	*Tier 2 Variable Costs ($)*	*Tier 2 Total Costs ($)*	*OBD II & ORVR for MDPVs ($)*	*Total With OBD II & ORVR for MDPVs ($)*
2004	0	0	0	5,907,154	5,907,154
2005	0	0	0	6,074,415	6,074,415
2006	0	0	0	6,173,995	6,173,995
2007	0	0	0	6,204,865	6,204,865
2008	5,346,756	61,813,742	67,160,497	6,235,889	73,396,386
2009	15,276,445	180,447,506	195,723,952	6,267,068	201,991,020
2010	15,276,445	173,942,913	189,219,358	6,298,404	195,517,762
2011	15,276,445	160,988,307	176,264,752	6,329,896	182,594,648
2012	15,276,445	161,793,249	177,069,694	6,361,545	183,431,239
2013	9,929,689	162,602,215	172,531,904	6,393,353	178,925,257
2014	0	163,415,226	163,415,226	6,425,320	169,840,545
2015	0	164,232,302	164,232,302	6,457,446	170,689,748
2016	0	165,053,464	165,053,464	6,489,733	171,543,197
2017	0	165,878,731	165,878,731	6,522,182	172,400,913
2018	0	166,708,125	166,708,125	6,554,793	173,262,918
2019	0	167,541,665	167,541,665	6,587,567	174,129,232
2020	0	168,379,373	168,379,373	6,620,505	174,999,878
2021	0	169,221,270	169,221,270	6,653,607	175,874,878
2022	0	170,067,377	170,067,377	6,686,875	176,754,252
2023	0	170,917,714	170,917,714	6,720,310	177,638,023
2024	0	171,772,302	171,772,302	6,753,911	178,526,213
2025	0	172,631,164	172,631,164	6,787,681	179,418,844
2026	0	173,494,319	173,494,319	6,821,619	180,315,939
2027	0	174,361,791	174,361,791	6,855,727	181,217,518
2028	0	175,233,600	175,233,600	6,890,006	182,123,606
2029	0	176,109,768	176,109,768	6,924,456	183,034,224
2030	0	176,990,317	176,990,317	6,959,078	183,949,395
2031	0	177,875,268	177,875,268	6,993,874	184,869,142
2032	0	178,764,645	178,764,645	7,028,843	185,793,488
2033	0	179,658,468	179,658,468	7,063,987	186,722,455
2034	0	180,556,760	180,556,760	7,099,307	187,656,068

Table V-21 (A). Annual Nationwide Costs For Tier 2 LDVs, LDTs and MDPVs

Calendar Year	*Tier 2 Fixed Costs ($)*	*Tier 2 Variable Costs ($)*	*Tier 2 Total Costs ($)*	*Including MDPV OBDII and ORVR Costs ($)*
2004	64,889,954	197,981,026	262,870,980	268,778,135
2005	130,649,690	394,185,715	524,835,406	530,909,821
2006	191,018,792	637,205,332	828,224,125	834,398,119
2007	267,887,764	1,108,451,819	1,376,339,582	1,382,544,447
2008	282,512,192	1,267,544,205	1,550,056,397	1,556,292,286
2009	227,551,928	1,344,643,272	1,572,195,200	1,578,462,268
2010	161,792,192	1,331,497,286	1,493,289,478	1,499,587,881
2011	101,423,090	1,324,330,452	1,425,753,541	1,432,083,437
2012	24,554,118	1,330,952,104	1,355,506,222	1,361,867,767
2013	9,929,689	1,337,606,865	1,347,536,554	1,353,929,907
2014	0	1,344,294,899	1,344,294,899	1,350,720,219
2015	0	1,351,016,374	1,351,016,374	1,357,473,820
2016	0	1,357,771,455	1,357,771,455	1,364,261,189
2017	0	1,364,560,313	1,364,560,313	1,371,082,495
2018	0	1,371,383,114	1,371,383,114	1,377,937,907
2019	0	1,378,240,030	1,378,240,030	1,384,827,597
2020	0	1,385,131,230	1,385,131,230	1,391,751,735
2021	0	1,392,056,886	1,392,056,886	1,398,710,493
2022	0	1,399,017,171	1,399,017,171	1,405,704,046
2023	0	1,406,012,256	1,406,012,256	1,412,732,566
2024	0	1,413,042,318	1,413,042,318	1,419,796,229
2025	0	1,420,107,529	1,420,107,529	1,426,895,210
2026	0	1,427,208,067	1,427,208,067	1,434,029,686
2027	0	1,434,344,107	1,434,344,107	1,441,199,835
2028	0	1,441,515,828	1,441,515,828	1,448,405,834
2029	0	1,448,723,407	1,448,723,407	1,455,647,863
2030	0	1,455,967,024	1,455,967,024	1,462,926,102
2031	0	1,463,246,859	1,463,246,859	1,470,240,733
2032	0	1,470,563,093	1,470,563,093	1,477,591,936
2033	0	1,477,915,909	1,477,915,909	1,484,979,896
2034	0	1,485,305,488	1,485,305,488	1,492,404,796

Table V-21 (B). Non-Annualized Nationwide Vehicle Costs For Tier 2 LDVs, LDTs and MDPVs

Calendar Year	*Tier 2 Fixed Costs ($)*	*Tier 2 Variable Costs ($)*	*Tier 2 Total Costs ($)*
2000	0	0	0
2001	158,787,057	0	158,787,057
2002	160,915,431	0	160,915,431
2003	214,584,860	0	214,584,860
2004	255,856,575	197,981,026	453,837,601
2005	97,985,003	394,185,715	492,170,718
2006	103,494,735	637,205,332	740,700,067
2007	15,074,888	1,108,451,819	1,123,526,707
2008	10,243,046	1,267,544,205	1,277,787,251
2009	0	1,344,643,272	1,344,643,272
2010	0	1,331,497,286	1,331,497,286
2011	0	1,324,330,452	1,324,330,452
2012	0	1,330,952,104	1,330,952,104
2013	0	1,337,606,865	1,337,606,865
2014	0	1,344,294,899	1,344,294,899
2015	0	1,351,016,374	1,351,016,374
2016	0	1,357,771,455	1,357,771,455
2017	0	1,364,560,313	1,364,560,313
2018	0	1,371,383,114	1,371,383,114
2019	0	1,378,240,030	1,378,240,030
2020	0	1,385,131,230	1,385,131,230
2021	0	1,392,056,886	1,392,056,886
2022	0	1,399,017,171	1,399,017,171
2023	0	1,406,012,256	1,406,012,256
2024	0	1,413,042,318	1,413,042,318
2025	0	1,420,107,529	1,420,107,529
2026	0	1,427,208,067	1,427,208,067
2027	0	1,434,344,107	1,434,344,107
2028	0	1,441,515,828	1,441,515,828
2029	0	1,448,723,407	1,448,723,407
2030	0	1,455,967,024	1,455,967,024
2031	0	1,463,246,859	1,463,246,859
2032	0	1,470,563,093	1,470,563,093
2033	0	1,477,915,909	1,477,915,909
2034	0	1,485,305,488	1,485,305,488

B. Gasoline Desulfurization Costs

1. Overview of Changes Since the NPRM

In the NPRM, we indicated that we expected to work with the Department of Energy (DOE) in using the Oak Ridge National Laboratory (ORNL) refinery model to estimate gasoline desulfurization costs. However, we discovered that the ORNL refinery model did not contain representations of certain technologies which we believe are important in the context of desulfurizing gasoline, and this was revealed in several of the early modeling case runs which were conducted by DOE. Thus, we continue to use our refinery model, with a number of adjustments discussed below, to estimate the gasoline desulfurization costs. We compare our refinery modeling results to those by DOE, and other cost studies which we received during this last year, after presenting our cost analysis and results. In general, these other cost studies support our cost estimates.

One of the principal comments to the NPRM which we wanted to address in our FRM cost study is that for the NPRM commenters stated that we inappropriately based our cost estimates on CDTech and and Mobil Oil's Octgain 220 desulfurization technologies which have not yet been "commercially proven."[10] Some refiners feel that these technologies will not have been operating long enough prior to when they have to decide on what technology they will want to use. Thus, these refiners may choose among the several commercially proven desulfurization technologies available today. We incorporated this point of view in our cost analysis for the final rule by assuming that some refiners in 2004 will use today's proven technologies.

Similarly, we became aware that technologies which desulfurize gasoline through adsorption, instead of hydrotreating, are commercially available starting this year. Since these technologies appear to desulfurize gasoline much more efficiently than other processes available today, we believe that a number of refiners will use these technologies, but to only a very limited extent starting in 2005, and increasing after that. We are assuming that these technologies will be used later on because these technologies are so new, and very different from other desulfurization technologies. A more elaborate discussion on all these desulfurization technologies can be found in Section IVB, which is the section containing our discussion of the feasibility of meeting the gasoline sulfur requirements. Many of the small refineries, which must meet a much less stringent set of interim phase-in requirements which will likely allow them to push off their capital investments until 2007 and 2008, are expected to take advantage of this revolutionary technology. The mix of technologies projected to be used in each year is

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a. Our understanding of what refiners generally mean when they say a process is commercially proven is that a process has operated successfully for at least two years in a refinery producing a refinery product.

summarized below in the section on technology cost.

We also received comments on our determination that available desulfurization capacity is available and will be used to desulfurize gasoline first before additional investments are made. Our analysis of the 1996 API/NPRA survey of refining operations and gasoline quality for the NPRM showed that fluidized catalytic cracker feed hydrotreaters are not operating at capacity which we used for an initial reduction in gasoline sulfur. The commenter claimed that these units are already operating at capacity, contrary to what is shown in API/NPRA survey. While we do not have information from refiners to verify or dispute such claims, we were able to address this issue through our analysis of gasoline sulfur levels. Refiners must report their gasoline sulfur levels to EPA to satisfy the RFG and Antidumping program reporting requirements. We analyzed the 1998 gasoline sulfur levels and found that the average sulfur level of domestically produced gasoline dropped from 314 ppm to about 270 ppm. This significant drop in sulfur level may have occurred with the use of excess capacity available from FCC feed hydrotreaters, and probably to meet the requirements of the 1998 requirements of the Reformulated Gasoline Program. Consistent with this new data on gasoline sulfur levels and our assumption that these sulfur reductions resulted from increased FCC feed hydrotreater use, we adjusted the gasoline pool sulfur levels using the 1998 gasoline sulfur data and dropped any assumptions that current gasoline sulfur levels could be reduced with existing FCC feed hydrotreaters. These adjustments made for each PADD are presented below in the section on blendstocks.

We applied two changes to the Octgain cost estimate methodology used in the NPRM which improved our cost estimates for this analysis for the FRM, and this improvement also applied to other fixed bed hydrotreaters as well. In the NPRM, we assumed that the Octgain unit would be used exclusively to treat the entire FCC naphtha stream. However, Mobil Oil, and the other vendors of these fixed bed desulfurization technologies, recommend that their processes be used with a type of distillation column called a splitting column and a catalytic extractive desulfurization unit for treating the light FCC naphtha. For fixed bed hydrotreaters, this combination seems to provide a high level of desulfurization at the lowest cost, so we used it for this analysis. We also based our NPRM cost estimate on the use of a FCC naphtha splitter which was inappropriate for the task. The naphtha splitter we used is for breaking out individual streams for additional processing, such as for separating out olefins for petrochemicals, or producing MTBE. However, for the simple job of creating two substreams for hydrotreating purposes, it is not necessary to boil away the heavier stream, thus the capital and operating costs are much lower. We obtained the cost for using such a splitting column from Mobil Oil. This cost agrees well with the cost of CDTech's CDHydro column which functions in this manner, so we believe the cost estimate from Mobil Oil is reasosnable and used it in this analysis.

We received a number of comments concerning the cost to refiners of meeting the 80 ppm cap standard. Refiners reported that if the FCC naphtha hydrotreater goes down, then high sulfur FCC naphtha would likely have to be either stored up or sold off until the hydrotreater can

be brought on line. Then the untreated, high sulfur blendstock must be dealt with. In most other cost studies, the contractor provided a cost estimate to cover this situation. We added the cost of a storage tank to our cost analysis which would allow for such storage of high sulfur blendstock. Furthermore, we provided excess desulfurization capacity for treating short term stores of high sulfur naphtha. These adjustments to our cost estimation methodology show up in our estimated cost for complying with the low sulfur program.

We maintained many of the aspects of the NPRM analysis. We performed our cost analysis on a PADD-by-PADD basis, based on gasoline production in each PADD (not gasoline consumption). Each PADD is represented by a single refinery which consists of refining units having the average capacity of all refineries of that PADD and which produces gasoline having the average sulfur level of that PADD. This allows us to compare the cost of desulfurizing gasoline between different parts of the country which allowed us to address some of the comments which we received. Like the NPRM, we are assuming that the cost for California refiners to produce non-California low sulfur gasoline is the same as the cost of producing low sulfur gasoline in the rest of the country. Since California refiners are already treating all their gasoline blendstocks, this assumption is probably very conservative. For calculating capital, fixed and variable operating costs, our methodology for the final rule is very similar to what we did for the NPRM, with some modifications, which are outlined below in their respective sections. Our cost analysis is not incremental, studying the cost of a progression of gasoline desulfurization levels, like the analysis for the NPRM, instead we only evaluated the cost of achieving 30 ppm, and we are providing an analysis for meeting a 5 ppm standard, and reviewed the Alliance's cost study for achieving 5 ppm gasoline.

2. Cost Estimation Methodology

a. Technology and Cost Inputs

As we stated above, we are basing our cost analysis for the final rule on a larger group of desulfurization technologies. To facilitate cost calculations with all these desulfurization technologies, we are assigning these technologies into three different groups. The first group comprises those technologies which have already had at least two years of commercial experience. The second group is comprised of CDTech and Octgain 220, which are the improved desulfurization technologies upon which we based the NPRM gasoline desulfurization costs. As stated in the NPRM these technologies are either being demonstrated now, or will start to be demonstrated in the next few months, as described in Chapter IV. The third group comprises desulfurization technologies which work through adsorption. Even though these adsorption technologies are commercially available now, they are newer and different enough from the other technologies that we felt they should be placed into their own group. Because they are newer and significantly different, we believe that most refiners would likely be hesitant in signing a licensing agreement without prior commercial experience, even those refiners which

would be willing to risk using a technology such as CDTech which has partial current commercial experience. These technologies are discussed in more detail in the feasibility section. The technologies considered which fall into these various categories are summarized in Table V-22.

Table V-22. List of Desulfurization Technologies by Technology Group

Technology Group	*Desulfurization Technology*
Proven Technologies	Exxon Scanfining, IFP Prime G, Mobil Oil Octgain 125
Improved Technologies	CDTech CDHydro/HDS, Mobil Oil Octgain 220
Adsorption Technologies	Black and Veatch IRVAD, Phillips S-zorb

It is important to point out that there are other desulfurization technologies available which refiners may use. For example, UOP has developed an improved desulfurization technology, and Mobil Oil licenses another desulfurization process named Octgain 100, distinguished by the different catalyst used in the process. However, we decided, as a matter of practicality, to not try to represent all technologies in our cost analysis. It is also important to point out that although Octgain 125 will likely be installed in sour crude oil refineries after 2004, as the program is phasing in, we model the cost of desulfurizing gasoline based on "typical" refineries with average gasoline sulfur levels. For these moderate applications, Mobil Oil recommends that these typical refineries use the Octgain 220 process. It is for this reason that we do not include the Octgain 125 process in the second group of technologies.

These technologies, by virtue of their respective groups, are assumed to be installed for startup in certain years, consistent with what the perceived status is of the technology when a refiner must make the decision on a desulfurization technology (approximately 3- 4 years before). We believe that of the refiners which must meet one of sulfur requirements in 2004, half of them will install a proven technology, while the other half of the refiners would be more willing to rely on a technology which has not been proven. A refiner may use the unproven technology for a variety of reasons. For example, a refiner with poor refining profit margins may assume the risk of using an unproven technology in the hope of desulfurizing its gasoline at a lower cost which will help the refiner to improve its refining margins. Another reason why a refiner may choose an unproven technology is that a refiner may have had a very positive experience with a licensor that could convince the refiner to use that licensor's technology despite whether the technology has been proven or not. Our assumptions of the mix of technologies to be installed for use starting in any one year of the phase-in is summarized in Table V-23 below. Since there are multiple desulfurization technologies in each group, for our cost analysis, we presume that refiners would use these technologies equally, rather than attempt to determine if refiners would

tend to use one more than another, and then project what the percentage of each desulfurization technology used.

Table V-23. Projected Use of Desulfurization Technology Types by Refiners During the Phase-in Period (from Section IV-B)

Initial Year of Full Operation	*Mix of Technology Groups used*
2004	1/2 Proven, 1/2 Improved
2005	3/4 Improved, 1/4 Adsorbent
2006	1/2 Improved, 1/2 Adsorbent
2007 & 2008	1/4 Improved, 3/4 Adsorbent

As discussed in Chapter IV, a number of desulfurization units are projected to begin operating prior to 2004. Five of these units will be demonstration units for the improved and adsorbent technologies. Two to five more units are expected to be operated by refiners desiring to generate early credits or allotments and to use low sulfur gasoline as a marketing tool. These latter units are likely to be a mixture of proven and improved technologies, much like that projected for 2004, possibly with a greater fraction of proven technology. Overall, we represented the cost of these pre-2004 units using the 2004 technology mix.

We acquired process operations information on each of these technologies through our participation with the National Petroleum Council (NPC). During 1999 the NPC was conducting a study of how potential fuel quality control programs will affect the cost and producibility of domestically produced motor vehicle fuels. During this study, the Technology Workgroup of the NPC requested input cost data from many different licensors of gasoline FCC naphtha desulfurization processes to study the cost of desulfurizing gasoline. We obtained that information and we used it in our cost study.[14] This cost input data is summarized in Table V-24.

Table V-24. Process Operations Information for FCC Naphtha Desulfurization Processes
(All Technologies are 95% Efficient for Desulfurizing Gasoline)

	Octgain 125	*Exxon Scanfining*	*IFP Prime G*	*Octgain 220*	*CDTech*	*Black&Veatch IRVAD*	*Phillips S-Zorb*
Capacity (MMbbl/day)	15,000	25,000	24,000	31,000	30,000	30,000	25,000
Capital Cost (MM$)	14.9	16.8	21.7	23.8	18.5	17.9	13.8
Hydrogen Consumption (SCF/bbl)	370	77	126	130	102	Negligible	70
Electricity (KwH/bbl)	2.0	0.61	1.3	1.5	0.44	1.82	-
HP Steam (Lb/bbl)	-	44.8	63	75	24.4	0	4.5
Fuel Gas (BTU/bbl)	84,400	14,500	9300	35,600	33,000	18,300	39,000
Catalyst Cost ($/bbl)	0.43	0.22	0.01	0.22	0.25	0.27	0.27
Cooling Water (Gal/bbl)	250	135	130	225	53.3	16.7	130
Yield Loss (%)	5	0	0.8	0.7	0	4.5	0
Octane Loss (R+M)/2	0	1.0	1.3	0.1	1.0	(2.0)	0.75

Besides these desulfurization technologies, we used additional technologies in our refinery modelling analysis. Depending on the desulfurization case which we were modeling, we used extractive desulfurization units for desulfurizing both light FCC naphtha and light straight run. We also needed to include distillation or splitting columns for fixed bed hydrotreaters for separating the FCC naphtha into two different streams so the light FCC naphtha could be treated by extractive desulfurization and the medium and heavy FCC naphtha could be treated by the hydrotreater. Most of the vendors which license fixed bed desulfurization processes already include the operating and capital costs of both the extractive desulfurization unit and splitting columns in their information submissions, however, we needed to add these costs to the Octgain costs. The process operation information for these other technologies are summarized in Table V-25. The splitting column inputs are from Mobil Oil which provided the information to the NPC Technology Workgroup along with information on their Octgain units. As we stated above, for the NPRM we used the splitter input information from the Oak Ridge National Laboratory refinery model. However, that splitter is really for creating multiple separate substreams out of the FCC naphtha while the Mobil Oil splitter is for creating a simple cut, which is all that is needed for this application. The capital and operating costs for the Mobil Oil splitter are much lower as a result. We provide the ORNL splitter information as a comparison.

In this analysis we also included costs for half of refiners adding an FCC naphtha storage tank.[15] The purpose of the storage tank would be for refiners to store up nonhydrotreated FCC naphtha, for up to 10 days, during a shutdown of the FCC naphtha hydrotreater. During the shutdown, the high sulfur blendstock cannot be blended into gasoline because it would cause the gasoline pool to exceed the 80 ppm cap. Then, after the hydrotreater is brought back on line, the high sulfur FCC naphtha in the storage tank would either be sent to the hydrotreater, in quantities which would not exceed the hydrotreater capacity, or it would be slowly blended into finished gasoline in a manner which allows the refiner to meet the 80 ppm cap. We sized the FCC naphtha hydrotreater large enough to handle the stored naphtha. The capital costs for the storage tank are summarized in Table V-25.

Table V-25. Process Operations Information for Additional Units used for Desulfurization Cost Analysis

	Extractive Desulfurization	*Splitter(Mobil Oil) (used in this analysis)*	*Splitter (ORNL) (used in NPRM)*	*FCC Naphtha Storage Tank*
Capacity (MMbbl/day)	10000	50000	20000	50,000 bbls
Capital Cost (MM$)	3.5	4.1	10.7	0.75
Electricity (KwH/bbl)	---	0.17	2.5	---
HP Steam (Lb/bbl)	---	36	10	---
Fuel Gas (BTU/bbl)	---	---	90000	---
Cooling Water (Gal/bbl)	---	13	---	---
Operating Cost ($/bbl)	0.06	---	---	none*

* No operating costs are estimated directly, however both the ISBL to OSBL factor and the capital contingency factor used for desulfurization processes is used for the tankage as well, which we believe to be excessive for storage tanks so it is presumed to cover the operating cost.

b. Capital Costs

Capital costs are the one-time costs incurred by purchasing and installing new hardware in refineries. The capital costs are calculated similar to how they were calculated for the NPRM, with some differences. Capital costs for a particular processing unit are supplied by the vendors for a particular volumetric capacity and desulfurization efficiency, and these costs are adjusted to match the volume of the particular case being analyzed using the sixth tenths rule.[11] The calendar day volume is increased by 7 percent to size the hydrotreating unit for stream days, the

[11] The capital cost is estimated at this other throughput using an exponential equation termed the "six-tenths rule." 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 splitters and 0.60 for desulfurization units.

days which the unit is operating. Unlike the NPRM, the hydrotreating unit volume is not increased by 15 percent as a safety factor. Instead, a 15 percent factor is applied to the capital costs after the outside battery limit costs and added capital installation costs (for higher labor rates) were calculated, and a 10 percent factor is applied to the operating costs. These two contingency factors are meant to account for costs not accounted for in the principal calculation, such as running the amine and sulfur plants harder for addressing the additional sulfur removed. The 5 percent capital adjustment factor applied to noncommercially demonstrated units for the NPRM is maintained in the final rule. An additional 5 percent factor is applied to size the units larger so that the unit can process untreated blendstock stored up during a shutdown or turnaround.

The capital costs are adjusted further to account for the offsite costs and differences in labor costs relative to the Gulf Coast. The same method for calculating the offsite costs and accounting for differences in labor costs used in the NPRM, which is from Gary and Handewerk, is used here.[16] The offsite and labor factors used for each PADD are summarized here.

Table V-26. Offsite and Location Factors Used for Estimating Capital Costs

	PADD 1	*PADD 2*	*PADD 3*	*PADD 4*	*PADD 5*
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 same economic assumptions used in the NPRM for amortizing the capital costs over the volume of gasoline produced are used for this analysis. These assumptions and the resulting capital amortization cost factors are summarized below in Table V-27. These capital amortization cost factors are used in the following section on the cost of desulfurizing gasoline to represent the capital cost as a cents per gallon cost.

Table V-27. Economic Cost Factors Used in Calculating the 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% 10%	0.12 0.16

c. Fixed Operating Cost

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. We are using the same cost factors to estimate fixed operating costs in this analysis as what we used for the analysis for the NPRM.

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 for PADDs other than PADD 3. This factor is based on the maintenance factor used in the ORNL refinery model.

Other fixed operating costs are accounted for as well, and these generic cost factors are also 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 (after adjusting for offsite costs and location factor) 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.

d. 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. The operating cost demands (utilities, hydrogen, octane

and yield loss) are from the licensors which license the gasoline desulfurization technologies and the basis for the values is 95 percent FCC naphtha desulfurization, since that level of desulfurization adequately exceeded the need by each average refinery modeled for reaching the sulfur target (30 ppm pool sulfur). We used the same variable operating cost factors, for such costs as utilities, hydrogen and octane costs, in this analysis as we used in the NPRM. We summarized these costs in the following table. We are no longer showing the costs for residual oil and diesel fuel, since we are no longer projecting the use of excess FCC feed hydrotreater capacity in achieving the 30 ppm standard. We did make one change in our operating cost calculation methodology. In the NPRM, we estimated the cost of producing steam based on the premise that heat demand for the steam is met by burning fuel gas, and we used the estimated price of fuel gas as our cost basis. For this analysis we are using the same methodology, except our costs are increased upward by a factor of two to be consistent with published cost estimation methodology which estimates the cost of supplying steam as two times the cost of the fuel gas consumed.[17] Our octane cost estimation methodology used for the analysis in the NPRM was corroborated by the cost estimating work by API, which estimated an octane cost just less than ours based on refinery modeling, thus we maintained this cost estimation methodology in our cost analysis.[18] These costs are summarized in Table V-28.

Table V-28. 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
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.

e. Determination of Blendstock Sulfur Levels

We maintained the alkylate, coker, and light straight run sulfur levels estimates which we summarized in the NPRM; however, we made an adjustment in the FCC gasoline sulfur levels based on the lower average gasoline sulfur levels in 1998. For the NPRM, we provided a sulfur balance for an average refinery in each PADD 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 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. The averaged value was determined to be 22 ppm, however, one refinery had a sulfur level of over 130 ppm. Since the promulgation of the NPRM, we contacted that refiner with the high alkylate sulfur level and found out that the operations of their alkylate unit has improved since 1990, and their alkylate is now averaging about 20 ppm sulfur. When we averaged that sulfur level with the alkylate sulfur levels of other refineries, the average alkylate sulfur level dropped to 7 ppm for those refineries.

For the NPRM, we also contacted several refining industry consultants to find out what alkylate sulfur levels they used in their refinery models. The alkylate sulfur levels in those refinery models averaged about 10 ppm (the values ranged from 0 to 25 ppm). For the final rule, we are maintaining the 10 ppm average sulfur level for alkylate we used for the NPRM, since both the RFG data base and refining industry consultants generally support this level.

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. We believe that for an analysis of the cost of achieving a 30 ppm gasoline pool sulfur level, that this assumption is appropriate. Even if their sulfur contribution is somewhat higher, both the 15 and10 percent capital and operating cost contingency factors and the excess 5 percent treating capacity of the FCC naphtha hydrotreater are conservative estimates, which could offset the additional desulfurization treatment cost of these other streams (or for further desulfurizing FCC naphtha to compensate for the small amount of sulfur in these other streams).

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. If there was disagreement, we adjusted one or the other, as summarized below.

For the NPRM we assumed that projected unused FCC feed hydrotreating capacity would

be used first by the average refinery to reduce their FCC naphtha sulfur level, and additional hydrotreating would be estimated from the revised FCC naphtha sulfur level. As stated above, comments which we received on our proposed rule stating that such capacity does not exist raised uncertainty about how much excess capacity there might be both now and projecting availability in the 2004 timeframe.

New analysis since the promulgation of the NPRM of the gasoline sulfur levels in 1998 shows that gasoline sulfur levels dropped significantly since 1997, possibly due to refiners having to meet the federal RFG and Antidumping requirements using the Complex Model. One possible explanation of how this reduction came about was that refiners used their existing spare FCC feed hydrotreater capacity to reduce their gasoline sulfur levels. Assuming that this is the case, we will use the new gasoline sulfur levels for each PADD to recalculate the FCC naphtha sulfur levels. All sulfur levels calculated are volume-weighted, not refinery-weighted. These adjustments are summarized below in the section on each PADD.

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. The gasoline production volume for the average refinery in PADD 1 is about 77 thousand barrels per day.

We analyzed whether these figures 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 Phase II RFG to be about 150 ppm, no changes in sulfur level are expected to occur to produce Phase II RFG.

In 1998, PADD 1 gasoline sulfur levels averaged 189 ppm, which is 27 ppm lower than the previous value. FCC sulfur levels are recalculated to be 381 ppm based on the lower pool sulfur level.

The PADD 1 blendstock sulfur levels and relative volumes are summarized in Table V-29.

Table V-29. PADD 1 Gasoline Blendstock and Pool Sulfur Levels and Pool Fractions

	FCC	*Alkylate*	*Straight Run*	*Coker*	*Gasoline Pool Sulfur Level*
Sulfur (ppm) NPRM FRM	442 381	10	343	3289	
Percentage of gasoline pool	42	10	4	0.44	
Contribution to pool (ppm) NPRM FRM	185 160	1	14	14	214 189

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 effect on the average sulfur level of PADD 2. The gasoline production volume for the average refinery in PADD 2 is about 66 thousand barrels per day.

In 1998, PADD 2 gasoline sulfur levels averaged 276 ppm, which is 62 ppm lower than the previous value. FCC sulfur levels are recalculated to be 745 ppm based on the lower pool sulfur level.

The PADD 2 blendstock sulfur levels and relative volumes are summarized in Table V-30.

Table V-30. PADD 2 Gasoline Blendstock and Pool Sulfur Levels and Pool Fractions

	FCC	*Alkylate*	*Straight Run*	*Coker*	*Gasoline Pool Sulfur Level*
Sulfur (ppm) NPRM FRM	924 745	10	397	0	
Percentage of gasoline pool	35	13	3.4	0	
Contribution to pool (ppm) NPRM FRM	323 261	1	14	0	338 276

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 gasoline production volume for the average refinery in PADD 3 is about 75 thousand barrels per day.

In 1998, PADD 3 gasoline sulfur levels averaged 288 ppm, which is 19 ppm lower than the previous value. FCC sulfur levels are recalculated to be 673 ppm based on the lower pool sulfur level.

The PADD 3 blendstock sulfur levels and relative volumes are summarized in Table V-31.

Table V-31. PADD 3 Gasoline Blendstock and Pool Sulfur Levels and Pool Fractions

	FCC	*Alkylate*	*Straight Run*	*Coker*	*Gasoline Pool Sulfur Level*
Sulfur (ppm) NPRM FRM	722 673	10	139	3255	
Percentage of gasoline pool	40	14	2.8	0.42	
Contribution to pool (ppm) NPRM FRM	288 269	1	4	14	307 288

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 gasoline production volume for the average refinery in PADD 4 is about 19 thousand barrels per day.

In 1998, PADD 4 gasoline sulfur levels averaged 282 ppm, which is 17 ppm higher than the previous value. FCC sulfur levels are recalculated to be 823 ppm based on the higher pool sulfur level.

The PADD 4 blendstock sulfur levels and relative volumes are summarized in Table V-32.

Table V-32. PADD 4 Gasoline Blendstock and Pool Sulfur Levels and Pool Fractions

	FCC	*Alkylate*	*Straight Run*	*Coker*	*Gasoline Pool Sulfur Level*
Sulfur (ppm) NPRM FRM	762 823	10	122	0	
Percentage of gasoline pool	31	12	21	0	
Contribution to pool (ppm) NPRM FRM	236 255	1	26	0	263 282

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 gasoline production volume for the average refinery in PADD 5, not including California refineries, is about 27 thousand barrels per day.

In 1998, PADD 5 gasoline sulfur levels averaged 301 ppm, which is 205 ppm lower than the previous value. FCC sulfur levels are recalculated to be 710 ppm based on the lower pool sulfur level.

The PADD 5 outside of California blendstock sulfur levels and relative volumes are summarized in Table V-33.

Table V-33. PADD 5 Outside of California Gasoline Blendstock and Pool Sulfur Levels and Pool Fractions

	FCC	*Alkylate*	*Straight Run*	*Coker*	*Gasoline Pool Sulfur Level*
Sulfur (ppm) NPRM FRM	1197 710	10	41	0	
Percentage of gasoline pool	42	10	5.9	0	
Contribution to pool (ppm) NPRM FRM	503 298	1	2	0	506 301

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. The future volume of gasoline produced is based on the increase in consumption summarized later on in this Section. These values are the same as those used in the NPRM.

These values are summarized below in Table V-34.

Table V-34. Projected Volume of Gasoline Produced by an Average Refinery in each PADD and Projected Gasoline Consumption 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.

f. Phase-In Desulfurization

To estimate the capital and per-gallon cost of the gasoline desulfurization program based on our projected use of gasoline desulfurization technologies, we needed to estimate the volume of gasoline each year which would have to be desulfurized to enable refiners to meet the standard which applies in that particular year. To make this estimation, we needed to project for what year refineries will need to have new capital investments installed to meet the requirements of this gasoline sulfur program. We made such an assessement, accounting for the small refiner and ABT programs contained in the final rule, as well as the geographic phase-in, and it is summarized in Section IV.

Based on this analysis we tallied the production volume of gasoline desulfurized for each year and by PADD. This allowed us to calculate our estimated capital and per-gallon costs each year. Our estimate incorporates the temporary exemption for the geographical phase-in as well as the small refiners. These volumes are summarized in Table V-35.

Table V-35. Cumulative Fraction of the Gasoline Pool Desulfurized by PADD and by Year

	PADD 1	*PADD 2*	*PADD 3*	*PADD 4*	*PADD 5OC*
2004*	0.25	0.63	0.65	0.15	0.66
2005	0.36	0.68	0.74	0.15	0.66
2006	0.99	0.93	0.96	0.15	1
2007	0.99	0.93	0.97	0.88	1
2008+**	1	1	1	1	1

* Includes early desulfurization units prior to 2004.
** Includes gasoline already meeting the 30 ppm standard which we included in our baseline gasoline sulfur level for estimating cost, thus it is appropriate to assign some cost to these gallons of gasoline.

g. Decreasing Costs in Future Years

Like the analysis completed for the NPRM, we are presuming that desulfurization costs decrease in future years, however, our methodology is somewhat different. For the NPRM, we presumed that operating costs decrease due to an improvement in catalyst technology. Based on this presumption, we projected that operating costs, including catalyst cost, hydrogen cost, octane cost, and yield loss, would decrease by 20 percent after two years. We also assumed that with debottlenecking, fixed operating costs would stay the same in total and decrease on a per-barrel basis.

Our analysis for the Final Rule incorporates operational cost reductions, but not the debottlencking cost reduction. The presumption here is that refiners will either operate the proven technologies more efficiently, or they would simply change out the catalyst to use the lowest cost fixed bed desulfurization catalyst, which would result in a 20 percent reduction in hydrogen consumption cost, octane recovery cost, yield loss, and catalyst cost starting in the third year. For example, if refiners initially installed a Mobil Oil Octgain 125 process and then later on decided to install the Octgain 220 process (which could be changed out after operating the unit for two years when the catalyst desulfurization efficiency begins to degrade), we estimate, based on the vendors information and our cost factors, that the Octgain 220 process would lower the aggregate cost of the desulfurization unit by 20 percent. But based on the operating cost alone, we estimate the cost savings to be almost 30 percent. Since this case is only one of several proven technologies and there may not be as dramatic as a reduction for the others, we only used

20 percent as our operational cost improvement. We did not assume that the same operational benefits applied to improved and adsorption technologies. We do presume, though, that after the proven and improved desulfurization units reach the end of their economic life, which is after 15 years, they would be replaced by the lower cost adsorption units.

3 The Cost of Desulfurizing Gasoline

a. EPA Costs

The refinery blendstock sulfur levels, the vendor desulfurization technology information, the various cost inputs, and the various desulfurization assumptions described above were combined together in our refinery model to estimate the cost of desulfurizing gasoline from the base sulfur level, down to 30 ppm. As stated above, we presume that refiners would choose a mix of proven and improved desulfurization technologies to meet the requirements of the first year of the program. Then for meeting the program requirements after 2004, some refiners would choose to use lower cost adsorption technologies for 2005, with more and more of them doing so toward the later years. For each technology group, we presume that equal use of each technology would be used. To estimate costs for each year based on this methodology, we used the projected volume of gasoline desulfurized for each PADD during each year of the phase-in period. To estimate national average costs, we volume weighted the PADD-specific cost estimates.

Based on this methodology we estimated the aggregate operating and capital cost, and the per-gallon cost, for the U.S. refining industry as a whole, each year starting in 2004. As expected the program's per-gallon cost decreases over time as lower cost desulfurization technology is implemented until 2008 when the last desulfurization units are installed. In 2006, a portion of the proven technologies' operational costs decrease. After 2008, the costs are constant until 2019 when the initial desulfurization units installed in 2004 reach the end of their useful life, and are replaced by adsorption units, the lowest cost desulfurization technologies. The aggregate operating costs increase due to the constant increase in growth in gasoline demand. These costs are summarized in Table V-36.

Table V-36. Estimated U.S. Aggregate Operating and Capital Cost, and Per-Gallon Cost of Desulfurizing Gasoline to 30 ppm (7% ROI, Before Taxes, $1997)

Year	*Estimated Aggregate Operating Cost ($Billion)**	*Estimated Aggregate Capital Cost ($Billion)*	*Estimated Total Aggregate Cost ($Billion)*	Estimated Per-Gallon Cost (c/gal)
2003	-	2.61**	2.61	
2004	1.21	0.29	1.50	1.95
2005	1.36	1.16	2.52	1.90
2006	1.84	0.34	2.18	1.70
2007	1.95	0.14	2.09	1.71
2008	2.02	-	2.02	1.70
2009	2.04	-	2.04	1.70
2010	2.05	-	2.05	1.70
2011	2.07	-	2.07	1.70
2012	2.08	-	2.08	1.70
2013	2.10	-	2.10	1.70
2014	2.12	-	2.12	1.70
2015	2.13	-	2.13	1.70
2016	2.14	-	2.14	1.70
2017	2.16	-	2.16	1.70
2018	2.17	2.20	4.37	1.70
2019	1.65	0.29	1.94	1.32
2020	1.63	1.24	2.87	1.30
2021	1.61	0.40	2.01	1.26
2022	1.63	0.17	1.80	1.26
2023	1.66	-	1.66	1.26
2024	1.68	-	1.68	1.26
2025	1.71	-	1.71	1.26
2026	1.73	-	1.73	1.26
2027	1.76	-	1.76	1.26
2028	1.78	-	1.78	1.26

Year	*Estimated Aggregate Operating Cost ($Billion)**	*Estimated Aggregate Capital Cost ($Billion)*	*Estimated Total Aggregate Cost ($Billion)*	Estimated Per-Gallon Cost (c/gal)
2029	1.80	-	1.80	1.26
2030	1.83	-	1.83	1.26

* Based on fuel consumption data summarized further below in Section V.
** Includes investments made to produce low sulfur gasoline before 2004 to accumulate credits.

Table V-36 shows that the aggregate capital cost to the U.S. refining industry for meeting the proposed 30 ppm sulfur standard during the initial phase-in is expected to total about 4.5 billion dollars. The program's phase-in causes the capital investments to be spread out over several years, with a little more than half of the capital investments being spent either during, or prior to the year 2004. This level of capital expenditure is less than previous capital expenditures made by the refining industry for environmental programs. As we discussed in the NPRM, during the early nineties the U.S. refining industry invested 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 made in the early '90s were incurred by less than three quarters of the refining industry, we believe that a program requiring the entire industry to spend, on average, about one billion dollars of capital costs per year over several years is not overly burdensome from an economic perspective. The relative value of the costs and benefits of this program are discussed in Chapter VII.

As stated above we estimated per-gallon cost by PADD based on an average refinery for each PADD using different amortization premises. In Table V-37 below, costs are shown for amortizing capital at a 7 percent rate of return on investment (ROI) before taxes which is to represent the cost to society. Then we provide a range of costs which is meant to represent the cost based on a rate of return on capital consistent with how refiners may recover their capital costs. This range is 6 to 10 percent ROI after taxes. To simplify this comparison, we are presenting these per-gallon costs for 2008, the year when the costs stabilize.

Table V-37. Post Phase-in Cost (year 2008) of Desulfurizing Gasoline to 30 ppm Based on Different Capital Amortization Rates

	PADD 1	PADD 2	PADD 3	PADD 4	PADD 5OC	National Average
Societal Cost 7% ROI before Taxes	2.00	1.65	1.52	2.32	2.63	1.70
Capital Payback (6% ROI, after Taxes)	2.04	1.69	1.54	2.41	2.67	1.73
Capital Payback (10% ROI, after Taxes)	2.22	1.85	1.65	2.76	2.87	1.87

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 refinery operating cost, producing low sulfur gasoline in PADD 4 is expected to be the most expensive, and, in the analysis for the NPRM, was about twice as costly to desulfurize gasoline as PADDs 2 and 3. However, because the PADD 4 refineries are subject to less stringent interim standards until 2007 and 2008 under the small refiner and geographical phase-in provisions, the costs are much lower and only 50 percent higher than those of 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 1.7 cents per gallon to desulfurize gasoline down to 30 ppm in 2008 after the program is fully phased-in.

To help the reader better understand the cost of the program for a typical refinery, the per-refinery capital and operating costs, and the estimated yearly aggregate capital and operating cost for each PADD and for the country as a whole of meeting a 30 ppm sulfur standards is summarized in Table V-38 below.

Table V-38. Estimated Average Per-Refinery and Aggregate Capital and Operating Cost of Desulfurizing Gasoline to 30 ppm

	PADD 1	*PADD 2*	*PADD 3*	*PADD 4*	*PADD 5OC*	*National*
Avg. per-refinery capital cost ($MM)	64	50	38	26	26	44
Avg. per-refinery operating cost ($MM)	20	15	17	5	11	16
Aggregate capital cost	691	1342	1674	327	259	4294
Aggregate operating cost	193	341	663	53	92	1343

Table V-38 shows that, on average, refiners would have to pay out $44 million in capital costs for each refinery to lower gasoline sulfur to 30 ppm. In addition, each refinery would incur about 16 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. Since these figures are averages, larger refineries with high gasoline sulfur levels will experience higher total costs, while smaller refineries with lower sulfur levels will experience lower total costs. The aggregate operating cost to the U.S. refining industry is expected to be about 1.3 billion dollars per year.

b. Other Low Sulfur Cost Studies

i. American Petroleum Institute (API) Study

API funded a study by Mathpro to estimate the cost of desulfurizing gasoline in PADDs 1, 2 and 3 down to 40 ppm.[19] Their study was based on CDTech and Mobil Oil Octgain 220 used in a notional refinery which is designed to represent all the refineries in those three PADDs. That

study estimated the cost of desulfurizing gasoline down to 40 ppm to be 2.6 c/gal for Octgain, and 2.25 c/gal for CDTech. The study amortized capital investment at a 10 percent rate of return, which is higher than the ROI which we use to evaluate and compare cost-effectiveness. In addition the Mathpro study allocated 0.5 c/gal for ancillary costs, such as reblending of offspec batches and accounting for overoptimization. These are costs which Mathpro feels is applicable, however, Mathpro has not justified these costs.

To compare our two studies, it is important to place their cost analysis on the same basis as ours. We did that by adjusting their capital cost to reflect a capital amortization rate consistent with a 7 percent ROI before taxes. We summarized the initial costs and the subsequent adjustments in the following table. The API costs increase by 0.25 c/gal for meeting a 30 ppm specification.[20] We next adjusted the 30 ppm cost to base the capital costs on a 7 percent ROI, which decreased the cost to 2.2 c/gal. The costs are even more in line with our costs if some of the ancillary costs are not justified. These costs are summarized in Table V-39.

Table V-39. API Gasoline Desulfurization Estimate, Adjusted and Compared to EPA's
(API cost adjustments are sequential which leads to the comparison with our costs)

Description	*Cost (c/gal)*	
	CDTech	Octgain
API study initial cost for meeting 40 ppm standard	2.25	2.6
API Study: Average CDTech & Octgain cost for 40 ppm std.	2.4	
Adjusted API cost estimate to include incremental cost to meet 30 ppm std. by Mathpro cost study for the Alliance	2.65	
EPA adjusted API Estimated cost based on 7% ROI before taxes	2.2	
EPA cost based on CDTech and Octgain 220 7% ROI before taxes	1.7	

ii. National Petrochemical and Refiners Association (NPRA) Study

NPRA funded a study by Mathpro to estimate cost to PADD 4 refineries of meeting a 40 ppm gasoline sulfur standard.[21] The study yielded a cost of 5.7 c/gal, however, we reviewed the bases for the study and a number of assumptions used in the study led to the much higher gasoline desulfurization cost than our analysis. First, the study assumed that only Octgain 125, which is a proven desulfurization technology, would be used. Then, their cost inputs for Octgain 125 are the older, conservative ones which were abandoned by Mathpro in the later study funded by API. Mathpro's analysis of the difference in cost between the two versions of Octgain 125 processes is about 1 c/gal for PADDs 1 - 3. Furthermore, like our NPRM analysis, the splitting

column used in the NPRA analysis to separate the FCC naphtha into two distinct streams for selectively treating only the heavier part of the FCC naphtha was for an overly conservative column for boiling the entire stream, not intended for making a crude cut for gasoline hydrotreating.

We estimated the cost to PADD 4 refiners to desulfurize their gasoline, based on our finalized program which exempts PADD 4 refineries for the first three years, and thus we assume that most will install absorption desulfurization technology. Based on this methodology, we derived a cost of 2.5 c/gal.

In the process of evaluating that cost, we looked at what the cost would be if PADD 4 refiners had to put in Octgain 125 desulfurization technology, and we can even estimate what it would cost these refineries if they were to install the full boiling range FCC naphtha splitter which, of course, is unnecessary for the simple cuts needed for hydrotreating. We used these cost estimates to adjust the NPRA costs downward to see what NPRA costs might be if they used the more efficient desulfurization and processing equipment, and revised capital amortization factors. We estimate that the 5.7 c/gal NPRA cost would decrease to 5.2 c/gal if their capital cost were amortized by a 7 percent ROI before taxes. Then if their cost estimate would have been based on the revised Octgain 125 cost, we estimate that their cost would decrease to 4.2 c/gal. Next, if their estimated cost were based on a more efficient FCC naphtha splitting column, we estimate that their gasoline desulfurization cost would decrease to 3.5 c/gal. Finally, if their estimated gasoline desulfurization cost were based mostly on adsorption desulfurization technology, we estimate that their estimated cost would decrease to about 2 c/gal, which would be a little higher if their cost estimate would have been for meeting a 30 ppm standard. These costs are summarized in Table V-40.

Table V-40. NPRA PADD 4 Gasoline Desulfurization Estimate, Adjusted and Compared to EPA's

(NPRA cost adjustments are sequential which leads to the comparison with our costs)

Description	*Cost (c/gal)*
NPRA estimated cost for PADD 4 refineries meeting 40 ppm standard based on 10% ROI after taxes	5.7
Incremental Adjustments by EPA	
To 7% ROI before taxes	5.2
To reflect new Octgain 125 cost	4.2
To reflect optimized splitting column	3.5
To reflect more efficient adsorption desulfurization technology	1.7
EPA cost for PADD 4 refineries meeting a 30 ppm standard based primarily on adsorption technology and based on a 7% ROI before taxes	2.5

iii. Association of International Automobile Manufacturers (AIAM) Study

AIAM funded a study by Mathpro to analyze the cost of meeting a 30 ppm standard in PADD 4 using improved desulfurization technology.[22] Mathpro used a spreadsheet to estimate the cost in a refinery-by-refinery analysis of meeting the low sulfur specification. The study assumed that CDTech would be the desulfurization technology used. The analysis estimated that it would cost 3.14 c/gal for PADD 4 refiners to meet the 30 ppm sulfur standard. However, the cost estimate is based on a 15% ROI, and adjusting the cost estimate to be based on a 7% ROI before taxes, reduces the cost estimate to 2.41 cents per gallon.

If we only base our cost to PADD 4 refiners of desulfurizing their gasoline on CDTech, our refinery model estimates that it would cost PADD 4 refiners 3.2 c/gal. Thus, our cost is much more conservative than that by Mathpro. This most likely reflects the higher labor costs for the installation of capital for PADD 4 which we use.

Table V-41. AIAM Gasoline Desulfurization Estimate for PADD 4, Adjusted and Compared to EPA's

Description	*Cost (c/gal)*
Mathpro's cost for desulfurizing gasoline to 30 ppm in PADD 4 based on 15% ROI	3.14
Mathpro's desulfurization cost based on 7% ROI, before taxes	2.14
EPA's cost for desulfurizing gasoline in PADD 4 using CDTech and based on 7% ROI before taxes	3.2

iv Department of Energy (DOE) Study

The Department of Energy used their refinery modeling resources at the Oak Ridge National Laboratory to estimate the cost of desulfurizing gasoline for the average refinery.[23 24] DOE also sought to determine if desulfurization costs varied significantly between average refineries and those for whom gasoline desulfurization might be more challenging. To answer these two questions, they evaluated desulfurization costs for two classes of refineries: mid-capability and challenged. In their analysis, the mid-capability refineries processed crude oil with a sulfur content of 1.6 weight percent, partially hydrotreated FCC feed and produced gasoline with an average sulfur content of 200 - 240 ppm. The challenged group processed crude oil with a sulfur content of 1.94 weight percent, did not hydrotreat FCC feed and produced gasoline with an average sulfur content of 500 ppm. The study was parametric, evaluating the cost of desulfurizing gasoline to 50, 30 and 10 ppm for the mid-capability refinery, and 30 ppm for the challenged refinery. The estimated costs for 10, 30 and 50 ppm sulfur are summarized in Table V-42.

Table V-42. DOE Gasoline Desulfurization Estimate, Adjusted and Compared to EPA's

Description	*Cost (c/gal)*		
	50 ppm	30 ppm	10 ppm
Mid-capability refinery Challenged refinery Based 10% ROI after taxes	2.1 ---	2.9 3.4	9.0 ---
Mid-capability refinery Challenged refinery Adjusted to 7% ROI before taxes	1.9 ---	2.6 2.4	6.7
EPA national average cost to produce 30 ppm gasoline; 7% ROI before taxes		1.7	---

For case where mid-capability refineries produced 30 ppm gasoline, the refinery model chose CDTech as the FCC naphtha hydrotreater. However, the model also chose to install a FCC naphtha splitter, and treat some of the light FCC naphtha with a catalytic extractive desulfurizing unit, and send some of the FCC naphtha to the naphtha hydrotreater/reformer train for hydrotreating and octane recovery. Splitting the FCC naphtha is an integral part of the CDTech unit, so it is unclear why the refinery model chose to install an additional splitter in front of the CDTech unit. Also, the FCC naphtha splitting column simulated by the refinery model is a full boiling range column. This type of column is more costly than a simpler two cut splitter which should be sufficient for this application, as we discussed above. Finally, it is also not clear why the refinery model chose to route some of the FCC naphtha to the reformer hydrotreater. We identified this technique above as a way to reduce sulfur operationally in the period of time prior to installation of a FCC gasoline desulfurization unit. However, this technique is generally not considered to be beneficial in the long run, as running FCC naphtha through the reformer affects the yield and octane of the reformate. It is not clear how this may have affected the costs projected by the DOE model, as the effect of running FCC naphtha through the reformer on reformate yield and octane was not presented. However, along with the inclusion of the full-range splitter, this could have increased costs beyond that necessary to achieve the sulfur standard.

The study's estimated high cost of producing 10 ppm gasoline also appears to be explainable. The refinery model did not include the severe hydrotreating representations of the improved and low cost, proven technologies. The Mathpro model and our model include these severe desulfurization representations. We present cost information in in Section c. below for

more greater than 95 percent efficient desulfurization. A comparison of these costs to those presented above in Tables V-24 and V-25 for 95 percent efficient desulfurization shows that increasing desulfurization efficiency increases costs, but not to the degree indicated by the results of DOE's refinery model. Thus, the absence of these more efficient units appears to have had a major impact on the refinery model's ability to achieve the 10 ppm standard. For example, the DOE refinery model estimated that the achieving the 10 ppm standard would cost $660 million in capital costs per refinery. This is more than an order of magnitude higher than the cost of a FCC gasoline hydrotreater and many times higher than the cost of an FCC feed hydrotreater coupled with a FCC gasoline hydrotreater. Thus, it appears that the model simply did not include cost effective means with which to achieve such low sulfur levels.

Regarding challenged refineries, the DOE study shows that it is only slightly more costly for the challenged refineries to meet the 30 ppm standard than for the mid-capability refineries. This difference disappears altogether using EPA's lower capital cost amortization factor based on a 7% ROI. This suggests that DOE's projected higher desulfurization cost for challenged refineries is due primarily to higher capital costs and operating costs may actually be lower. This suggests that for ROI's below 10%, the difference in costs for average and challenged refineries is small. However, since it appears that the cost for average refineries included some unnecessary costs, the actual cost difference for average and challenged refineries may be larger than indicated in Table V-42.

c. Cost of Meeting a 5 ppm Averaging Standard

We received comments from the automobile industry that we should finalize our gasoline sulfur program with a 5 ppm average sulfur standard. We analyzed the cost of meeting that standard. We contacted CDTech and Mobil Oil and obtained input and process information on how their processes could be used by refiners to desulfurize their FCC naphtha to 5 ppm. The CDTech unit which was costed out above to desulfurize the FCC naphtha to below 100 ppm for a pool average of 30 ppm, can be modified to desulfurize FCC naphtha to 5 ppm. The CDTech unit normally is comprised of two columns, one is the CDHydro column, and the second is named CDHDS. To attain very low sulfur FCC naphtha, CDTech informed us that they could use two of their CDHDS columns to attain FCC desulfurization beyond 99 percent. Similar to the use of CDTech process for treating gasoline down to 30 ppm, the CDHydro unit is commercially demonstrated, but the CDHDS unit is not.

Mobil Oil has commercial desulfurization experience with their Octgain 125 process desulfurizing the FCC naphtha by over 99 percent. However, because of the amount of olefin desulfurization and octane loss by the Mobil process, if it were used to desulfurize light FCC naphtha, Mobil Oil recommends that their process be coupled with an less aggressive hydrotreating process for treating the light FCC naphtha to reduce octane loss. We considered using an extractive desulfurization unit, or CDTech's CDHydro process. The CDHydro process

has two advantages over the extractive desulfurization unit. First, it removes more sulfur out of the light FCC naphtha pool. Second it is a desulfurization unit coupled with a distillation column, saving the need for a separate splitting column. Therefore, we coupled CDTech's CDHydro process with Octgain's 125 process to most cost-effectively desulfurize the FCC naphtha, both of which are commercially demonstrated.

Finally, other desulfurization technologies which can be used to desulfurize gasoline to 5 ppm is the combination of an FCC feed hydrotreater with a CDTech unit, or any other FCC gasoline hydrotreater. In this case, the FCC feed hydrotreater is commercially demonstrated, but the CDTech unit has not yet been demonstrated. This strategy is particularly likely for refineries which already have an FCC feed hydrotreater.

The process operation information for these processes is summarized in Table V-43. The processing costs for the CDTech unit presented here are greater than those presented in Table V-24 above, due to the need to achieve a greater degree of desulfurization.

Table V-43. Process Operation Information for Deep Desulfurization of FCC Naphtha

Technology *(sulfur removal efficiency)*	*CDTech* *(99.4%)*	*CDHydro* *(98%)*	*Octgain 125* *(99.9%)*	*FCC Feed Hydrotreater* *(93%)*
Capacity (MMbbl/day)	20,000	8800	8000	34,500
Capital Cost (MM$)	25.7	4.6	14.5	60
Hydrogen Consumption (SCF/bbl)	165	30	420	290
Electricity (KwH/bbl)	0.75	0.5	2.3	1.5
HP Steam (Lb/bbl)	-	-	-	14
Fuel Gas (BTU/bbl)	81,240	55,000	51,000	56,000
Catalyst Cost ($/bbl)	0.23	0.02	0.50	0.04
Cooling Water (Gal/bbl)	83	60	45	-
Yield Loss (%)	0	0	8.5	0.9
Octane Loss (R+M)/2	2.1	0	0	-

Meeting a 5 ppm specification day-in and day-out would require refiners to ensure that each and every stream is low in sulfur. Thus, gasoline blendstocks which are sufficiently low in sulfur for meeting a 30 ppm specification may have to be monitored more closely and the sulfur level would, perhaps, have to be controlled tighter than what they are now. These streams include reformate, isomerate, alkylate, hydrocrackate, and even MTBE. Since these streams are already low in sulfur (10 ppm or lower except for MTBE which can be two to three times that) not much monitoring or treating is necessary to ensure that these streams remain low in sulfur, and the cost is expected to be low. We did not provide our own estimates of these costs; instead we used the costs from the Alliance of Automobile Manufacturer's study by Mathpro on the cost of meeting a 5 ppm gasoline sulfur specification. These monitoring or sulfur controlling strategies and their respective costs are summarized below in Table V-44. In sum, accounting for these refinery processing changes add an additional 0.2 cents per gallon to the cost of producing gasoline.

Table V-44. Other Refinery Process Changes Potentially Needed to Meet a 5 ppm Sulfur Standard *($1997)*

Description	*Unit Cost*	*Cost Impact on Gasoline Pool*
Install extractive desulfurization treating for captive MTBE	see extractive desulfurization costs	0.008
Install extractive desulfurization treating for light straight run and natural gasoline	see extractive desulfurization costs	0.03
Provide additional hydrotreating of hydrocrackate for recombinant mercaptans	$400/bbl/day + extractive desulfurization oper costs	0.04
Add three stage washing facilities for alkylate production	$200/bbl/day + extractive desulfurization oper cost	0.09
Apply good refinery practice to control reformate sulfur to <=1 ppm	$500/day	0.02

In addition to the information summarized above, we make additional assumptions with respect to estimating the cost of producing 5 ppm gasoline. To simplify the analysis, we created a national average refinery based on the individual PADD-average refineries, by volume weighting those average refineries. We volume-weighted the utility and other operational costs for the national average refinery. Like the analysis for the 30 ppm standard, we applied a 15 percent contingency factor to the final estimated cost of meeting the 5 ppm standard. We adjusted the capital capacity upward by 10 percent to account for the uncertainty of meeting the 5 ppm standard, and this is additional to the 7 percent factor to adjust calendar day throughput to stream day throughput. We added the tankage allowance like the 30 ppm analysis.

Based on the information summarized above, we estimated the cost of desulfurizing gasoline to 5 ppm. We included the 0.2 c/gal treatment costs for the other gasoline blendstocks in our cost calculation. Our cost estimate, however, does not include any additional distribution costs which may be incurred by distributing a much cleaner product. Our costs of achieving 5 ppm are summarized in Table V-45.

Table V-45. Estimated Cost of Meeting a 5 ppm Sulfur Standard
($1997)

Technology	Cost (c/gal)	Incremental Cost to 30 ppm Standard (c/gal)
CDTech	3.1	1.4
CDHydro/Octgain 125	3.4	1.7
FCC Feed HT/CDTech	3.8	2.1

The American Automobile Alliance funded a study by Mathpro to estimate the cost of producing 5 ppm sulfur gasoline.[25] The study is based on the same two of three desulfurization technologies which we used in our cost study, which is CDTech by itself or Octgain 125 coupled with CDHydro. The study estimated a cost of 2.0 and 2.5 c/gal incremental to 30 ppm gasoline, which Mathpro estimated to be 2.5 c/gal. Thus, the study's total estimated cost of meeting a 5 ppm sulfur standard is 4.5 to 5.0 c/gal.

The Alliance's cost study estimated a higher desulfurization cost than our study which is explainable by two primary differences. One, Mathpro, applied a very large 1.8 inside battery limit (ISBL) to outside battery limit (OSBL) capital cost adjustment factor, which is two times larger than typical. Second, the study amortized the capital costs on a 10 percent ROI. Amortizing the capital costs at a 7 percent ROI before taxes and using our ISBL to OSBL cost adjustment factor yields a cost which is essentially the same as ours.

4. Other Effects of This Program

a. Effect of the Cap Standard

In addition to the 30 ppm averaging standard, we are finalizing an 80 ppm per-gallon standard. This additional standard will help to avoid high sulfur batches of gasoline from causing reversibility problems with the emission control hardware. The per-gallon standard or cap on sulfur level provides an additional challenge to refiners by preventing them from producing moderate or high sulfur batches of gasoline, which could be possible while meeting the 30 ppm average standard.

There are a number of situations when refineries tend to produce batches of gasoline with high sulfur levels. The most obvious situation is 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.

In the Draft RIA for the NPRM, we laid out our premise that the cost of meeting the cap standard could be estimated by estimating the cost of reducing gasoline sulfur to meet the average sulfur level which refiners would be producing their gasoline at under the cap. This is based on a past communication with API on how to estimate the cost of the cap standard.[26] Since the averaging standard is at or below the average sulfur level which we expect refiners to operate at if only a 80 ppm cap standard applied, we assumed that there would be no new cost accrued by the cap standard. Upon investigating this further, we believe that situations could occur when a refiner could produce gasoline above an 80 ppm cap while still meeting a 30 ppm average standard. For example, if a refiner typically produced 25 ppm sulfur gasoline to meet this program's sulfur requirement, he could produce gasoline with 400-500 ppm sulfur for 3-4 days or 200-300 ppm gasoline for 4-6 days and still average 30 ppm for the calendar year. For example, these periods of producing high sulfur gasoline could occur if a refiner had to perform a turnaround of his FCC naphtha hydrotreater.

We received a couple of comments from refiners on our approach on not estimating a separate cost for the cap standard. These refiners said that they would accrue additional costs for the cap standard, especially during turnarounds, and that EPA should include these costs. The comments point out that refiners will overbuild on hydrotreating capacity to treat the high sulfur FCC naphtha which will need to be treated due to turnarounds of the desulfurization equipment.

Based on these comments, we modified the costs described above for producing low sulfur gasoline to account for those situations when refiners would otherwise produce high sulfur gasoline. There were four aspects to these modifications. First, we believe that refiners could store FCC naphtha during a shutdown of the FCC naphtha hydrotreater. Gasoline production would decrease in the short term, but gasoline meeting applicable commercial and regulatory specifications could still be produced and the rest of the refinery could remain operative. To facilitate this, we provided for the installation of a tank that would store 10 days of FCC naphtha production. This amount of storage should be adequate for most unanticipated turnarounds. We presumed that half of refiners would need to add such storage, the other half of refineries either already having such storage available, or have the capability to send the untreated blendstock to a nearby refinery which had spare capacity for treating this high sulfur blendstock. Second, we assumed that refineries would design and operate their desulfurization units to normally produce gasoline with 25 ppm sulfur. This would allow them to blend in some higher sulfur blendstock directly into their gasoline pool. Third, we assumed that refiners would install 5 percent more desulfurization capacity than necessary, in order to treat the blendstock which had been stored during a turnaround. We did this for all refiners, though it is possible that only one refiner out of a number of geographically grouped refiners might actually need to invest in extra capacity.

Finally, we include a 15 percent capital cost contingency factor, and a 10 percent operational cost contingency factor to account for costs related to the FCC naphtha hydrotreater and other units in the refinery which may not have been accounted for in the licensor estimates.

We believe that refinery managers will have to place a greater emphasis on the proper operation of all of their desulfurization units, not just the new FCC gasoline desulfurization unit, in order to consistently deliver low sulfur gasoline. This improved operations management could involve enhancements to the computer systems which control the refinery operations, as well as improved maintenance practices.[27] Refiners may be able to recoup some or all of these costs through improved throughput. However, even if they cannot do so, these costs are expected to be less than 1 percent of those estimated above for FCC gasoline desulfurization.[28] [29]

Refiners will also likely invest in a gasoline sulfur analyzer.[30] The availability of a sulfur analyzer at the refinery would provide essentially real-time information regarding the sulfur levels of important streams in the refinery and facilitate operational modifications to prevent excursions above the sulfur cap. Based on information from a manufacturer of such an analyzer, the cost for a gasoline sulfur analyzer would be about $50,000, and the installation cost would be another $5000.[31] Compared to the capital and operating cost of desulfurizing gasoline, the cost for this instrumentation is far below 1 percent of the total cost of this program.

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 the quantity of gasoline demanded would be expected due to the price increase in gasoline. This would mitigate the increase 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.[32] 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 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.[33] 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.[34] 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.[35] 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, the final rule contains a number of provisions which are intended to prevent refinery closures due to financial hardship. The small refiner provisions are projected to give 16 small refineries which are owned by small businesses until 2008 in order to meet the 30 and 80 ppm standards. Between 2004 and 2008, these refiners have to meet interim standards which are related to their current sulfur levels. The geographic phase in delays the 30 and 80 ppm standards until 2007 for 14 refiners located in PADD 4, but will also benefit those refiners located outside of PADD 4 but who sell a significant amount of gasoline in PADD 4. Finally, this final rule also includes a hardship provision applicable to up to about 1 percent of U. S. gasoline production. This provision is intended to benefit refiners who are not able to produce complying gasoline because of extreme and unusual circumstances outside the refiner's control that could not have been avoided through the exercise of due diligence. In all three of these cases, the additional time provided to meet the 30 and 80 ppm standards would allow these refiners 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 or emerging desulfurization technology. Other refiners not covered by these provisions may also be able to delay compliance with the 30 and 80 ppm standards until 2006 through the Averaging, Banking and Trading program (ABT). The ABT program allows a refiner to phase-in the gasoline sulfur program across its refineries to its best financial advantage, or gain even more leeway through the generation and purchase of sulfur credits. For the Final Rule, we are providing more flexibility to refiners by opening up the provisions governing the trading of allotments to allow trading among all refineries to meet the corporate sulfur standard.

We received several comments that we should do a refinery closure analysis. However, we feel that these provisions, which are all designed to minimize the impact of the sulfur standards on refiners, will address the concerns related to the issue of refinery closures. We can also point to Mathpro's refinery-by-refinery analysis for the Alliance which provides us with additonal assurance that refineries will not close.[36] Mathpro first analyzed the cost of the gasoline sulfur program on each refinery in PADD 4. Then it compared the cost to the cash operating margins of these refineries, and concluded that the relative cost is insufficient to cause refinery closures in PADD 4. After our own review of the work completed by Mathpro we reached the same conclusion as Mathpro.

c. Other Fuel Issues Which May Affect the Cost to Desulfurize Gasoline

We received several comments on our proposed rule that we should consider the impact of the expected phase-down of MTBE use in gasoline, and the potential reduction of diesel sulfur, in our cost analysis of desulfurizing gasoline. With respect to an expected phase-down of MTBE, we expect that the MTBE content in gasoline will be limited, but not phased out, which will still allow for the blending of a small volume of MTBE into gasoline. Thus some refiners which may not be using MTBE now may actually have more access to MTBE for blending into their gasoline, while other refiners which make a lot of RFG or oxyfuels, may have to reduce their MTBE use. For desulfurizing their gasoline, refiners can choose among a number of different desulfurization technologies which have varying impacts on gasoline octane levels. Since refiners can expect MTBE levels to be phased down, we believe refiners' technology choice for desulfurizing gasoline will include how an MTBE phase-down will affect their particular situation, and they will choose the gasoline desulfurization technology that will reduce their costs while meeting both requirements. Thus, despite not knowing what the final requirements will be of an MTBE phase-down program, we believe that the phase-down of MTBE will not have a significant impact on the costs of desulfurizing gasoline.

With respect to diesel desulfurization, we heard from a number of refiners that they can address both gasoline and diesel desulfurization most cost-effectively with separate hydrotreating units. The alternative to separate "end of the pipe" hydrotreaters, is to put in a FCC feed hydrotreater which would still require the two additional desulfurization units (although an existing diesel hydrotreater could suffice as the second unit). However, FCC feed hydrotreaters incurs high capital costs which is a significant disincentive to their use. Because refiners aim to minimize their costs, with a bias away from capital costs, we are convinced that treating the diesel and gasoline blendstocks separately will be the method of choice for the majority of refiners, which is corroborated by the comments we received from the oil industry, and this strategy ensures that the costs of the two programs will be separate. Since there are still overlapping elements to both programs, such as hydrogen supply, the costs of which can be reduced if refiners can plan to implement both programs together, refiners want to know what the eventual diesel program will be before building their gasoline desulfurization units. We are working to accommodate them with a proposed rule on desulfurizing diesel fuel soon after this final rule. In the diesel desulfurization rule, we will evaluate the impact of both programs on the refining industry.

5. 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 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[37], 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[12]. Using the projected long-term distribution of 40 percent LDV and 60 percent LDT in the fleet[38], 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[13]. Applying the average fuel economy factor of 19.0 miles per gallon and the initial cost for low sulfur fuel of 1.93 ¢/gal leads us to a per-vehicle estimate of $11.68. This is the additional cost that the average vehicle owner will incur in the first year of the program due to the sole use of low sulfur gasoline.

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[12] In the NPRM, the value of 15.5 mpg was used for all light-duty trucks. For the final rulemaking, we have instead applied different mpg values to the different weight classes of trucks: LDT1, 18.7 mpg; LDT2, 15.7 mpg; LDT3, 13.2 mpg; LDT4, 12.2 mpg. Using the weighting factors in Table VI-4, the weighted average of these values remains 15.5 mpg.

[13] Calculated from the annual miles traveled per vehicle for each year of a vehicle's life, multiplied by a distribution of vehicle registrations 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.

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:

$$LFC = \sum [(AVMT)_i \bullet (SURVIVE)_i \bullet (C) \div (FE)]$$

Where:

LFC	= Lifetime fuel costs in $/vehicle
$(AVMT)_i$	= Annual vehicle miles travelled in year i of a vehicle's operational life[39]
$(SURVIVE)_i$	= Fraction of vehicles still operating after i years of service[40]
C	= Cost of low sulfur gasoline in $/gal
FE	= Fuel economy in miles per gallon. 24.2 for LDV, 15.5 average 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 1.93 ¢/gal applies only in the first year of low sulfur gasoline production. In subsequent years, costs will decrease as refiners make use of more advanced technology. 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 standards take effect (i.e., 2004)

2) Long-term, representing a vehicle whose operational life begins six years after low sulfur gasoline standards take effect (i.e., 2010)

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-46.

Table V-46. Undiscounted Per-vehicle Costs of Low Sulfur Gasoline

	Near-term ($)	*Long-term ($)*
LDV	95.03	89.45
LDT1	168.15	157.78
LDT2	200.27	187.93
LDT3	255.95	240.10
LDT4	276.93	259.78

We then weighted the per-vehicle costs for the individual vehicle categories in Table V-46 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 $164.83 on a near-term basis and $154.77 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:

$$LFC = \sum [\{(AVMT)_i \bullet (SURVIVE)_i \bullet (C) \div (FE)\}/(1.07)^{i-1}]$$

Once again, we calculated lifetime fuel costs separately for LDV, LDT1, LDT2, LDT3, and LDT4. These values are shown in Table V-47.

Table V-47. Discounted Per-vehicle Costs of Low Sulfur Gasoline

	Near-term ($)	*Long-term ($)*
LDV	69.38	65.51
LDT1	119.60	112.65
LDT2	142.45	134.17
LDT3	181.21	170.55
LDT4	196.06	184.53

Once again, we then weighted the per-vehicle costs for the individual vehicle categories in Table V-47 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 $117.82 on a near-term basis and $111.01 on a long-term basis.

A summary of all per-vehicle fuel costs described in this section is given in Table V-48 below.

Table V-48. Fleet Average Per-vehicle Costs Of Low Sulfur Gasoline

	Cost per vehicle ($)
First year	11.68
Lifetime, undiscounted, near-term	164.83
Lifetime, undiscounted, long-term	154.77
Lifetime, discounted, near-term	117.82
Lifetime, discounted, long-term	111.01

6. Aggregate Annual Fuel Costs

Aggregate fuel costs are those costs associated with the increased price 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).[41] The resultant aggregate annual fuel costs are summarized in Table V-49. It is important to note that the capital costs associated with the proposed sulfur controls have been amortized for this analysis at a seven percent rate of return before taxes. 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-49. Summary of the Increased Annualized Social Cost of Gasoline as a Result of the Tier 2 Gasoline Sulfur Controls ($Million)

Calendar Year	*Including Non-Road and Excluding California*[14]
2000	0
2004	1,618
2010	2,553
2015	2,648
2020	2,153

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 for 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 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

[14]The aggregate fuel costs used in the economic impact analysis 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 (roughly 1 percent) relative to the gasoline consumed by vehicles and trucks under 10,000 pounds.

The motorcycle (MC) fuel economy value used is a very rough estimate (45 mpg), but the value chosen has little impact on this analysis given the relatively low VMT of motorcycles relative to LDVs and LDTs (<1 percent).

The stratification of EPA VMT projections between the 8500 to 10,000 pound trucks and the over 10,000 pound trucks was done by using draft MOBILE6 fleet characterization data which showed that approximately 83 percent of heavy-duty gasoline trucks are in the 8500 to 10,000 pound range with the remaining 17 percent in the >10,000 pound range.

The projected VMT values within each category (MC, LDV, LDT, HDG<10,000 pounds, and HDG>10,000 pounds) were then divided by the corresponding DRI projected fuel economy estimates (or the MC fuel economy estimate) 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.

b. Explanation of Results

The aggregate fuel costs used in the economic impact analysis 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.[15] 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.[42] The highway gasoline consumption, including the non-road contribution and excluding the California contribution, was then

[15]Based on EPA VMT estimates that California accounts for approximately 11 percent of nationwide VMT.

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 include non-road sources because gasoline used to power these sources will incur the increased per gallon cost, but exclude California because this rule 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 an increased cost due to this rule.

The aggregate annual fuel costs change as projected per gallon costs and annual fuel consumption change over time. For information on how the per gallon costs change over time, see the discussion earlier in this Chapter. As a result of these changes, the aggregate annual fuel costs 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-50. Calculation of Gasoline Consumption by Highway Sources

	Motorcycle				PassCar				LDT<8500				HDG 8500-10k					HDG>10k			Totals	
CY	AMD Gasoline MC VMT ex CA,AL,HI Bmiles (1)	Gasoline MC VMT nation Bmiles (2)	Esti-mated MC mpg	MC Gasoline Consump nation Bgal	AMD Gasoline PassCar VMT ex CA,AK,HI Bmiles (1)	Gasoline PassCar VMT nation Bmiles (2)	S&P DRI PassCar mpg (3)	PassCar Gasoline Consump nation Bgal	AMD LDT VMT ex CA,AL,HI Bmiles (1)	LDT Gasoline VMT nation Bmiles (2)	S&P DRI <10k Truck mpg (3)	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 (4)	S&P DRI <10k Truck mpg (3)	8500-10k Gasoline Consump nation Bgal	>10k HDG VMT nation Bmiles (4)	S&P DRI >10k mpg (3)	>10k Gasoline Consump nation Bgal	EPA Total Hwy Gasoline Consump nation Bgal	S&PDRI Hwy Gasoline Consump nation Bgal (5)
1996	9				1272				711				46									120.94
2000	10	12	45	0.26	1204	1368	21.2	64.51	961	1092	15.9	68.66	54	61	51	15.9	3.18	10	7.1	1.46	138.07	132.72
2001	10	12	45	0.26	1186	1348	21.3	63.30	1023	1163	16.0	72.67	55	63	52	16.0	3.27	11	7.1	1.50	141.00	134.90
2002	11	12	45	0.27	1169	1329	21.4	61.96	1086	1234	16.1	76.44	57	65	54	16.1	3.35	11	7.2	1.55	143.56	137.07
2003	11	13	45	0.28	1152	1309	21.6	60.63	1148	1304	16.3	80.14	59	67	56	16.3	3.43	11	7.2	1.59	146.07	139.25
2004	12	13	45	0.29	1135	1290	21.7	59.33	1210	1375	16.4	83.78	61	69	58	16.4	3.50	12	7.2	1.63	148.54	141.43
2005	12	13	45	0.30	1118	1271	21.9	58.02	1273	1446	16.5	87.65	63	71	59	16.5	3.59	12	7.4	1.64	151.20	142.44
2006	12	14	45	0.31	1101	1251	22.0	56.75	1335	1517	16.6	91.18	65	74	61	16.6	3.67	13	7.4	1.68	153.59	144.62
2007	13	14	45	0.32	1084	1232	22.2	55.49	1398	1588	16.8	94.66	67	76	63	16.8	3.74	13	7.5	1.72	155.93	146.79
2008	13	15	45	0.33	1086	1234	22.3	55.25	1439	1635	16.9	96.64	69	78	65	16.9	3.82	13	7.5	1.77	157.80	148.97
2009	13	15	45	0.34	1089	1237	22.5	55.00	1480	1681	17.1	98.58	71	80	67	17.1	3.90	14	7.5	1.81	159.63	151.15
2010	14	16	45	0.35	1091	1240	23.2	53.44	1521	1728	17.3	99.88	73	82	68	17.3	3.95	14	7.5	1.87	159.48	151.56
2011	14	16	45	0.36	1093	1242	23.4	53.02	1562	1774	17.5	101.66	75	85	70	17.5	4.03	14	7.5	1.92	160.97	152.47
2012	14	16	45	0.37	1096	1245	23.7	52.61	1603	1821	17.6	103.39	77	87	72	17.6	4.10	15	7.5	1.96	162.43	153.38
2013	15	17	45	0.37	1098	1248	23.9	52.21	1644	1868	17.8	105.09	79	89	74	17.8	4.17	15	7.6	2.01	163.85	154.29
2014	15	17	45	0.38	1100	1250	24.1	51.82	1685	1914	17.9	106.75	81	91	76	17.9	4.23	16	7.6	2.05	165.25	155.20
2015	16	18	45	0.39	1103	1253	24.6	50.94	1726	1961	18.2	107.74	83	94	78	18.2	4.28	16	7.6	2.10	165.44	157.48
2016	16	18	45	0.40	1105	1256	24.8	50.57	1767	2007	18.4	109.31	85	96	80	18.4	4.34	16	7.6	2.14	166.77	158.39
2017	16	19	45	0.41	1107	1258	25.1	50.20	1808	2054	18.5	110.85	87	98	82	18.5	4.40	17	7.6	2.19	168.06	159.30
2018	17	19	45	0.42	1110	1261	25.3	49.85	1849	2101	18.7	112.36	89	101	83	18.7	4.46	17	7.7	2.23	169.33	160.21
2019	17	19	45	0.43	1112	1264	25.5	49.50	1890	2147	18.9	113.83	91	103	85	18.9	4.52	18	7.7	2.28	170.56	161.12
2020	17	20	45	0.44	1114	1266	25.5	49.66	1931	2194	19.0	115.46	93	105	87	19.0	4.59	18	7.8	2.29	172.45	161.66
2021	18	20	45	0.45	1117	1269	25.5	49.76	1972	2240	19.0	117.92	95	107	89	19.0	4.69	18	7.8	2.34	175.16	162.63
2022	18	21	45	0.46	1119	1272	25.5	49.87	2013	2287	19.0	120.37	97	110	91	19.0	4.79	19	7.8	2.39	177.88	163.60
2023	19	21	45	0.47	1121	1274	25.5	49.97	2054	2334	19.0	122.82	99	112	93	19.0	4.89	19	7.8	2.44	180.59	164.57
2024	19	22	45	0.48	1124	1277	25.5	50.08	2095	2380	19.0	125.27	101	114	95	19.0	4.99	19	7.8	2.49	183.31	165.54
2025	19	22	45	0.49	1126	1280	25.5	50.18	2136	2427	19.0	127.73	103	116	97	19.0	5.09	20	7.8	2.54	186.02	166.51
2026	20	22	45	0.50	1128	1282	25.5	50.28	2177	2473	19.0	130.18	105	119	99	19.0	5.19	20	7.8	2.59	188.74	167.48
2027	20	23	45	0.51	1131	1285	25.5	50.39	2218	2520	19.0	132.63	106	121	100	19.0	5.29	21	7.8	2.64	191.45	168.45
2028	21	23	45	0.52	1133	1288	25.5	50.49	2259	2567	19.0	135.08	108	123	102	19.0	5.38	21	7.8	2.69	194.17	169.42
2029	21	24	45	0.53	1135	1290	25.5	50.60	2300	2613	19.0	137.53	110	126	104	19.0	5.48	21	7.8	2.74	196.88	170.39
2030	21	24	45	0.54	1138	1293	25.5	50.70	2341	2660	19.0	139.99	112	128	106	19.0	5.58	22	7.8	2.79	199.60	171.36

(1) See Chapter III of this Tier 2 Final Rule RIA for a discussion of these VMT projections.

(2) CA = 11% of nation; CA,AK,HI= 12% of nation

(3) From S&P DRI World Energy Service U.S. Outlook, April 1998, Table 17 (mpg values include diesel), S&P does not provide mpg estimates for 2021-2030 so the 2020 estimate is assumed for those years

(4) Uses Draft MOBILE6 Fleet Characterization Data for MOBILE6; OMS/T.Jackson, March 1999; uses fleet mix projections where ~83% of HDG are 8500-10K and ~17% of HDG are >10K

(5) Presented for comparison only. Discrepancy in later years due mainly to OMS's larger LDT VMT share (67% of LD VMT) vs S&P (~53% of <10k VMT)

Table V-51. Aggregate Annualized Fuel Costs per Year from 2004 to 2030

		Increased Social Costs for Gasoline			
CY	EPA Total Hwy Gasoline Consumption Bgal	Total Hwy Gasoline Consumption excluding CA Bgal (2)	Non-road Gasoline Consumption excluding CA Bgal (3)	% of Total that is 30/80 ppm Sulfur Gasoline Bgal (4)	Annual Tier2 Cost excluding CA & including NonRoad $B
2000	138.07	122.89	7.86	0	0
2001	141.00	125.49	8.03	0	0
2002	143.56	127.77	8.18	0	0
2003	146.07	130.00	8.32	0	0
2004	148.54	132.20	8.46	0.5947	1.618
2005	151.20	134.57	8.61	0.6744	1.819
2006	153.59	136.69	8.75	0.9253	2.268
2007	155.93	138.78	8.88	0.9253	2.302
2008	157.80	140.44	8.99	1.0000	2.526
2009	159.63	142.07	9.09	1.0000	2.555
2010	159.48	141.94	9.08	1.0000	2.553
2011	160.97	143.27	9.17	1.0000	2.577
2012	162.43	144.56	9.25	1.0000	2.600
2013	163.85	145.83	9.33	1.0000	2.623
2014	165.25	147.07	9.41	1.0000	2.645
2015	165.44	147.24	9.42	1.0000	2.648
2016	166.77	148.42	9.50	1.0000	2.670
2017	168.06	149.58	9.57	1.0000	2.690
2018	169.33	150.70	9.64	1.0000	2.711
2019	170.56	151.80	9.71	1.0000	2.161
2020	172.45	153.48	9.82	1.0000	2.153
2021	175.16	155.90	9.98	1.0000	2.133
2022	177.88	158.31	10.13	1.0000	2.166
2023	180.59	160.73	10.29	1.0000	2.200
2024	183.31	163.14	10.44	1.0000	2.233
2025	186.02	165.56	10.60	1.0000	2.266
2026	188.74	167.98	10.75	1.0000	2.299
2027	191.45	170.39	10.91	1.0000	2.332
2028	194.17	172.81	11.06	1.0000	2.365
2029	196.88	175.23	11.21	1.0000	2.398
2030	199.60	177.64	11.37	1.0000	2.431

(1) See Chapter V, section B of this Tier 2 Final Rule RIA for a discussion of these estimates.

(2) CA = 11% of total nation; CA,AK,HI = 12% of nation

(3) OMS/T.Sherwood; NonRoad fraction = 6.4%; see memo to Docket A-97-10, 2/19/99

(4) Represents the fraction of total consumption, exluding CA, that is 30 ppm average/80 ppm max sulfur gasoline.

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-52 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-52 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.[16]

Table V-52. Total Incremental Per Vehicle Costs to Consumers Over the Life of a Tier 2 Vehicle

	LDV ($)	*LDT1 ($)*	*LDT2 ($)*	*LDT3 ($)*	*LDT4/MDPV ($)*
Near-term Costs					
Vehicle costs	82	74	130	249	273
Fuel costs*	69	120	143	181	196
Total	151	194	273	430	469
Long-term Costs					
Vehicle costs	53	49	101	203	223
Fuel costs*	66	113	134	171	185
Total	119	162	235	374	408

* Discounted lifetime fuel costs

[16] Includes estimated costs for OBD II and ORVR requirements for MDPVs.

2. Combined Total Annual Nationwide Costs

Figure V-2 and Table V-53 summarize EPA's estimates of total annual costs to the nation both for Tier 2 vehicles and low sulfur gasoline.[17] 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. 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 $4.1 billion in 2009. Total annualized costs are projected to remain at about $4 billion through 2018. After 2018, annualized fuel costs are projected to decrease somewhat due to the use of new technologies which would enable refiners to produce low sulfur fuel at a lower cost. The gradual rise in costs long term is due to the effects of projected growth in vehicle sales and fuel consumption.

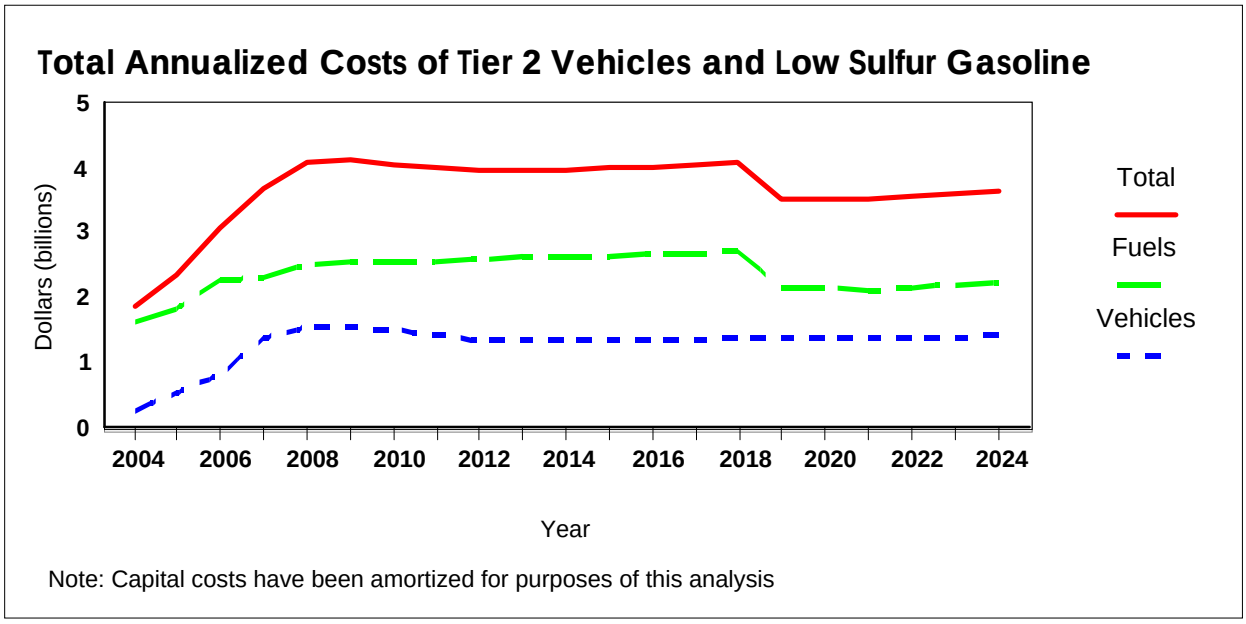

Figure V-2. Total Annualized Costs of Tier 2 Vehicles and Low Sulfur Gasoline.

[17] Excluding vehicles and fuel sold in California.

Table V-53. Total Annualized Costs to the Nation for Tier 2 Vehicles and Low Sulfur Gasoline ($million)

Calendar Year	*Vehicle Costs ($)*	*Fuel Costs ($)*	*Total ($)*
2004	$269	$1,618	$1,887
2005	$531	$1,819	$2,350
2006	$834	$2,268	$3,102
2007	$1,383	$2,302	$3,685
2008	$1,556	$2,526	$4,082
2009	$1,578	$2,555	$4,133
2010	$1,500	$2,553	$4,053
2011	$1,432	$2,577	$4,009
2012	$1,362	$2,600	$3,962
2013	$1,354	$2,623	$3,977
2014	$1,351	$2,645	$3,996
2015	$1,357	$2,648	$4,005
2016	$1,364	$2,670	$4,034
2017	$1,371	$2,690	$4,061
2018	$1,378	$2,711	$4,089
2019	$1,385	$2,161	$3,546
2020	$1,392	$2,153	$3,545
2021	$1,399	$2,133	$3,532
2022	$1,406	$2,166	$3,572
2023	$1,413	$2,200	$3,613
2024	$1,420	$2,233	$3,653

Chapter V References

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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 dollars per ton of total NOx + NMHC emission reductions after the Tier 2 standards have been fully implemented. The tons reduced used in this analysis are the same as those used in our air quality modeling analysis. We have also expanded our cost-effectiveness analysis from that presented in the NPRM to include another approach, aggregate cost-effectiveness, which accounts for all costs and emission reductions over a 30 year period beginning in 2004. 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. Our responses to comments submitted to us on the subject of cost-effectiveness can be found in the Response To Comments document, Issue Number 24.

The emission reductions used to calculate the cost-effectiveness levels reported here are based on those reductions used for our air quality analysis modeling and benefits analysis. This was done to maintain consistency in the analyses. As noted in section III.A, we have updated our inventory model since the air quality modeling inventories were calculated. Table III.A.-3 compares the updated Tier 2 model with the air quality analysis modeling and shows that the emission reductions expected from Tier 2/gasoline sulfur will be substantially greater than the amounts originally calculated. If the updated numbers were incorporated into our cost-effectiveness we would expect the results to be improved over those shown in this section.

A. Overview of the Analysis

We have calculated the cost-effectiveness of the exhaust emission/gasoline sulfur standards and the evaporative emission standards, based on two different approaches. The first considers the net present value of all costs incurred and emission reductions generated over the life of an average Tier 2 vehicle. This per-vehicle approach focuses on the cost-effectiveness of the program from the point of view of the Tier 2 vehicles which will be used to meet the new requirements, and is the method used in our proposal. However, the per-vehicle approach does not capture all of the costs or emission reductions from the Tier 2/gasoline sulfur program since it does not account for the use of low sulfur gasoline in pre-Tier 2 vehicles. Therefore, we have also calculated an aggregate cost-effectiveness using the net present value of costs and emission reductions for all in-use vehicles over a 30-year time frame. Both approaches have been used in previous mobile-source programs, though the per-vehicle approach is more common.

Sections A through C describe how we developed our per-vehicle cost-effectiveness results. This is followed, in Section D, with the extension of these techniques to the aggregate cost-effectiveness. All of our results are then presented and discussed in Section E.

The per-vehicle cost-effectiveness analysis conducted for our 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 this approach to cost-effectiveness follow.

1. Temporal and Geographic Applicability

The per-vehicle approach to our cost-effectiveness calculations 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 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 rulemaking, therefore, we will present cost-effectiveness of our 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 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 standards would be calculated with respect to another set of potential standards which is less stringent than our 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.

An average approach to cost-effectiveness, on the other hand, requires that we compare the costs and emission reductions associated with our 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 standards.

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 standards, both the emission reductions and the fuel cost as a function of sulfur content are nearly linear, though the vehicle costs do contain some nonlinearity. In addition, nearly all past mobile source programs have calculated cost-effectiveness with respect to the previous set of standards. Therefore, we have chosen to calculate cost-effectiveness on an average rather than an incremental basis.

Since today's 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 sulfur standard would go into effect. The national average sulfur content of current conventional gasoline is approximately 300 ppm.. This is a change from the NPRM value of 330 ppm based on more recent survey data. 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[1]. Based on the fact that the high ozone season covers approximately 4.5 months, we estimate that 38 vol% of the annual pool is summer gasoline, with the remainder being winter gasoline. Applying these fractions to the Phase II RFG sulfur levels produces an annual 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 285 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 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 Tier 2 evaporative emission standards. Instead, the 2.0 gram/test standards under the enhanced evaporative

[1] 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.

procedure, initially implemented in 1996, have been used as the baseline.

B. Costs

The costs used in our per-vehicle 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 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 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 amortization has ended and all learning curve cost savings have been accounted for. For the purposes of this rulemaking, therefore, we will present cost-effectiveness of our 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 Tier 2 program. For instance, the costs associated with our gasoline sulfur control program will decline in steps due to rotating capital expenditures. 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 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 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 amortization has 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 standards. For the purposes of calculating cost-effectiveness, we first subtracted out the costs attributable to compliance with our 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 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 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-46. 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	121.04	4.10	117.82	242.96
Long-term	89.56	4.10	111.01	204.67

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 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 program.

The reduction in gasoline sulfur levels that would result from our 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. We are not setting Tier 2 standards in order to control emissions of SO_2, so we have not calculated the cost-effectiveness of SO_2 control. Likewise for sulfate PM, manufacturers are already meeting the Tier 2 PM standard, so that there are no additional costs for compliance and PM cost-effectiveness is not relevant. However, reductions in emissions of SO_2 and sulfate PM represent real benefits of our program, and it is appropriate to account for them in some way in our cost-effectiveness calculations. To do this, 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 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 drawn from other sources.

In concept, we would consider the most expensive program needed to reach attainment to be 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.E 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 cost-effectiveness of the eight SO_2 control programs ranged from $1600/ton to $111,500/ton. In this particular rulemaking, 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 $PM_{2.5}$). The particulate matter that would be reduced as a result of our Tier 2/gasoline sulfur program could be categorized as fine PM having mean particle diameters of less than 2.5 microns. Despite the fact that the revised NAAQS for PM was remanded, $PM_{2.5}$ remains a bigger health hazard than PM_{10}, and it is therefore still valid to examine cost-effectiveness values for both PM_{10} and $PM_{2.5}$. Furthermore, 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 standards.

The cost crediting was applied after all costs associated with compliance with our 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, $50.61 of the total costs were apportioned to SO_2, while $3.72 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 lifetime 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	242.96	204.67
SO_2 credit allocation	-50.61	-50.61
Direct PM credit allocation	-3.72	-3.72
Total credited costs	188.63	150.34

C. Emission Reductions

In order to determine the overall per-vehicle 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, sulfate 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 standards are intended primarily to reduce emissions of NOx and NMHC. As a result, we have determined that the cost-effectiveness of our standards should be determined for both NOx and NMHC. It is true the our program does include new standards for PM. However, these standards are already being met by manufacturers. Thus manufacturers will incur no new costs to comply with the Tier 2 PM standard and a cost-effectiveness analysis of the PM standards is therefore unnecessary.

Several past rulemakings which produced reductions in both NOx and NMHC 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 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 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 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:

$$LE = \sum [\{(AVMT)_i \bullet (SURVIVE)_i \bullet (ER)_i \bullet (K)\}/(1.07)^{i-1}]$$

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, where LDT4 includes MDPV) 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 and 300 ppm for the winter; conventional gasoline in the remaining areas, modeled at 300 ppm sulfur year-round). 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 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 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 38 percent of the year, while winter-grade Phase II RFG having approximately 300 ppm sulfur will be used for the remaining 62 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.

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

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 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.

The final step before calculating the cost-effectiveness of our 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	0.400
LDT1	0.102
LDT2	0.340
LDT3	0.103
LDT4	0.055

The values in Table VI-4 differ slightly from those in the draft RIA due to the inclusion of larger trucks above 8500 lb GVWR (a class now called medium duty passenger vehicles, or MDPV) into the LDT4 category. 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

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[2]	0.14331	0.03686	0.04192
285	0.11556	0.03319	0.04192

Table VI-6. Fleet-average, Per-vehicle Discounted Lifetime Tons for Tier 2 Standards

Sulfur (ppm)	*NOx (tons)*	*Exhaust NMHC (tons)*	*Evap NMHC (tons)*
80	0.03565	0.02369	0.03887
30	0.02744	0.02250	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.

2. Irreversibility

As described in Appendix B, we believe that Tier 1, LEV, and Tier 2 vehicles meeting the SFTP 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.

[2] Tonnage values at 800 ppm and 80 ppm sulfur were used for estimating the impacts of irreversibility. See Section VI.C.2 for details.

The increased emissions that result when an SFTP-compliant 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 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 in the range of 20 to 65 percent, meaning that 20 to 65 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, 20 to 65 percent of the sensitivity effect is permanent or “irreversible” regardless of the 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.

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.

Under our gasoline sulfur program, the average sulfur level will be 30 ppm and the maximum allowable level will be 80 ppm after full implementation. Per-vehicle lifetime emissions at these two sulfur levels from Table VI-6 were used to determine the effect of irreversibility on Tier 2 vehicles. For simplicity, we have used the midpoint of our estimated range of irreversibility effects, 42.5 percent. 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:

$$ILE_{30} = (IE) \bullet (LE_{80} - LE_{30}) + LE_{30}$$

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, 0.425
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 285 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 285 ppm and 800 ppm from Table VI-5 were used to determine the effect of irreversibility on vehicles meeting NLEV standards. As discussed in Appendix B, we believe that irreversibility applies to any SFTP-compliant vehicle, including LDT3 and LDT4 meeting Tier 1 standards under the NLEV program. Thus the calculations followed the same procedure as that used for Tier 2 vehicles:

$$ILE_{285} = (IE) \bullet (LE_{800} - LE_{285}) + LE_{285}$$

Where:

ILE_{285} = Irreversibility-impacted, discounted lifetime emissions of SFTP-complaint NLEV vehicles at 285 ppm sulfur in tons/vehicle, for each vehicle class
IE = Irreversibility impact, 0.425
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 285 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 285 ppm	0.12735	0.03475	0.04192	0.20402
Target: Tier 2 at 30 ppm	0.03093	0.02300	0.04020	0.09413

3. Primary Particulate Matter

Vehicles meeting our 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 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 gasoline sulfur standard are calculated according to the following equation:

$$LE = \sum [\{(AVMT)_i \bullet (SURVIVE)_i \div (FE) \bullet (D) \bullet (SUL) \bullet (F) \bullet (MC) \bullet (K)\}/(1.07)^{i-1}]$$

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, 2.55×10^{-4} lb sulfur/lb fuel (255 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 0.00037. 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 gasoline sulfur standard are calculated according to the following equation:

$$LE = \sum [\{(AVMT)_i \bullet (SURVIVE)_i \div (FE) \bullet (D) \bullet (SUL) \bullet (F) \bullet (MC) \bullet (K)\}/(1.07)^{i-1}]$$

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, 2.55×10^{-4} lb sulfur/lb fuel (255 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 0.01054. 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. Aggregate Cost-Effectiveness

Since the per-vehicle approach to cost-effectiveness considers only Tier 2 vehicles, it does not reflect the costs and emission reductions from pre-Tier 2 vehicles operating on low sulfur gasoline. An alternative approach for evaluating the cost-effectiveness of our program involves calculating the net present value of all nationwide emission reductions and costs for a 30 year period. This timeframe captures both the early period of the program when very few Tier 2 vehicles will be in the fleet, and the later period when essentially all vehicles in the fleet will meet Tier 2 standards. We have calculated this "aggregate" cost-effectiveness using the net present value of the annual emission reductions and costs. The calculation of aggregate cost-effectiveness follows the pattern described above for the per-vehicle analysis:

$$DNAE = \sum (NE)_i / (1.07)^{i-2004}$$

Where:

DNAE = Reduction in discounted, nationwide aggregate emissions in tons
$(NE)_i$ = Reduction in nationwide emissions in tons for year i of the program
i = Year of the program, counting from 2004 to 2034

and

$$DNAC = \sum (NC)_i / (1.07)^{i-2004}$$

Where:

DNAC = Discounted, nationwide aggregate costs in dollars
$(NC)_i$ = Nationwide costs in dollars for year i of the program
i = Year of the program, counting from 2004 to 2034

The inputs for annual nationwide emission reductions and costs used to calculate the aggregate cost-effectiveness are given in Appendix VI-C. Aggregate cost-effectiveness is produced by dividing DNAC by DNAE. The results are given in Section VI.E below.

E. Results

The results of our cost-effectiveness analysis are given in Tables VI-8 (per-vehicle) and VI-9 (30 year aggregate). We calculated the per-vehicle cost-effectiveness of our 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 285 ppm, and our Tier 2 standards at our sulfur standard of 30 ppm. The aggregate values were calculated as described in Section D above.

Table VI-8. Per-vehicle cost-effectiveness of the Tier 2/gasoline sulfur standards

	Credited costs ($)	*Uncredited costs ($)*	*Tons NOx+NMHC*	*Credited $/ton*	*Uncredited $/ton*
Near term	188.63	242.96	0.10989	1717	2211
Long term	150.34	204.67	0.10989	1368	1863

Table VI-9. Aggregate cost-effectiveness of the standards

Discounted aggregate vehicle & fuel costs	*Discounted aggregate NMHC + NOx reduction (tons)*	*Discounted aggregate cost-effectiveness per ton*	*Discounted aggregate cost-effectiveness per ton with SO_2 and direct PM credit*[a]
$48.1 billion	23.5 million	$2,047	$1,311

[a] $13.8 billion credited to SO_2 ($4800/ton), $3.5 billion to direct PM ($10,000/ton).

The values in Table VI-8 differ slightly from those in the NPRM for several reasons. First, the truck category has been expanded to include the larger trucks weighing greater than 8500 lb GVWR (the medium-duty passenger vehicles), causing a small increase in both the emission reductions and vehicle costs associated with our Tier 2 standards. Second, the baseline sulfur level changed from 305 ppm in the NPRM to 285 ppm in this final rule as described in Section VI.A.2. The reduction in baseline sulfur means that emissions from baseline vehicles were slightly lower than presented in the NPRM, and thus the emissions benefit of reducing sulfur to 30 ppm is also slightly lower. Third, there was a change in our approach to irreversibility, in that we revised our estimate of the irreversibility effect to encompass the range

of 20 to 65 percent, as described in Appendix B. Using the midpoint of 42.5 percent resulted in a small decrease in overall emission reductions resulting from Tier 2 vehicles operating on 30 ppm fuel. Finally, the costs associated with both fuel desulfurization and vehicle aftertreatment changed, as described in Sections V.A and V.B.

Because the primary purpose of cost-effectiveness is to compare our program to alternative programs, we made a comparison between the values in Tables VI-8 and VI-9 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[2]
NLEV	1,859
Marine SI engines	1,128-1,778
On-board diagnostics	2,228

By comparing the values from Table VI-8 and VI-9 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 Tier 2/gasoline sulfur standards. Vehicle standards, most similar to today's proposal, have comparable or higher values than our 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, the values in

[2] 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.

Table VI-10 might imply that further reductions in NOx and VOC from heavy-duty engines could be more cost-effective than the reductions that will be produced from our Tier 2/gasoline sulfur program. However, we do not believe that to be the case. While we are indeed developing a proposal for further control from heavy-duty engines, we expect that substantial further emission reductions will require advanced after-treatment devices. These devices will be more costly than methods use to meet our past standards, and will have difficulty functioning properly without changes to diesel fuel. We therefore expect that the cost effectiveness of future heavy-duty standards is not likely to be significantly less than the cost effectiveness of today's rule.

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 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)[3]. 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.

We recognize that the cost effectiveness calculated for our 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 Tier 2/gasoline sulfur program would apply nationwide. However, in dealing with the question of comparing local and national programs, it is also relevant to point out that, because of air transport, the need for NOx control is a broad regional issue not confined to non-attainment areas only. To reach attainment, future controls will need to be applied over widespread areas of the

[3] This rulemaking was remanded by the D.C. Circuit Court on May 14, 1999. However, the analyses completed in support of that rulemaking are still relevant, since they were designed to investigate the cost-effectiveness of a wide variety of potential future emission control strategies.

country. In the analyses supporting the recent NOx standards for highway diesel engines,[4] we looked at this question in some detail and concluded that the regions expected to impact ozone levels in ozone nonattainment areas accounted for over 85% of total NOx emissions from a national heavy-duty engine control program. Similarly, NOx emissions in attainment areas also contribute to particulate matter nonattainment problems in downwind areas. Thus, the distinction between local and national control programs for NOx is less important than it might appear.

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.

[4] Final Regulatory Impact Analysis: Control of Emissions of Air Pollution from Highway Heavy-Duty Engines, September 16, 1997

APPENDIX VI-A : Discounted Lifetime Tonnage Values for Exhaust Emissions

Stnd	Veh clas	IM case	Sulfur	Fuel	NOx tons	NMHC tons
NLEV	LDT1	IM	30	Conventional	0.04614	0.01839
NLEV	LDT1	IM	30	RFG	0.04494	0.01565
NLEV	LDT1	No IM	30	Conventional	0.06646	0.03540
NLEV	LDT1	No IM	30	RFG	0.06478	0.03000
NLEV	LDT2	IM	30	Conventional	0.07705	0.02205
NLEV	LDT2	IM	30	RFG	0.07503	0.01878
NLEV	LDT2	No IM	30	Conventional	0.09894	0.03943
NLEV	LDT2	No IM	30	RFG	0.09642	0.03344
NLEV	LDT3	IM	30	Conventional	0.15696	0.05429
NLEV	LDT3	IM	30	RFG	0.15282	0.04632
NLEV	LDT3	No IM	30	Conventional	0.18307	0.07525
NLEV	LDT3	No IM	30	RFG	0.17836	0.06396
NLEV	LDT4	IM	30	Conventional	0.23321	0.06443
NLEV	LDT4	IM	30	RFG	0.22703	0.05498
NLEV	LDT4	No IM	30	Conventional	0.26188	0.08646
NLEV	LDT4	No IM	30	RFG	0.25512	0.07351
NLEV	LDV	IM	30	Conventional	0.03043	0.01124
NLEV	LDV	IM	30	RFG	0.02963	0.00957
NLEV	LDV	No IM	30	Conventional	0.03939	0.01892
NLEV	LDV	No IM	30	RFG	0.03839	0.01605
Tier 2	LDT1	IM	30	Conventional	0.02183	0.01839
Tier 2	LDT1	IM	30	RFG	0.02128	0.01565
Tier 2	LDT1	No IM	30	Conventional	0.04163	0.03540
Tier 2	LDT1	No IM	30	RFG	0.04060	0.03000
Tier 2	LDT2	IM	30	Conventional	0.02033	0.01832
Tier 2	LDT2	IM	30	RFG	0.01982	0.01559
Tier 2	LDT2	No IM	30	Conventional	0.04101	0.03535
Tier 2	LDT2	No IM	30	RFG	0.04000	0.02996
Tier 2	LDT3	IM	30	Conventional	0.02730	0.02130
Tier 2	LDT3	IM	30	RFG	0.02661	0.01813
Tier 2	LDT3	No IM	30	Conventional	0.05087	0.04114
Tier 2	LDT3	No IM	30	RFG	0.04961	0.03486
Tier 2	LDT4	IM	30	Conventional	0.02970	0.02152
Tier 2	LDT4	IM	30	RFG	0.02894	0.01831
Tier 2	LDT4	No IM	30	Conventional	0.05402	0.04138
Tier 2	LDT4	No IM	30	RFG	0.05268	0.03506
Tier 2	LDV	IM	30	Conventional	0.01364	0.01124
Tier 2	LDV	IM	30	RFG	0.01328	0.00957
Tier 2	LDV	No IM	30	Conventional	0.02237	0.01892
Tier 2	LDV	No IM	30	RFG	0.02181	0.01605
NLEV	LDT1	IM	80	Conventional	0.06296	0.01989
NLEV	LDT1	IM	80	RFG	0.06132	0.01694

NLEV	LDT1	No IM	80	Conventional	0.08716	0.03669
NLEV	LDT1	No IM	80	RFG	0.08495	0.03110
NLEV	LDT2	IM	80	Conventional	0.08783	0.02329
NLEV	LDT2	IM	80	RFG	0.08552	0.01984
NLEV	LDT2	No IM	80	Conventional	0.11092	0.04051
NLEV	LDT2	No IM	80	RFG	0.10809	0.03436
NLEV	LDT3	IM	80	Conventional	0.15929	0.05585
NLEV	LDT3	IM	80	RFG	0.15508	0.04765
NLEV	LDT3	No IM	80	Conventional	0.18545	0.07659
NLEV	LDT3	No IM	80	RFG	0.18068	0.06510
NLEV	LDT4	IM	80	Conventional	0.23669	0.06632
NLEV	LDT4	IM	80	RFG	0.23042	0.05659
NLEV	LDT4	No IM	80	Conventional	0.26534	0.08807
NLEV	LDT4	No IM	80	RFG	0.25849	0.07489
NLEV	LDV	IM	80	Conventional	0.04183	0.01224
NLEV	LDV	IM	80	RFG	0.04073	0.01043
NLEV	LDV	No IM	80	Conventional	0.05250	0.01983
NLEV	LDV	No IM	80	RFG	0.05116	0.01683
Tier 2	LDT1	IM	80	Conventional	0.02903	0.01989
Tier 2	LDT1	IM	80	RFG	0.02828	0.01694
Tier 2	LDT1	No IM	80	Conventional	0.05338	0.03669
Tier 2	LDT1	No IM	80	RFG	0.05206	0.03110
Tier 2	LDT2	IM	80	Conventional	0.02685	0.01982
Tier 2	LDT2	IM	80	RFG	0.02617	0.01687
Tier 2	LDT2	No IM	80	Conventional	0.05236	0.03663
Tier 2	LDT2	No IM	80	RFG	0.05106	0.03105
Tier 2	LDT3	IM	80	Conventional	0.03626	0.02302
Tier 2	LDT3	IM	80	RFG	0.03533	0.01960
Tier 2	LDT3	No IM	80	Conventional	0.06519	0.04260
Tier 2	LDT3	No IM	80	RFG	0.06358	0.03611
Tier 2	LDT4	IM	80	Conventional	0.03954	0.02326
Tier 2	LDT4	IM	80	RFG	0.03853	0.01981
Tier 2	LDT4	No IM	80	Conventional	0.06935	0.04286
Tier 2	LDT4	No IM	80	RFG	0.06763	0.03633
Tier 2	LDV	IM	80	Conventional	0.01831	0.01224
Tier 2	LDV	IM	80	RFG	0.01783	0.01043
Tier 2	LDV	No IM	80	Conventional	0.02905	0.01983
Tier 2	LDV	No IM	80	RFG	0.02832	0.01683
NLEV	LDT1	IM	150	RFG	0.07523	0.01787
NLEV	LDT1	No IM	150	RFG	0.10209	0.03192
NLEV	LDT2	IM	150	RFG	0.09307	0.02059
NLEV	LDT2	No IM	150	RFG	0.11650	0.03502
NLEV	LDT3	IM	150	RFG	0.15830	0.04960
NLEV	LDT3	No IM	150	RFG	0.18399	0.06677
NLEV	LDT4	IM	150	RFG	0.29048	0.06432
NLEV	LDT4	No IM	150	RFG	0.32511	0.08390
NLEV	LDV	IM	150	RFG	0.05016	0.01106
NLEV	LDV	No IM	150	RFG	0.06201	0.01740
Tier 2	LDT1	IM	150	RFG	0.03424	0.01787

Tier 2	LDT1	No IM	150	RFG	0.06180	0.03192
Tier 2	LDT2	IM	150	RFG	0.03157	0.01780
Tier 2	LDT2	No IM	150	RFG	0.06047	0.03187
Tier 2	LDT3	IM	150	RFG	0.04274	0.02066
Tier 2	LDT3	No IM	150	RFG	0.07544	0.03703
Tier 2	LDT4	IM	150	RFG	0.04667	0.02089
Tier 2	LDT4	No IM	150	RFG	0.08032	0.03728
Tier 2	LDV	IM	150	RFG	0.02170	0.01106
Tier 2	LDV	No IM	150	RFG	0.03386	0.01740
NLEV	LDT1	IM	300	RFG	0.09463	0.01901
NLEV	LDT1	No IM	300	RFG	0.12597	0.03297
NLEV	LDT2	IM	300	RFG	0.10225	0.02147
NLEV	LDT2	No IM	300	RFG	0.12671	0.03586
NLEV	LDT3	IM	300	RFG	0.16546	0.05410
NLEV	LDT3	No IM	300	RFG	0.19134	0.07062
NLEV	LDT4	IM	300	RFG	0.30482	0.06969
NLEV	LDT4	No IM	300	RFG	0.33951	0.08822
NLEV	LDV	IM	300	RFG	0.06330	0.01182
NLEV	LDV	No IM	300	RFG	0.07713	0.01812
Tier 2	LDT1	IM	300	RFG	0.04253	0.01901
Tier 2	LDT1	No IM	300	RFG	0.07537	0.03297
Tier 2	LDT2	IM	300	RFG	0.03909	0.01893
Tier 2	LDT2	No IM	300	RFG	0.07357	0.03291
Tier 2	LDT3	IM	300	RFG	0.05307	0.02197
Tier 2	LDT3	No IM	300	RFG	0.09198	0.03822
Tier 2	LDT4	IM	300	RFG	0.05802	0.02221
Tier 2	LDT4	No IM	300	RFG	0.09802	0.03848
Tier 2	LDV	IM	300	RFG	0.02709	0.01182
Tier 2	LDV	No IM	300	RFG	0.04157	0.01812
NLEV	LDT1	IM	300	Conventional	0.09718	0.02232
NLEV	LDT1	No IM	300	Conventional	0.12925	0.03887
NLEV	LDT2	IM	300	Conventional	0.10502	0.02520
NLEV	LDT2	No IM	300	Conventional	0.13003	0.04227
NLEV	LDT3	IM	300	Conventional	0.16996	0.06339
NLEV	LDT3	No IM	300	Conventional	0.19639	0.08304
NLEV	LDT4	IM	300	Conventional	0.30513	0.07907
NLEV	LDT4	No IM	300	Conventional	0.33962	0.10044
NLEV	LDV	IM	300	Conventional	0.06501	0.01386
NLEV	LDV	No IM	300	Conventional	0.07916	0.02134
Tier 2	LDT1	IM	300	Conventional	0.04366	0.02232
Tier 2	LDT1	No IM	300	Conventional	0.07729	0.03887
Tier 2	LDT2	IM	300	Conventional	0.04012	0.02222
Tier 2	LDT2	No IM	300	Conventional	0.07544	0.03880
Tier 2	LDT3	IM	300	Conventional	0.05446	0.02579
Tier 2	LDT3	No IM	300	Conventional	0.09432	0.04507
Tier 2	LDT4	IM	300	Conventional	0.05956	0.02608
Tier 2	LDT4	No IM	300	Conventional	0.10052	0.04538
Tier 2	LDV	IM	300	Conventional	0.02781	0.01386
Tier 2	LDV	No IM	300	Conventional	0.04264	0.02134

NLEV	LDT1	IM	800	Conventional	0.13343	0.02424
NLEV	LDT1	IM	800	RFG	0.12953	0.02061
NLEV	LDT1	No IM	800	Conventional	0.18824	0.04059
NLEV	LDT1	No IM	800	RFG	0.16619	0.03424
NLEV	LDT2	IM	800	Conventional	0.11983	0.02668
NLEV	LDT2	IM	800	RFG	0.11660	0.02271
NLEV	LDT2	No IM	800	Conventional	0.14896	0.04306
NLEV	LDT2	No IM	800	RFG	0.14218	0.03688
NLEV	LDT3	IM	800	Conventional	0.18512	0.07818
NLEV	LDT3	IM	800	RFG	0.17755	0.06646
NLEV	LDT3	No IM	800	Conventional	0.22195	0.09850
NLEV	LDT3	No IM	800	RFG	0.20478	0.08046
NLEV	LDT4	IM	800	Conventional	0.28329	0.09441
NLEV	LDT4	IM	800	RFG	0.27546	0.08026
NLEV	LDT4	No IM	800	Conventional	0.30934	0.11431
NLEV	LDT4	No IM	800	RFG	0.30272	0.09452
NLEV	LDV	IM	800	Conventional	0.08982	0.01517
NLEV	LDV	IM	800	RFG	0.08723	0.01291
NLEV	LDV	No IM	800	Conventional	0.11664	0.02264
NLEV	LDV	No IM	800	RFG	0.10329	0.01903
Tier 2	LDT1	IM	800	Conventional	0.05863	0.02470
Tier 2	LDT1	IM	800	RFG	0.05683	0.02055
Tier 2	LDT1	No IM	800	Conventional	0.11031	0.04041
Tier 2	LDT1	No IM	800	RFG	0.09735	0.03416
Tier 2	LDT2	IM	800	Conventional	0.05357	0.02459
Tier 2	LDT2	IM	800	RFG	0.05191	0.02045
Tier 2	LDT2	No IM	800	Conventional	0.10723	0.04033
Tier 2	LDT2	No IM	800	RFG	0.09464	0.03413
Tier 2	LDT3	IM	800	Conventional	0.07307	0.02848
Tier 2	LDT3	IM	800	RFG	0.07083	0.02369
Tier 2	LDT3	No IM	800	Conventional	0.13467	0.04681
Tier 2	LDT3	No IM	800	RFG	0.11874	0.03979
Tier 2	LDT4	IM	800	Conventional	0.08008	0.02883
Tier 2	LDT4	IM	800	RFG	0.07763	0.02398
Tier 2	LDT4	No IM	800	Conventional	0.14375	0.04714
Tier 2	LDT4	No IM	800	RFG	0.12673	0.04006
Tier 2	LDV	IM	800	Conventional	0.03766	0.01556
Tier 2	LDV	IM	800	RFG	0.03653	0.01293
Tier 2	LDV	No IM	800	Conventional	0.06155	0.02244
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

APPENDIX VI-C :Aggregate Annual Tons and Costs

	NOx (tons)	*VOC (tons)*	*PM10 (tons)*	*SOx (tons)*	*Fuel cost ($Million)*	*Vehicle costs ($Million)*
2004	338,231	85,688	14,127	123,849	1,618	269
2005	469,037	91,310	17,307	147,096	1,819	531
2006	748,269	136,232	22,865	189,462	2,268	834
2007	856,471	143,507	23,427	193,779	2,302	1,383
2008	977,740	153,281	24,049	198,127	2,526	1,556
2009	1,105,762	165,486	24,609	202,374	2,555	1,578
2010	1,235,882	178,886	25,131	206,480	2,553	1,500
2011	1,364,290	191,563	25,728	210,601	2,577	1,432
2012	1,488,166	204,728	26,275	214,688	2,600	1,362
2013	1,605,738	217,743	26,836	218,668	2,623	1,354
2014	1,715,040	230,828	27,404	222,591	2,645	1,351
2015	1,816,767	244,080	27,950	226,458	2,648	1,357
2016	1,911,270	256,575	28,504	230,288	2,670	1,364
2017	1,998,345	269,066	29,042	234,068	2,690	1,371
2018	2,078,026	281,325	29,607	237,813	2,710	1,378
2019	2,151,690	293,408	30,144	241,517	2,161	1,385
2020	2,220,210	305,470	30,685	245,179	2,153	1,392
2021	2,284,625	315,447	31,220	248,825	2,134	1,399
2022	2,345,739	325,009	31,762	252,461	2,166	1,406
2023	2,404,807	334,331	32,288	256,049	2,200	1,413
2024	2,461,670	343,560	32,813	259,638	2,233	1,420
2025	2,523,034	352,415	33,339	263,215	2,266	1,427
2026	2,573,768	361,364	33,864	266,785	2,299	1,434
2027	2,623,506	370,210	34,390	270,347	2,332	1,441
2028	2,693,468	384,152	34,944	273,906	2,365	1,448
2029	2,745,571	392,438	35,474	277,462	2,398	1,456
2030	2,795,551	400,968	36,004	281,016	2,431	1,463
2031	2,853,945	411,917	36,540	284,581	2,464	1,470
2032	2,911,214	422,174	37,078	288,138	2,497	1,478
2033	2,967,538	432,141	37,614	291,695	2,530	1,485
2034	3,020,448	441,308	38,146	295,253	2,563	1,492

Chapter VI References

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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.

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6. “Development of Light-Duty Emission Inventory Estimates in the Notice of 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 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

This chapter reports EPA's analysis of the economic benefits of the final Tier 2/Gasoline Sulfur rulemaking reducing air pollution from mobile sources. EPA is required by Executive Order 12866 to estimate the benefits of major new pollution control regulations. The analysis presented here attempts to answer three questions: 1) what are the physical effects of changes in ambient air quality resulting from reductions in NOx and SO_2 emissions?; 2) how much are the changes in air quality worth to U.S. citizens as a whole in monetary terms?; and 3) how do the benefits compare to the costs? It constitutes one part of EPA's thorough examination of all aspects of the relative merits of regulatory alternatives.

The BCA that we performed for our final rule 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 ozone and particulate matter (PM) that will result from our proposed standards.

3. A benefits analysis to determine the changes in human health and welfare, both in terms of physical effects and monetary value, that result from the changes in ambient concentrations of various pollutants.

4. Calculation of the costs of the standards for purposes of comparison to the monetized benefits.

EPA has used the best available information and tools of analysis to quantify the expected changes in public health and environment and the economic benefits of the final Tier 2/Gasoline Sulfur rule, given the constraints on time and resources available for the analysis. We have attempted to be as clear as possible in presenting our assumptions, sources of data, and sources of potential uncertainty in the analysis. We urge the reader to particularly pay attention to the fact that not all the benefits of the rule can be estimated with sufficient reliability to be quantified and included in monetary terms. The omission of these items from the total of monetary benefits reflects our inability to measure them. It does not indicate their lack of importance in the consideration of the benefits of this rulemaking. When it is possible to qualitatively characterize a benefits category, we provide a discussion, although the benefit is not included in the estimate of total benefits.

We use the term benefits to refer to any and all positive effects of emissions changes on

social welfare that we expect to result from the final rule. We use the term environmental costs (also commonly referred to as "disbenefits") to refer to any and all negative effects of emissions changes in social welfare that result from the final rule. Where it is possible to quantify benefits and environmental costs, our measures are those associated with economic surplus in accepted applications of welfare economics. They measure value by estimating (primarily through benefits transfer) the willingness of the affected population to pay for changes in environmental quality and associated health and welfare effects.

This analysis presents estimates of the potential benefits from the Tier 2/Gasoline Sulfur rule occurring in 2030. The emissions reductions that will result from the Tier 2/Gasoline Sulfur rule have of course not actually occurred yet. The actual changes in human health and welfare outcomes to which economic values are ascribed are predictions. These predictions are based on the best available scientific evidence and judgment, but there is unavoidable uncertainty associated with each step in the complex process between regulation and specific health and welfare outcomes. The ways in which we deal with these uncertainties are discussed in Section C.

Figure VII-1 illustrates the steps necessary to link the Tier 2/Gasoline Sulfur rule with economic measures of benefits. The first two steps involve the specification and implementation of the regulation. First, the specific standards for reducing air pollution from mobile sources are established. Next, the necessary changes in vehicle technology and fuels are determined (see Chapters IV and V). The changes in pollutant emissions resulting from the hypothesized vehicle and fuel changes are then calculated for input into an air quality model, along with predictions of emissions for other industrial sectors in the baseline. Next, the predicted emissions are used as inputs to air quality models that predict ambient concentrations of pollutants over time and space. These concentrations depend on climatic conditions and complex chemical interactions. We have used the best available air quality models to estimate the changes in ambient concentrations (from baseline levels) that are used as the basis for this benefits analysis.

The predicted changes in ambient air quality then serve as inputs into functions to predict changes in health and welfare outcomes. We use the term "endpoints" to refer to specific effects that can be associated with changes in air quality. Table VII-1 lists the human health and welfare effects identified for ozone, PM, CO, and hazardous air pollutants (HAP). This list includes both those effects quantified (and/or monetized) in this analysis and those for which we are unable to provide quantified estimates. All of the effects related to CO and HAPs are not quantified for this analysis due to a lack of appropriate air quality models for these pollutants. For changes in risks to human health from ozone and PM, quantified endpoints include changes in mortality and in a number of pollution-related non-fatal health effects. To estimate these endpoints, EPA combines changes in ambient air quality levels with clinical and epidemiological evidence about population health response to pollution exposure. For welfare effects, the endpoints are defined in terms of levels of physical damage (for materials damage), economic output (agriculture and forestry),

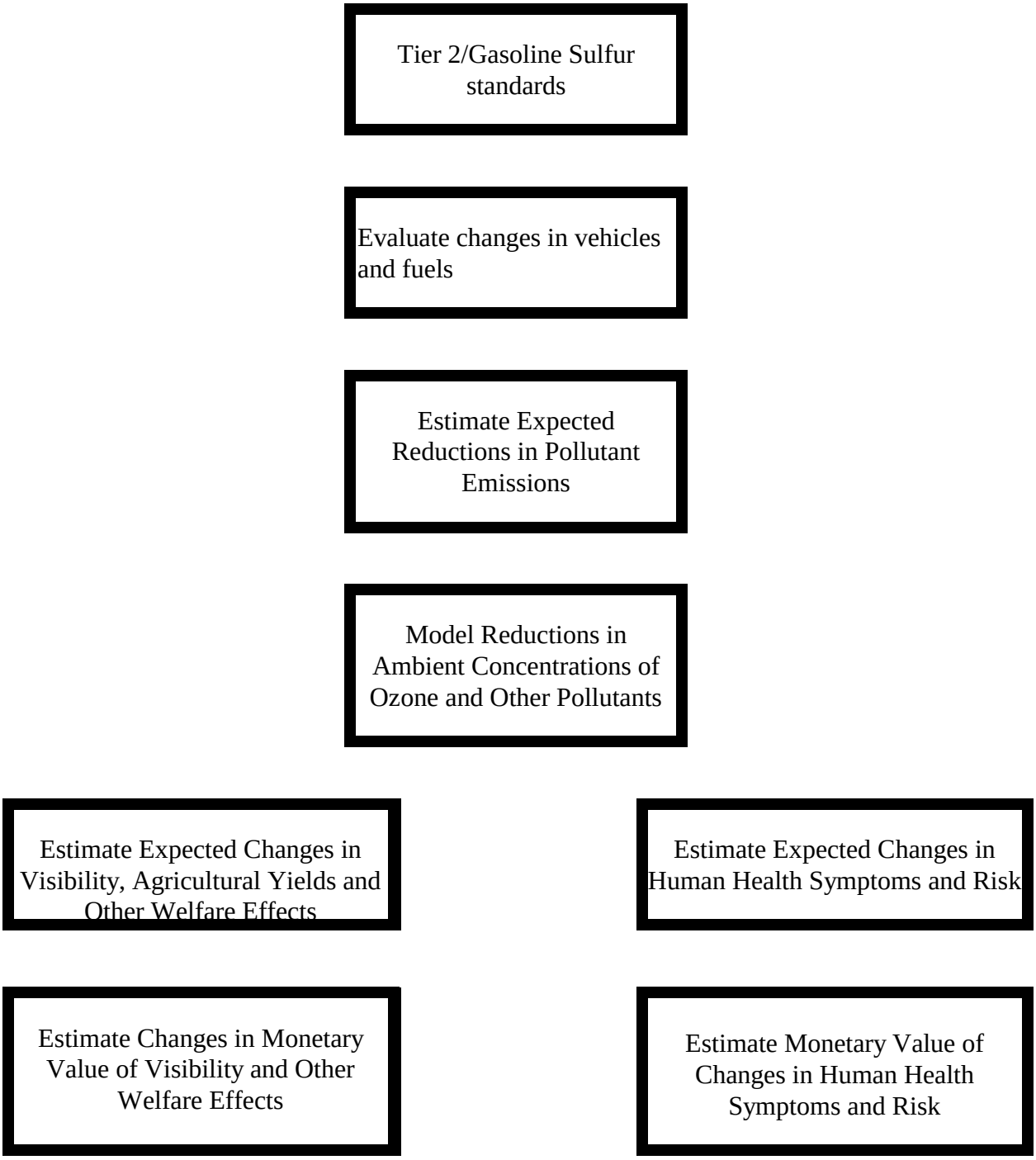

Figure VII-1
Steps in the Tier 2/Gasoline Sulfur Benefits Analysis

Table VII-1. Human Health and Welfare Effects of Pollutants Affected by the Tier 2/Gasoline Sulfur Rule

Pollutant	Primary Quantified and Monetized Effects	Alternative Quantified and/or Monetized Effects	Unquantified Effects
Ozone Health	Chronic asthma[a] Minor restricted activity days/acute respiratory symptoms Hospital admissions - respiratory and cardiovascular Emergency room visits for asthma		Premature mortality[b] Increased airway responsiveness to stimuli Inflammation in the lung Chronic respiratory damage Premature aging of the lungs Acute inflammation and respiratory cell damage Increased susceptibility to respiratory infection Non-asthma respiratory emergency room visits
Ozone Welfare	Decreased worker productivity Decreased yields for commercial crops		Decreased yields for commercial forests Decreased yields for fruits and vegetables Decreased yields for non-commercial crops Damage to urban ornamental plants Impacts on recreational demand from damaged forest aesthetics Damage to ecosystem functions
PM Health	Premature mortality Bronchitis - chronic and acute Hospital admissions - respiratory and cardiovascular Emergency room visits for asthma Lower and upper respiratory illness Shortness of breath Minor restricted activity days/acute respiratory symptoms Work loss days		Infant mortality Low birth weight Changes in pulmonary function Chronic respiratory diseases other than chronic bronchitis Morphological changes Altered host defense mechanisms Cancer Non-asthma respiratory emergency room visits
PM Welfare	Visibility in California, Southwestern, and Southeastern Class I areas	Visibility in Northeastern, Northwestern, and Midwestern Class I areas	
Nitrogen and		Costs of nitrogen controls to reduce	Impacts of acidic sulfate and nitrate deposition on

Pollutant	Primary Quantified and Monetized Effects	Alternative Quantified and/or Monetized Effects	Unquantified Effects
CO Health			Premature mortality[b] Behavioral effects Hospital admissions - respiratory, cardiovascular, and other Other cardiovascular effects Developmental effects Decreased time to onset of angina Non-asthma respiratory ER visits
HAPS Health			Cancer (benzene, 1,3-butadiene, formaldehyde, acetaldehyde) Anemia (benzene) Disruption of production of blood components (benzene) Reduction in the number of blood platelets (benzene) Excessive bone marrow formation (benzene) Depression of lymphocyte counts (benzene) Reproductive and developmental effects (1,3-butadiene) Irritation of eyes and mucus membranes (formaldehyde) Respiratory irritation (formaldehyde) Asthma attacks in asthmatics (formaldehyde) Asthma-like symptoms in non-asthmatics (formaldehyde) Irritation of the eyes, skin, and respiratory tract (acetaldehyde)
HAPS Welfare			Direct toxic effects to animals Bioaccumlation in the food chain

[a] While no causal mechanism has been identified linking new incidences of chronic asthma to ozone exposure, a recent epidemiological study shows a statistical association between long-term exposure to ozone and incidences of chronic asthma in some non-smoking men, but not in women.
[b] Premature mortality associated with ozone is not separately included in this analysis. It is assumed that the Pope, et al. C-R function for premature mortality captures both PM mortality benefits and any mortality benefits associated with other air pollutants.

light transmission (for visibility), and increases in terrestrial and estuarine nutrient loading (for ecological effects).

As with emissions and air quality estimates, EPA's estimates of the effect of ambient pollution levels on all of these endpoints represent the best science available to the Agency. The majority of the analytical assumptions used to develop our estimates have been reviewed and approved by the EPA Science Advisory Board. However, like all estimates, they also contain unavoidable uncertainty, as does any prediction of the future. In Section C and in the subsections on health and welfare endpoints, this uncertainty is discussed and characterized.

This chapter proceeds as follows: Sections A and B summarize emissions and air quality results and discuss the way that emissions and air quality changes are used as inputs to the benefits analysis. Section C introduces the kinds of benefits that are estimated, presents the techniques that are used, and provides a discussion of how we incorporate uncertainty into our analysis. In Section D, we describe individual health effects and report the results of the analysis for human health effects. In Section E, we describe individual welfare effects and report the results of the analysis for welfare effects. Section F reports our estimates of total monetized benefits and alternative calculations. Finally, Section G presents a comparison of monetized benefits and costs.

A. Emissions

In order to determine the air quality impact of the Tier 2 program, 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[1] inventories for NOx, NMHC, SO2, and PM. This Section describes how these inventory impacts were determined.

At proposal, we evaluated the impact of the Tier 2 program using a 1990 emissions inventory from the CAA Section 812 study (Ref.), and considered the effect of full-fleet turnover that was expected to occur well into the future on populations estimated for 2010. This approach to the analysis was necessary because at the time of proposal, we had no available baseline data set beyond the year 2010, since the Section 812 inventory was developed only for this year. The analysis at proposal, 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 the final rule's analysis, we have enhanced the analysis significantly. We updated the emissions inventory to reflect new CAA programs and changes in inventories through the year 1996. We then evaluated the impact

[1] 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.

of the program in 2030 and on 2030 populations.

The inventories developed for our air quality assessment and for the benefit-cost analysis have already been presented and discussed in Chapter III and in the supporting documents referenced in that chapter. Interested readers desiring more information about the inventory methodologies or results should consult that chapter for details.

The Tier 2/gasoline sulfur program 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. Because of this inconsistency and our desire to more appropriately match the costs and emission reductions of our proposed program, our analysis uses a future year when the fleet is nearly fully turned over. For today's rule this stability does not occur until well into the future. For the purpose of the benefit calculations, we assume that 2030 is a representative year to consider in comparison with the costs.

The resulting analysis represents a snapshot of benefits and costs in a future year in which the light-duty fleet consists almost 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 because of growth in vehicle miles traveled and population.) 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).

B. Air Quality Impacts

In Chapter III, we described the Tier 2 program's impact on air quality in 2007. The 2007 analysis shows the initial impact of the rule on area that must attain the NAAQS by 2007. Using this information the Agency provides its justification for the need for the rule. For purposes of the benefit-cost analysis, EPA prepared a second air quality analysis to evaluate the impact of the rule after it is fully implemented (i.e., when all on-highway vehicles are expected to be compliant with the new Tier 2 controls). We chose 2030 as this analytical year reflecting full-fleet turnover and, thus, all costs are realized as well as most benefits.[2]

This section summarizes the methods for and results of estimating air quality for the 2030

[2] We recognize that program costs and benefits will continue to accrue as new vehicles are purchased.

base case and Tier 2 control scenario. EPA has focused on the air quality changes that have been linked to health, welfare, and ecological effects. These air quality changes include the following:

- Ambient ozone–as estimated using a regional-scale version of the Urban Airshed Model (UAM-V),

- Ambient particulate matter (PM_{10} and $PM_{2.5}$)–as projected from a Source-Receptor Matrix (S-R Matrix) based on the Climatological Regional Dispersion Model (CRDM),

- Airborne nitrogen deposition–as predicted using local and regional coefficients of nitrogen deposition for selected estuaries from the Regional Acid Deposition Model (RADM) in combination with modeled reduction in NOx emissions, and

- Visibility degradation (i.e., regional haze), as developed using empirical estimates of light extinction coefficients and efficiencies in combination with modeled reductions in pollutant concentrations.

The air quality estimates in this section are based on the emission changes discussed in Section A. Using the methods identified and described in Section C, the air quality impacts listed above are then associated with human populations and ecosystems to estimate changes in health and welfare effects.

The air quality analysis used in the benefits estimation at proposal was based on results from the UAM-V and S-R Matrix models to estimate 1990 baseline and 2010 base case air quality for ozone and particulate matter, respectively. We then applied the Tier 2 control scenario to the 2010 estimates to derive the associated air quality changes. For the final rule's analysis, we updated all aspects of the analysis by estimating 1996 baseline (rather than 1990) and 2030 base case air quality (rather than using 2010 as a surrogate for full-implementation of the program). We applied the same Tier 2 control scenario (i.e., same level of stringency and control) as was used at proposal and evaluated the impact on 2030 air quality (using 2030 VMT and population projections). These updates to the analysis have augmented the preliminary benefit-cost analysis provided at proposal.

Section VII.B.1 describes the estimation of ozone air quality using UAM-V, while Section VII.B.2 covers the estimation of PM air quality using the CRDM S-R Matrix. Section VII.B.3 discusses the estimation of nitrogen deposition. Lastly, Section VII.B.4 covers the estimation of visibility degradation.

1. Ozone Air Quality Estimates

We use the previously described emissions inputs with a regional-scale version of UAM-V to estimate ozone air quality. UAM-V is an "eulerian" three-dimensional grid photochemical air quality model designed to calculate the concentrations of both inert and chemically reactive pollutants by simulating the physical and chemical processes in the atmosphere that affect ozone formation. 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 impacts of the Tier 2 rule on U.S. ozone concentrations.[3] Our analysis applies the modeling system for a base-year of 1996 and for two future-year scenarios: a 2030 base case and a 2030 Tier 2 control scenario. As discussed later, we use the two separate years because ambient air quality observations from 1996 are used to calibrate the model. These results are used solely in the benefits analysis and are not used as part of the justification for the rule. A 2007-based analysis described in Chapter III is used for that purpose.

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 continental United States into two regions: East and West. It then segments the area in each region into square blocks called grids (roughly equal in size to counties), 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 calibrate the results of this process to develop 2030 ozone profiles at monitor sites by normalizing the observations to the actual 1996 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 to the health and welfare concentration-response (C-R) functions of the benefits analysis. The following sections provide a more detailed discussion of each of the steps in this evaluation and a summary of the results.

a. Modeling Domain

The modeling domain representing the eastern U.S. is the same as that used in EPA's "Regulatory Impact Analysis for the NO_x SIP Call, FIP, and Section 126 Petitions" (EPA, 1998b). As shown in Figure VII-2, this domain encompasses most of the eastern U.S. from the east-coast to mid-Texas and consists of two grids with differing resolutions. The shaded area of Figure VII-2 uses a relatively fine grid of 12 km consisting of seven vertical layers. The unshaded area of Figure VII-2 has less resolution, as it uses a 36 km grid consisting of five

[3]Douglas and Iwamiya (1999) provide further information on the UAM-V modeling used in this analysis.

vertical layers. The vertical height of the modeling domain is 4,000 meters above ground level, for both the shaded and unshaded regions.

The modeling domain used to obtain results for the western U.S. comprises the entire contiguous 48 states. Even though the modeling domain covers the entire United States, the modeling results are only used for benefit analysis of western U.S. locations (i.e., within the region not shown in Figure VII-2). 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 approximately 56 km (or 2/3 longitude by ½ latitude) resulting in a 90 by 56 grid for each vertical layer, with eight vertical layers in all. The smaller 36 km and 12 km resolution for the eastern U.S. runs better capture the photochemical processes for that region.

b. Simulation Periods

A simulation period, or episode, consists of meteorological data characterized over a block of days that are used as inputs to the air quality model. A simulation period is selected to characterize a variety of ozone conditions including some days with high ozone concentrations in one or more portions of the U.S. and observed exceedances of the 1-hour NAAQS for ozone being recorded at monitors. This study used four multi-day simulation periods to prepare the future-year ozone profiles. For the eastern U.S. ozone analysis, we modeled two simulation periods: July 12-24 and July 5-15, 1995. For the western U.S. analysis, the simulation periods were July 5-15 and July 18-31, 1996. These episodes include a 2-3 day “ramp-up” period to initialize the model, but the results for these days are not used in this analysis.

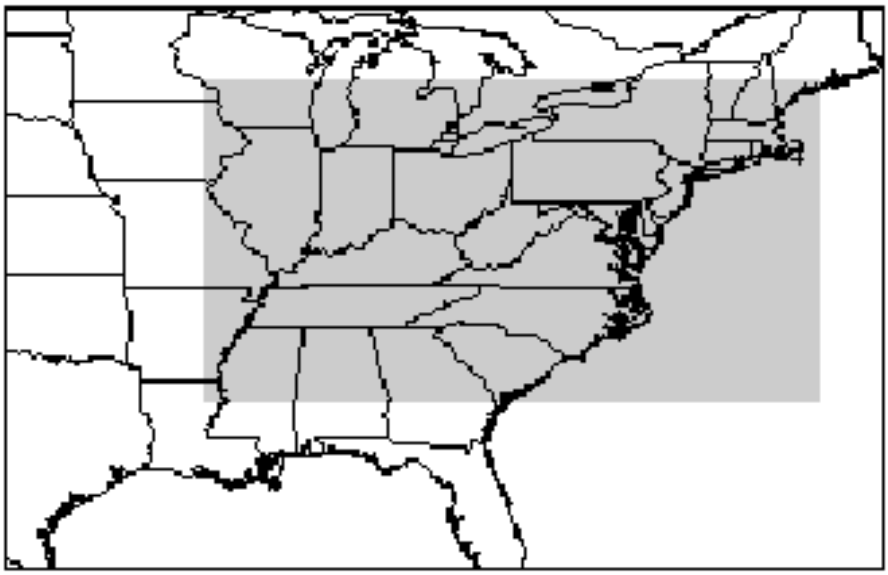

Figure VII-2. UAM-V Modeling Domain for Eastern U.S.

c. Converting UAM-V Outputs to Full-Season Profiles for Benefits Analysis

This study extracted hourly, surface-layer ozone concentrations for each grid-cell from the standard UAM-V output file containing hourly average ozone values. These model predictions are used in conjunction with the observed concentrations as obtained from the Aerometric Information Retrieval System (AIRS) to generate ozone concentrations for the entire ozone season.[4,5] The predicted changes in ozone concentrations from the 2030 basecase to 2030 policy scenario serve as inputs to the health and welfare concentration-response (C-R) functions of the benefits analysis, i.e., the Criteria Air Pollutant Modeling System (CAPMS). In order to estimate ozone-related health and welfare effects for the entire United States, full-season ozone data is required for every CAPMS grid-cell. Given available ozone monitoring data, we generated full-season ozone profiles for each location in the contiguous 48 states in two steps: (1) we combine monitored observations and modeled ozone predictions to interpolate hourly ozone concentrations to a grid of eight km by eight km population grid-cells, and (2) we converted these full-season hourly ozone profiles to an ozone measure of interest, such as the daily average [6,7] For the analysis of ozone impacts on agriculture, we use a similar approach except air quality is interpolated to county centroids as opposed to population grid-cells. Each approach is fully detailed in Abt Associates (1999).

d. Ozone Air Quality Results

Table VII-2 provides a summary of the predicted ambient ozone concentrations from the UAM-V model for the 2030 base case and changes associated with Tier 2 control scenario. As shown, the mean seasonal average ozone concentrations across all U.S. population grid-cells declines by almost 2 percent, or 0.6 ppb. A similar relative decline is predicted for the population-weighted average, which indicates rather uniform reductions in these concentrations across urban and rural areas. The impact of Tier 2 on seasonal SUM06 ozone metric are significantly greater with the average across all U.S. counties declining by almost 26 percent, or

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[4] The ozone season for this analysis is defined as the 5-month period from May to September; however, to estimate certain crop yield benefits the modeling results were extended to include months outside the 5-month ozone season.

[5] Based on AIRS, there were 949 ozone monitors with sufficient data, i.e., at least 9 hourly observations per day (8 am to 8 pm) in a given season.

[6] The 8 km grid squares contain the population data used in the health benefits analysis model, CAPMS. See Section C of this chapter for a discussion of this model.

[7] This approach is a generalization of planar interpolation that is technically referred to as enhanced Voronoi Neighbor Averaging (VNA) spatial interpolation (See Abt Associates (1999) for a more detailed description).

2.2 ppb. Alternatively, although the absolute change predicted for the population-weighted is similar to that for the simple average (i.e., 2.4 ppb versus 2.2 ppb), the relative change is less at 12.4 percent because of higher observed baseline values for this ozone metric.

Table VII-2. Summary of UAM-V Derived Hourly Ozone Air Quality for 2030 Base Case and Change Due to Tier 2 Standards

Statistic [a]	*2030 Base Case*	*Change* [b]	*Percent Change* [b]
Seasonal Average (ppb)			
Minimum [c]	11.98	-0.51	-4.26%
Maximum [c]	77.23	-0.16	-0.20%
Average	29.85	-0.59	1.98%
Median	29.45	-0.50	-1.69%
Population-Weighted Average [d]	29.80	-0.47	1.57%
Seasonal SUM06 (ppb)			
Minimum [c]	0.00	0.00	0.00%
Maximum [c]	118.58	-9.72	-8.20%
Average	8.31	-2.20	-26.48%
Median	4.97	-2.33	-46.88%
Population-Weighted Average [d]	19.60	-2.44	-12.43%

[a] The seasonal average and SUM06 are calculated at the CAPMS gridcell level and at the county level, respectively. There are at two levels since health effects estimates are generated at each CAPMS gridcell, and agricultural benefits (which require SUM06) are generated at the county level. Both ozone measures are based on the results of enhanced spatial interpolation. The seasonal average is the average over all hours in May through September. SUM06 is defined as the cumulative sum of hourly ozone concentrations over 0.06 ppb that occur during daylight hours (from 8am to 8pm) in the months of May through September.

[b] The change is defined as the control case value minus the base case value. The percent change is the "Change" divided by the "2030 Base Case."

[c] The base case minimum (maximum) is the value for the CAPMS gridcell with the lowest (highest) seasonal average.

[d] Calculated by summing the product of the projected 2030 CAPMS gridcell population and the estimated 2030 CAPMS gridcell seasonal ozone concentration, and then dividing by the total population. The SUM06 estimates are calculated analogously at the county level.

2. PM Air Quality Estimates

EPA used the previously described emissions inputs with a national-scale S-R Matrix based on CRDM to evaluate the effects of the Tier 2 rule on ambient concentrations of both PM_{10} and $PM_{2.5}$. Ambient concentrations of PM are composed of directly emitted particles and of secondary aerosols of sulfate, nitrate, ammonium, and organics. Relative to more sophisticated and resource-intensive three-dimensional modeling approaches, the CRDM and its associated S-R Matrix do not fully account for all the complex chemical interactions that take place in the atmosphere in the secondary formation of PM. Instead it relies on more simplistic species dispersion–transport mechanisms supplemented with chemical conversion at the receptor location.

The S-R Matrix consists of fixed-coefficients that reflect the relationship between annual average PM concentration values at a single receptor in each county (i.e., 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 as well as receptors in 10 Canadian provinces and 29 Mexican cities/states. The methodology used in this RIA for estimating PM air quality concentrations is detailed in Pechan-Avanti (1999) and is similar to the method used in the July 1997 PM and Ozone NAAQS RIA (U.S. EPA, 1997e) and the RIA for the final Regional Haze Rule (U.S. EPA, 1999). The following sections summarize the steps taken to apply the S-R Matrix for this analysis and to derive the resulting changes in PM air quality.

a. Development of the S-R Matrix

The S-R Matrix was developed using the CRDM, which uses assumptions similar to the Industrial Source Complex Short Term model (ISCST3), an EPA-recommended short range Gaussian dispersion model. The 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. Meteorological data for 1990 coupled with emissions data from version 2.0 of the 1990 National Particulate Inventory (NPI) were used with CRDM to develop the S-R Matrix.

The NPI was separated into 5,944 sources (i.e., industrial point, utility, area, nonroad, and motor vehicle) of primary and precursor emissions. Each individual unit in the inventory was associated with one of four modeled source types (i.e., area, point sources with effective stack height of 0 to 250m or 250m to 500m, and individual point sources with effective stack height above 500m) for each county. Emissions that were modeled include SO_2, NO_x, and ammonia, which are needed to calculate ammonium sulfate and ammonium nitrate concentrations; VOC, which are needed to calculate secondary organic aerosols; and directly emitted PM_{10} and $PM_{2.5}$.

Both anthropogenic and natural sources of each species were included.

The resulting transfer coefficients are adjusted to account for the chemical balance between sulfate, nitric acid, and ammonium (Latimer, 1996). The coefficients for SO_2, NO_x, and ammonia were multiplied 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.[8] In the presence of sulfate and nitric acid (the gas phase oxidation product of NOx), ammonia reacts preferentially with sulfate to form particulate ammonium sulfate rather than react with nitric acid to form particulate ammonium nitrate. So, ammonium nitrate forms under conditions of excess ammonium, and only under relatively low temperatures. Accordingly, for each county receptor, the sulfate-nitrate-ammonium equilibrium is estimated based on the following simplifying assumptions:

1. All sulfate is neutralized by ammonium;
2. Ammonium nitrate forms only when there is excess ammonium;
3. Average annual particle nitrate concentrations are divided by four assuming that sufficiently low temperatures are present only one-quarter of the year.

The total particle mass of ammonium sulfate and ammonium nitrate is calculated by multiplying the anion concentrations of sulfate and nitrate by 1.375 and 1.290 respectively.

b. Fugitive Dust Adjustment Factor

As demonstrated in the RIA for the PM and Ozone NAAQS (U.S. EPA, 1997e), 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; however, monitoring data from the IMPROVE network show that minerals (i.e., crustal material) comprise only about five percent of $PM_{2.5}$ mass in the East and roughly 15 percent of $PM_{2.5}$ mass in the West (U.S. EPA, 1996a). 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 NPI significantly overestimates fugitive dust emissions. A comparison with a more 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[9] (U.S. EPA, 1997c).

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[8] Ratio of molecular weights: Sulfate/SO_2= 1.50; nitrate/nitrogen dioxide = 1.35; ammonium/ammonia = 1.06.

[9] 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 1997 version of the National Emission Trends Inventory.

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_{10} and $PM_{2.5}$ and actual ambient data. This adjustment results in a fugitive dust contribution to modeled ambient $PM_{2.5}$ concentrations of 10 percent to 17 percent.[10] 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 brings the modeled fugitive dust contribution to $PM_{2.5}$ mass more 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 in some locations.

c. Normalizing S-R Matrix Results to Observed Data

In an attempt to further ensure comparability between S-R Matrix results and measured annual average PM values, we also calibrated these results to observed monitoring data 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 based on monitoring data from 1993 to 1995 for PM_{10} from the AIRS database.[11] This calibration procedure was applied to all S-R Matrix predictions, regardless of overprediction or underprediction relative to monitored values, and equally across all particle species contributing to the annual average PM value at a county-level receptor. 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}.[12]

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[10] 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.

[11] 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. Tier 4 covers the remaining 2369 non-monitored counties.

[12] 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).

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 monitored 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 the S-R Matrix model predictions of annual average $PM_{2.5}$.

d. PM Air Quality Results

Table VII-3 provides a summary of the predicted ambient PM_{10} and $PM_{2.5}$ concentrations from the S-R Matrix for the 2030 base case and changes associated with Tier 2 control scenario. As shown, the average annual mean concentrations of PM_{10} across all U.S. counties declines by almost 1 percent, or 0.22 g/m^3. The same relative decline is predicted for the population-weighted average for mean PM_{10}, which indicates rather uniform reductions in these concentrations across urban and rural areas. The impact of Tier 2 on $PM_{2.5}$ concentrations are slightly greater with average annual mean concentrations of $PM_{2.5}$ across all U.S. counties declining by almost 2 percent, or 0.22 g/m^3. Similar to PM_{10} concentrations, the relative change predicted for the population-weighted average does not differ much from the spatial average.

Table VII-3. Summary of 2030 Base Case PM Air Quality and Changes Due to Tier 2 Standards

Statistic	*2030 Base Case*	*Change*[a]	*Percent Change*
PM_{10}			
Minimum Annual Mean PM_{10} (g/m^3) [b]	6.64	-0.03	-0.5%
Maximum Annual Mean PM_{10} (g/m^3) [b]	145.11	-0.09	-0.1%
Average Annual Mean PM_{10} (g/m^3)	24.89	-0.22	-0.9%
Median Annual Mean PM_{10} (g/m^3)	23.90	-0.20	-0.6%
Population-Weighted Average Annual Mean PM_{10} (g/m^3) [c]	36.21	-0.31	-0.9%
$PM_{2.5}$			
Minimum Annual Mean $PM_{2.5}$ (g/m^3) [b]	0.86	0.00	0.0%
Maximum Annual Mean $PM_{2.5}$ (g/m^3) [b]	88.47	-0.08	-0.1%
Average Annual Mean $PM_{2.5}$ (g/m^3)	11.93	-0.22	-1.8%
Median Annual Mean PM_{10} (g/m^3)	11.96	-0.20	-1.7%
Population-Weighted Average Annual Mean $PM_{2.5}$ (g/m^3) [c]	15.52	-0.31	-2.0%

[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 is the observed change for the county with the lowest (highest) annual average in the base case.

[c] Calculated by summing the product of the projected 2030 county population and the estimated 2030 county PM concentration, and then dividing by the total population in the 48 contiguous states.

Table VII-4 provides additional insights on the changes in PM air quality resulting from the motor vehicle Tier 2 and fuel standards. This table focuses on the absolute change (in terms of g/m^3) and relative change (in terms of percent) observed across individual U.S. counties. As shown, the absolute reduction in annual mean PM_{10} concentration ranged from a low of 0.01 g/m^3 to and high of 1.25 g/m^3, while the relative reduction ranged from a low of 0.04 percent to a high of 3.3 percent. Alternatively, for mean $PM_{2.5}$, the absolute reduction ranged from zero to 1.23 g/m^3, while the relative reduction ranged from zero to 5.4 percent.

Table VII-4. Summary of Absolute and Relative Changes in PM Air Quality Due to Tier 2 Standards

Statistic	*Absolute Change from 2030 Base Case (g/m^3)* [a]	*Relative Change from 2030 Base Case (%)* [b]
PM_{10}		
Minimum	-0.01	-0.04%
Maximum	-1.25	-3.30%
Average	-0.22	-0.87%
Median	-0.20	-0.94%
Population-Weighted Average [c]	-0.31	-0.91%
$PM_{2.5}$		
Minimum	0.00	0.00%
Maximum	-1.23	-5.42%
Average	-0.22	-1.77%
Median	-0.20	-1.88%
Population-Weighted Average [c]	-0.31	-1.95%

[a] The absolute change is defined as the control case value minus the base case value for each county.

[b] The relative change is defined as the absolute change divided by the base case value, or the percentage change, for each county. The information reported in this column does not necessarily reflect the same county as is portrayed in the absolute change column.

[c] Calculated by summing the product of the projected 2030 county population and the estimated 2030 county PM absolute/relative measure of change, and then dividing by the total population in the 48 contiguous states.

3. Visibility Degradation Estimates

Visibility degradation is often directly proportional to decreases in light transmittal in the atmosphere. Scattering and absorption by both gases and particles decrease light transmittance. To quantify changes in visibility, our analysis computes a light-extinction coefficient, based on the work of Sisler (1996), which shows the total fraction of light that is decreased per unit distance. This coefficient accounts for the scattering and absorption of light by both particles and gases, and accounts for the higher extinction efficiency of fine particles compared to coarse particles. Fine particles with significant light-extinction efficiencies include sulfates, nitrates, organic carbon, elemental carbon (soot), and soil (Sisler, 1996).

Based upon the light-extinction coefficient, we also calculated a unitless visibility index,

called a "deciview," which is 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.

Because the visibility benefits analysis (see Section VII.C) distinguishes between general regional visibility degradation and that particular to Federally-designated Class I areas (i.e., national parks, forests, recreation areas, wilderness areas, etc.), we separated estimates of visibility degradation into "residential" and "recreational" categories. The estimates of visibility degradation for the "recreational" category apply to Federally-designated Class I areas, while estimates for the "residential" category apply to non-Class I areas. Deciview estimates are developed from the estimated county-level changes in particulate matter generated from results of the S-R Matrix for the 2030 base case and Tier 2 control scenarios. These deciview estimates are then aggregated to one of eight regions in the case of the residential category (as defined by the underlying study) and one of six regions in the case of the recreational category (as defined by Class I Visibility Regions described in Section VII.C). More detail on this approach and results may be found in Pechan-Avanti (1999).

Table VII-5 provides a summary of the visibility degradation estimates in terms of deciviews by residential category across U.S. regions. As shown, the national improvement in residential visibility is 1 percent, or 0.23 deciviews. Predicted visibility improvements are the largest for the North Central and Northwest (both at 1.3 percent), the South Central (1.2 percent), and the Southeast (1.1percent). Smaller visibility improvements are predicted in the Southwest (0.5 percent) and the Northeast (0.5 percent).

Table VII-6 provides a summary of the visibility degradation estimates in terms of deciviews for Class I areas (i.e., recreational category) across U.S. visibility regions. As shown, the national improvement in visibility for these areas is 0.6 percent, or 0.12 deciviews. Predicted visibility improvements are the largest for the Northwest (1.4 percent), the Southeast (0.9 percent), and the Northeast/Midwest (0.7 percent). Smaller visibility improvements are predicted in the Southwest (0.3 percent).

Table VII-5. Summary of 2030 Visibility Degradation Estimates by Region: Residential (Annual Average Deciviews)

Study Regions	*2030 Base Case*	*Change*[a]	*Percent Change*
Southeast	23.79	-0.27	-1.1%
Southwest	17.49	-0.09	-0.5%
California	20.91	-0.04	-0.2%
Northeast	24.53	-0.12	-0.5%
North Central	22.52	-0.29	-1.3%
South Central	20.28	-0.24	-1.2%
Rocky Mountain	18.27	-0.16	-0.9%
Northwest	21.08	-0.28	-1.3%
National Average (unweighted)	22.00	-0.23	-1.0%

[a] The change is defined as the control case deciview level minus the base case deciview level.

Table VII-6. Summary of 2030 Visibility Degradation Estimates by Region: Recreational (Annual Average Deciviews)

Class I Visibility Regions	*2030 Base Case*	*Change*[a]	*Percent Change*
Southeast	22.78	-0.20	-0.9%
Southwest	17.61	-0.05	-0.3%
California	20.54	-0.04	-0.2%
Northeast/Midwest	21.34	-0.15	-0.7%
Rocky Mountain	17.80	-0.10	-0.6%
Northwest	22.09	-0.32	-1.4%
National Average (unweighted)	19.99	-0.12	-0.6%

[a] The change is defined as the control case deciview level minus the base case deciview level.

4. Nitrogen Deposition Estimates

This section presents the methods and results of estimating the potential reductions in airborne nitrogen deposition loadings to estuaries associated with the motor vehicle Tier 2 and fuel standards. A sampling of 12 estuaries (10 East Coast and 2 Gulf Coast estuaries) were used for this analysis because of the availability of necessary data and their potential representativeness. For each estuary, we completed the following steps as part of this analysis:

Baseline loadings of atmospherically supplied nitrogen were obtained from data provided in Valigura et al (1996) and from local offices of the Chesapeake Bay Program and the National Estuary Program,

- Deposition from atmospheric emissions were divided into local and regional areas that contribute to airborne nitrogen deposition,

- Deposition coefficients, which relate NOx emission changes from a source region to nitrogen deposition changes at a receptor region, were derived for local and regional contributors, and

- Changes in nitrogen deposition loadings were estimated by multiplying NOx emission changes for the local and regional contributing areas by the appropriate deposition coefficients.

For five of the 12 estuaries, estimates of both direct deposition to the tidal waters and indirect deposition to the entire watershed were available from the literature. For the remaining seven estuaries, only the direct deposition estimates were available. Therefore, to obtain indirect deposition estimates where missing, we used RADM-derived nitrogen flux for the watershed (Dennis, 1997). This analysis assumes that 10 percent of nitrogen deposited onto the watershed is delivered via export (pass-through) to the estuary.[13] This calculated indirect deposition value is then added to the direct deposition value obtained from the literature to arrive at the total load from atmospheric deposition.

As stated in Step 4 above, the nitrogen deposition results are heavily dependent upon the deposition coefficients that estimate the impact of NOx emission changes on nitrogen deposition loadings. For this analysis, two S-R coefficients, an *alpha* and a *beta*, were developed for each estuary. The alpha coefficient relates local emissions to deposition and the beta coefficient relates regional emissions to deposition. These coefficients are calculated for each estuary using

[13] This assumption is consistent with reported case studies such as Valiela et al, 1997. These authors report that 89% of atmospherically deposited nitrogen was retained by the watershed of Waquoit Bay, suggesting an 11% pass through factor.

deposition outputs from RADM as employed for the final Regional NOx SIP Call (EPA, 1998b). More detail on this approach and results may be found in Pechan-Avanti (1999).

Table VII-7 provides a summary of the baseline deposition and change in nitrogen deposition estimates for the selected estuaries as a result of the Tier 2 rule. As shown, implementation of the Tier 2 controls results in a 14.1 percent reduction in the average annual deposition across these estuaries. These predicted reductions range from a low of 10.1 percent for Delaware Inland Bay to a high of 15.5 percent for Long Island Sound.

Table VII-7. Summary of 2030 Nitrogen Deposition in Selected Estuaries and Changes Due to Tier 2 Standards (million kg/year)

Estuary	*2030 Base Case*	*Change*[a]	*Percent Change*
Albemarle/Pamlico Sound	13.20	-1.83	-13.8%
Cape Cod Bay	4.63	-0.65	-14.1%
Chesapeake Bay	20.71	-2.80	-13.5%
Delaware Bay	4.08	-0.57	-14.0%
Delaware Inland Bays	0.59	-0.06	-10.1%
Gardiners Bay	1.44	-0.21	-14.9%
Hudson River/Raritan Bay	4.59	-0.69	-15.1%
Long Island Sound	6.71	-1.04	-15.5%
Massachusetts Bay	1.58	-0.22	-14.2%
Narragansett Bay	1.37	-0.20	-14.3%
Sarasota Bay	0.46	-0.06	-14.1%
Tampa Bay	2.96	-0.44	-14.9%
All Selected Estuaries	62.32	-8.77	-14.1%

[a] Change is defined here as the emissions level after implementing the Tier 2 rule minus the base case emissions.

C. Benefit Analysis

1. Methods for Estimating Benefits from Air Quality Improvements

Environmental and health economists have a number of methods for estimating the economic value of improvements in (or deterioration of) environmental quality. The method used in any given situation depends on the nature of the effect and the kinds of data, time and resources that are available for investigation and analysis. This section provides an overview of the methods EPA selected to monetize the benefits included in the Tier 2/Gasoline Sulfur RIA.

We note at the outset that EPA rarely has the time or resources to perform extensive new research to measure economic benefits for individual rulemakings. As a result, our estimates are based on the best available methods of benefits transfer. Benefits transfer is the science and art of adapting primary benefits research from similar contexts to obtain the most accurate measure of benefits for the environmental quality change under analysis. Where appropriate, adjustments are made for the level of environmental quality change, the sociodemographic and economic characteristics of the affected population, and other factors in order to improve the accuracy and robustness of benefits estimates.

In general, economists tend to view an individual's willingness-to-pay for a improvement in environmental quality as the appropriate measure of the value of a risk reduction. An individual's willingness-to-accept (WTA) compensation for not receiving the improvement is also a valid measure. However, WTP is generally considered to be a more readily available and conservative measure of benefits. Adoption of WTP as the measure of value implies that the value of environmental quality improvements is dependent on the individual preferences of the affected population and that the existing distribution of income (ability to pay) is appropriate.

For many goods, WTP can be observed by examining actual market transactions. For example, if a gallon of bottled drinking water sells for one dollar, it can be observed that at least some persons are willing to pay one dollar for such water. For goods not exchanged in the market, such as most environmental "goods," valuation is not as straightforward. Nevertheless, a value may be inferred from observed behavior, such as sales and prices of products that result in similar effects or risk reductions, (e.g., non-toxic cleaners or bike helmets). Alternatively, surveys may be used in an attempt to directly elicit WTP for an environmental improvement.

One distinction in environmental benefits estimation is between use values and non-use values. Although no general agreement exists among economists on a precise distinction between the two (see Freeman, 1993), the general nature of the difference is clear. Use values are those aspects of environmental quality that affect an individual's welfare more or less directly. These effects include changes in product prices, quality, and availability, changes in the quality of outdoor recreation and outdoor aesthetics, changes in health or life expectancy, and the costs of actions taken to avoid negative effects of environmental quality changes.

Non-use values are those for which an individual is willing to pay for reasons that do not relate to the direct use or enjoyment of any environmental benefit. Non-use values are most frequently divided into two categories: existence values and bequest values. Existence values refer to situations where individuals value (are willing to pay for) the knowledge of an improved environmental state (or avoidance of a deteriorating environmental state) . An example is the willingness to pay (WTP) for the preservation of the blue whale even when an individual has no plan to take a trip to observe the species nor to derive any direct benefit from its survival. Existence values commonly rise from philosophical, ethical, or religious attitudes about the rights of nature and the responsibilities of humans. The other commonly posited category of non-use benefits is bequest value. People are willing to devote resources to environmental preservation because of their perceived obligation or desire to leave higher states of environmental quality to future generations. Bequest values can also be thought of as arising from the philosophical, ethical, and religious beliefs of individuals.

Non-use values are not traded, directly or indirectly, in markets. For this reason, the measurement of non-use values has proved to be significantly more difficult than the measurement of use values. The air quality changes produced by the final Tier 2/Gasoline Sulfur rule cause changes in both use and non-use values, but the monetary benefit estimates are almost exclusively for use values.

More frequently than not, the economic benefits from environmental quality changes are not traded in markets, so direct measurement techniques can not be used. Avoided cost methods are ways to estimate the costs of pollution by using the expenditures made necessary by pollution damage. For example, if buildings must be cleaned or painted more frequently as levels of PM increase, then the appropriately calculated increment of these costs is a reasonable estimate of true economic benefits when PM levels are reduced. A variation on the avoided cost method is used to provide an alternative estimate of the benefits of reductions in nitrogen deposition to estuaries (see Sections C.4 and F). Avoided costs methods are also used to estimate some of the health-related benefits related to morbidity, such as hospital admissions (see section D).

Indirect market methods can also be used to infer the benefits of pollution reduction. The most important application of this technique for our analysis is the calculation of the value of a statistical life for use in the estimate of benefits from mortality reductions. There exists no market where changes in the probability of death are directly exchanged. However, people make decisions about occupation, precautionary behavior, and other activities associated with changes in the risk of death. By examining these risk changes and the other characteristics of people's choices, it is possible to infer information about the monetary values associated with changes in mortality risk (see section D). For measurement of health benefits, this analysis captures the WTP for most use and non-use values, with the exception of the value of avoided hospital admissions, which only captures the avoided cost of illness.

The most direct way to measure the economic value of air quality changes is in cases

where the endpoints have market prices. For the final rule, this can only be done for effects on commercial agriculture and forestry. Well-established economic modeling approaches are used to predict price changes that result from predicted changes in agricultural and forestry outputs. Consumer and producer surplus measures can then be developed to give reliable indications of the benefits of changes in ambient air quality for these categories (see section E).

Estimating benefits for visibility and ecosystem services is a more difficult and less precise exercise because the endpoints are not directly or indirectly valued in markets. For example, the loss of a species of animal or plant from a particular habitat does not have a well-defined price. The contingent valuation method (CVM) has been employed in the economics literature to value endpoint changes for both visibility and ecosystem functions (Chestnut and Dennis, 1997). CVM values endpoints by using carefully structured surveys to ask a sample of people what amount of compensation is equivalent to a given change in environmental quality. There is an extensive scientific literature and body of practice on both the theory and technique of CVM. EPA believes that well-designed and well-executed CVM studies are valid for estimating the benefits of air quality regulation[14].

2. Methods for Describing Uncertainty

In any complex analysis using estimated parameters and inputs from numerous models, there are likely to be many sources of uncertainty[15]. This analysis is no exception. As outlined both in this and preceding chapters, there are many inputs used to derive the final estimate of benefits, including emission inventories, air quality models (with their associated parameters and inputs), epidemiological estimates of concentration-response (C-R) functions, estimates of values (both from WTP and cost-of-illness studies), population estimates, income estimates, and

[14]Concerns about the reliability of value estimates that come from CVM 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 WTP responses are consistent with established economic principles.

[15] It should be recognized that in addition to uncertainty, the annual benefit estimates for the final Tier 2/Gasoline Sulfur rule presented in this analysis are also inherently variable, due to the truly random processes that govern pollutant emissions and ambient air quality in a given year. Factors such as electricity demand and weather display constant variability regardless of our ability to accurately measure them. As such, the estimates of annual benefits should be viewed as representative of the types of benefits that will be realized, rather than the actual benefits that would occur every year.

estimates of the future state of the world (i.e., regulations, technology, and human behavior). Each of these inputs may be uncertain, and depending on their location in the benefits analysis, may have a disproportionately large impact on final estimates of total benefits. For example, emissions estimates are used in the first stage of the analysis. As such, any uncertainty in emissions estimates will be propagated through the entire analysis. When compounded with uncertainty in later stages, small uncertainties in emission levels can lead to much larger impacts on total benefits. A more thorough discussion of uncertainty can be found in the benefits technical support document (TSD) for this RIA, *Tier II Final Rule: Air Quality Estimation, Selected Health and Welfare Benefits Methods, and Benefit Analysis Results* (Abt Associates, 1999).

Some key sources of uncertainty in each stage of the benefits analysis are:

- gaps in scientific data and inquiry
- variability in estimated relationships, such as C-R functions, introduced through differences in study design and statistical modeling
- errors in measurement and projection for variables such as population growth rates
- errors due to misspecification of model structures, including the use of surrogate variables, such as using PM_{10} when $PM_{2.5}$ is not available, excluded variables, and simplification of complex functions
- biases due to omissions or other research limitations.

Some of the key uncertainties in the benefits analysis are presented in Table VII-8. Given the wide variety of sources for uncertainty and the potentially large degree of uncertainty about any primary estimate, it is necessary for us to address this issue in several ways. These include qualitative discussions, probabilistic assessments, and alternative calculations. For some parameters or inputs it may be possible to provide a statistical representation of the underlying uncertainty distribution. For other parameters or inputs, the information necessary to estimate an uncertainty distribution is not available. Even for individual endpoints, there is usually more than one source of uncertainty. This makes it difficult to provide a quantified uncertainty estimate. For example, the C-R function used to estimate avoided premature mortality has an associated standard error which represents the sampling error around the pollution coefficient in the estimated C-R function. It would be possible to report a confidence interval around the estimated incidences of avoided premature mortality based on this standard error. However, this would omit the contribution of air quality changes, baseline population incidences, projected populations exposed, and transferability of the C-R function to diverse locations to uncertainty about premature mortality. Thus, a confidence interval based on the standard error would provide a misleading picture about the overall uncertainty in the estimates. Information on the uncertainty surrounding particular C-R and valuation functions is provided in the benefits TSD for this RIA (Abt Associates, 1999). But, this information should be interpreted within the context of the larger uncertainty surrounding the entire analysis.

Our approach to characterizing model uncertainty in the estimate of total benefits is to present a primary estimate, based on the best available scientific literature and methods, and to then provide alternative calculations to illustrate the effects of uncertainty about key analytical assumptions. We do not attempt to assign probabilities to these alternative calculations, as we believe this would only add to the uncertainty of the analysis or present a false picture about the precision of the results[16]. Instead, the reader is invited to examine the impact of applying the

[16] Some recent benefit-cost analyses in Canada and Europe (Holland, et al., 1999; Lang, et al., 1995) have estimated ranges of benefits by assigning *ad hoc* probabilities to ranges of parameter values for different endpoints. Although this does generate a quantitative estimate of an uncertainty range, the estimated points on these distributions are themselves highly uncertain and very sensitive to the subjective judgements of the analyst. To avoid these subjective judgements, we choose to allow the reader to determine the weights they would assign to alternative estimates.

Table VII-8. Primary 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. -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 literature supporting a direct biological mechanism for observed epidemiological evidence. -Direct causal agents within the complex mixture of PM responsible for reported health effects have not been identified. -The extent to which adverse health effects are associated with low level exposures that occur many times in the year versus peak exposures. -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.
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 underestimated.

different assumptions on the estimate of total benefits. While it is possible to combine all of the alternative calculations with a positive impact on benefits to form a "high" estimate or all of the alternative calculations with a negative impact on benefits to form a "low" estimate, this would not be appropriate because the probability of all of these alternative assumptions occurring simultaneously is extremely low. Instead, the alternative calculations are intended to demonstrate the sensitivity of our benefits results to key parameters which may be uncertain. Alternative calculations are presented in Table VII-18.

Many benefits categories, while known to exist, do not have enough information available to provide a quantified or monetized estimate. The uncertainty regarding these endpoints is such that we could determine neither a primary estimate nor a plausible range of values.

Our estimate of total benefits should be viewed as an approximate result because of the sources of uncertainty discussed above (see Table VII-8). The total benefits estimate may understate or overstate actual benefits of the rule. The remainder of this section describes in greater detail two potential sources of uncertainty that can impact multiple aspects of the analysis: 1) the inability to quantify or monetize many of the benefits and costs associated with the rule; and 2) adjustments for changes in income in the future.

a. Unquantifiable Environmental Benefits and Costs

In considering the monetized benefits estimates, the reader should remain aware of the many limitations for conducting these analyses mentioned throughout this RIA. One significant limitation of both the health and welfare benefits analyses is the inability to quantify many of the PM and ozone-induced adverse effects listed in Table VII-1. For many health and welfare effects, such as PM-related materials damage, reliable C-R functions and/or valuation functions are not currently available. In general, if it were possible to monetize these benefits categories, the benefits estimates presented in this analysis would increase. Unquantified benefits are qualitatively discussed in the health and welfare effects sections. In addition to unquantified benefits, there may also be environmental costs that we are unable to quantify. Several of these environmental cost categories are related to nitrogen deposition, while one category is related to the issue of ultraviolet light. These endpoints are qualitatively discussed in the health and welfare effects sections as well. The net effect of excluding benefit and disbenefit categories from the estimate of total benefits depends on the relative magnitude of the effects.

b. Projected Population and Income Growth

As indicated above, our analysis predicts the benefits of the Tier 2/Gasoline Sulfur rule in 2030. As such, we use projections of populations in 2030. The total projected population in the 47 states covered by the Tier 2/Gasoline Sulfur rule in 2030 is 300 million. The total projected population potentially affected by air quality changes resulting from the Tier 2/Gasoline Sulfur rule includes California, which adds an additional 45 million people. These projections are uncertain, although they are based on projection methods used by the U.S. Census Bureau (Abt Associates, 1999b). To the extent that populations are over- or under-predicted, benefits may be over- or under-stated.

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. There is substantial empirical evidence that the income elasticity[17] of WTP for health risk reductions is positive, although there is uncertainty about its exact value. While many analyses assume that the income elasticity of WTP is unit elastic (i.e., ten percent higher income level implies a ten percent higher willingness to pay to reduce risk changes), empirical evidence suggests that income elasticity is substantially less than one and thus inelastic. The effects of income changes on WTP estimates can influence benefit estimates in two different ways: (i) as changes that reflect estimates of income change in the affected population over time; and (ii) as changes based on differences in income between study populations and the affected populations at a particular time. Empirical evidence of the effect of income on WTP gathered to date is based on studies examining the latter. Income elasticity adjustments to better account for changes over time, therefore, will necessarily be based on potentially inappropriate data. The degree to which WTP may increase for the specific health and welfare benefits provided by the final Tier 2/Gasoline Sulfur rule is not estimated due to the high degree of uncertainty in the income elasticity information.

D. Assessment of Human Health Benefits

The most significant monetized benefits of reducing ambient concentrations of PM and ozone are attributable to reductions in health risks associated with air pollution. EPA's criteria documents for ozone and PM list numerous health effects known to be linked to ambient concentrations of these pollutants (EPA, 1996). This section describes individual effects and the methods used to quantify and monetize changes in the expected number of incidences of various health effects.

[17]Income elasticity is a common economic measure equal to the percentage change in WTP for a one percent change in income.

In section 1, we discuss how we have determined the baseline incidences for the health effects impacted by changes in PM and ozone. In section 2, we explain how we deal with the issue of health effects thresholds. In section 3, we describe how we quantify and value changes in individual health effects. Finally, in section 4 we present quantified estimates of the reductions in health effects resulting from the Tier 2 standards and their associated monetary values.

1. Estimating Baseline Incidences for Health Effects

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 total mortality rates used in the estimation of PM-related premature 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) (U.S. Centers for Disease Control, 1999a). An additional adjustment was necessary to provide baseline incidences for adults 30 and older for use in the Pope, et al. (1995) PM mortality C-R function. We estimated county-specific baseline mortality incidences for this population 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. We used national incidence rates whenever possible, because these data are most applicable to a national assessment of benefits. However, for some studies, the only available incidence information comes from the studies themselves; in these cases, incidence in the study population is assumed to represent typical incidence at the national level.

2. Accounting for Potential Health Effect Thresholds

When conducting clinical (chamber) and epidemiological studies, C-R functions may be estimated with or without explicit thresholds. Air pollution levels below the threshold are assumed to have no associated adverse health effects. When a threshold is not assumed, as is often the case in epidemiological studies, any exposure level is assumed to pose a non-zero risk

of response to at least one segment of the population.

The possible existence of an effect threshold is a very important scientific question and issue for policy analyses such as the final Tier 2/Gasoline Sulfur RIA. In the benefits analysis for the Tier 2 Proposal RIA, the low-end estimate of benefits assumed a threshold in PM health effects at 15 $\mu g/m^3$. However, the most recent advice from EPA's Science Advisory Board is that there is currently no scientific basis for selecting a threshold of 15 $\mu g/m^3$ or any other specific threshold for the PM-related health effects considered in this analysis (EPA-SAB-Council-ADV-99-012, 1999). Therefore, for our benefits analysis of the final Tier 2/Gasoline Sulfur rule, we assume there are no thresholds for modeling health effects. It is not appropriate to adopt a threshold for use in either the primary analysis or any alternative calculations because there is no adequate scientific evidence to support such a calculation. The potential impact of a health effects threshold on avoided incidences of PM-related premature mortality is explored as a key sensitivity analysis presented in Appendix VII-A.

3. Quantifying and Valuing Individual Health Endpoints

Health benefits of the final Tier 2/Gasoline Sulfur rule may be related to ozone only, PM only, or both pollutants. The ozone only health effects included in our primary benefits estimate are chronic asthma in adult males and decreased worker productivity. The PM only health effects include premature mortality, chronic bronchitis, acute bronchitis, upper and lower respiratory symptoms, shortness of breath, and work loss days[18]. The health effects related to both PM and ozone include hospital admissions, and minor restricted activity days.

For this analysis, we rely on C-R functions estimated in published epidemiological studies relating adverse health effects to ambient air quality. The specific studies from which C-R functions are drawn are included in Table VII-9. A complete discussion of the C-R functions used for this analysis is contained in the benefits TSD for this RIA (Abt Associates, 1999).

[18] In the benefits analysis for the Tier 2 Proposal RIA, we also estimated reductions in the incidence of premature mortality associated with reduced exposures to ozone. At least some evidence has been found linking both PM and ozone with premature mortality. The SAB has raised concerns that mortality-related benefits of air pollution reductions may be overstated if separate pollutant-specific estimates, some of which may have been obtained from models excluding the other pollutants, are aggregated. In addition, there may be important interactions between pollutants and their effect on mortality (EPA-SAB-Council-ADV-99-012, 1999)

The Pope et al. (1995) study used to quantify PM-related mortality included only PM, so it is unclear to what extent it may include the impacts of ozone or other gaseous pollutants. Because of concern about overstating of benefits and because the evidence associating mortality with exposure to particulate matter is currently stronger than for ozone, only the benefits of PM-related premature mortality avoided are included in the total benefits estimate. The benefits associated with ozone reductions are presented as a sensitivity analysis in Appendix VII-A but are not included in the estimate of total benefits.

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-1 and described more fully in the ozone and PM criteria documents (EPA, 1996a, 1996b), we include only a subset of health effects in this quantified benefit analysis. Health effects are excluded from this analysis for three reasons: (i) the possibility of double counting (such as hospital admissions for specific respiratory diseases); (ii) uncertainties in applying effect relationships based on clinical studies to the affected population; or (iii) 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 health endpoints selected for inclusion in the benefits analysis. A

Table VII-9. Endpoints and Studies Included in the Primary Analysis

Endpoint	*Pollutant*	*Study*	*Study Population*
Mortality			
Ages 30 and Older	PM	Pope et al. (1995)	Adults, 30 and older
Chronic Illness			
Chronic Bronchitis	PM	Multiple Studies	Multiple Studies
Chronic Asthma	Ozone	McDonnell et al. (1999)	Non-asthmatic adults, 27 and older
Hospital Admissions			
All Respiratory	PM, Ozone	Multiple Studies	Multiple Studies
Total Cardiovascular	PM, Ozone	Multiple Studies	Multiple Studies
Asthma-Related ER Visits	PM, Ozone	Multiple Studies	Multiple Studies
Other Illness			
Acute Bronchitis	PM	Dockery et al. (1996)	Children, 8-12
Upper Respiratory Symptoms	PM	Pope et al. (1991)	Asthmatic children, 9-11
Lower Respiratory Symptoms	PM	Schwartz et al. (1994)	Children, 7-14
Shortness of Breath	PM	Ostro et al. (1995)	African American asthmatic children, 7-12
Work Loss Days	PM	Ostro (1987)	Adults, 18-65
Minor Restricted Activity Days / Any of 19 respiratory Symptoms	PM, Ozone	Multiple Studies	Multiple Studies

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.

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. The benefits TSD provides details of the procedures used to combine multiple C-R functions (Abt Associates, 1999). Pooled C-R functions are used to estimate incidences of chronic bronchitis related to PM exposure, hospital admissions from cardiovascular and respiratory causes related to PM and ozone exposure, and emergency room visits for asthma related to PM and ozone exposure.

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 at all locations in the U.S. 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 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 the general application of a single C-R function everywhere.

The appropriate economic value of a change in a health effect depends on whether the health effect is viewed ex ante (before the effect has occurred) or ex post (after the effect has occurred). Reductions in ambient concentrations of air pollution generally lower the risk of future adverse health affects by a fairly small amount for a large population. The appropriate economic measure is therefore ex-ante WTP for changes in risk. However, epidemiological studies generally provide estimates of the expected number of incidences of a particular health effect avoided due to a reduction in air pollution. A convenient way to use this data in a consistent framework is to convert probabilities to units of avoided statistical incidences. This measure is calculated by dividing individual WTP for a risk reduction by the related observed change in risk. For example, suppose a measure is able to reduce the risk of premature mortality from 2 in 10,000 to 1 in 10,000 (a reduction of 1 in 10,000). If individual WTP for this risk reduction is $100, then the WTP for an avoided statistical premature mortality amounts to $1 million ($100/0.0001 change in risk). Using this approach, the size of the affected population is automatically taken into account by the number of incidences predicted by epidemiological studies applied to the relevant population. The same type of calculation can produce values for statistical incidences of other health endpoints.

For some health effects, such as hospital admissions, WTP estimates are generally not available. In these cases, we use the cost of treating or mitigating the effect as an alternative estimate. For example, for the valuation of hospital admissions we use the avoided medical costs as an estimate of the value of avoiding the health effects causing the admission. These costs of

illness (COI) estimates generally understate the true value of avoiding a health effect. They tend to reflect the direct expenditures related to treatment but not the value of avoided pain and suffering from the health effect. Table VII-10 summaries the value estimates per health effect that we use in this analysis. Alternative values used to derive the alternative estimates listed in Table VII-18 are indicated in parentheses. Note that there is not a specific value listed for hospital admissions. This reflects the fact that there are a range of symptoms for which individuals are admitted, each of which has a different associated cost. The estimated benefit of avoided hospital admissions reflects the distribution of symptoms across the total incidence of hospital admissions. The study-specific values for hospital admissions can be found in the benefits TSD for this RIA (Abt Associates, 1999).

In the following sections, we describe individual health endpoints and the C-R functions we have selected to provide quantified estimates of the avoided health effects associated with the final Tier 2/Gasoline Sulfur rule. In addition, we discuss how these changes in health effects should be valued and indicate the value functions selected to provide monetized estimates of the value of changes in health effects.

Table VII-10. Unit Values Used for Economic Valuation of Health Endpoints

Health or Welfare Endpoint	*Estimated Value Per Incidence (1997$) Central Estimate*	***Derivation of Estimates***
Mortality	$5.9 million per statistical life	Value is the mean of value-of-statistical-life estimates from 26 studies (5 contingent valuation and 21 labor market studies) reviewed for the section 812 Prospective analysis.
Chronic Bronchitis (CB)	$319,000	Value is the mean of a generated distribution of WTP to avoid a case of pollution-related CB. WTP to avoid a case of pollution-related CB is derived by adjusting WTP (as described in Viscusi et al., 1991) to avoid a severe case of CB for the difference in severity and taking into account the elasticity of WTP with respect to severity of CB.
Chronic Asthma	$31,000	Based on results reported in two studies (Blumenschein and Johannesson, 1998; O'Connor and Blomquist, 1997). Assumes a 5% discount rate and reflects adjustments for age distribution among adults (ages 27 and older) and projected life years remaining.
Hospital Admissions		
All Respiratory (ICD codes: 460-519)	variable — function of the analysis	The COI estimates are based on ICD-9 code level information (e.g., average hospital care costs, average length of hospital stay, and weighted share of total respiratory illnesses) reported in Elixhauser (1993).
All Cardiovascular (ICD codes: 390-429)	variable — function of the analysis	The COI estimates are based on ICD-9 code level information (e.g., average hospital care costs, average length of hospital stay, and weighted share of total cardiovascular illnesses) reported in Elixhauser (1993).
Emergency room visits for asthma	$280	COI estimate based on data reported by Smith et al. (1997).
Respiratory Ailments Not Requiring Hospitalization		
Upper Respiratory Symptoms (URS)	$23	Combinations of the 3 symptoms for which WTP estimates are available that closely match those listed by Pope et al. result in 7 different “symptom clusters,” each describing a “type” of URS. A dollar value was derived for each type of URS, using mid-range estimates of WTP (IEc, 1994) to avoid each symptom in the cluster and assuming additivity of WTPs. The dollar value for URS is the average of the dollar values for the 7 different types of URS.
Lower Respiratory. Symptoms (LRS)	$15	Combinations of the 4 symptoms for which WTP estimates are available that closely match those listed by Schwartz et al. result in 11 different “symptom clusters,” each describing a “type” of LRS. A dollar value was derived for each type of LRS, using mid-range estimates of WTP (IEc, 1994) to avoid each symptom in the cluster and assuming additivity of WTPs. The dollar value for LRS is the average of the dollar values for the 11 different types of LRS.

Health or Welfare Endpoint	*Estimated Value Per Incidence (1997$) Central Estimate*	***Derivation of Estimates***
Acute Bronchitis	$55	Average of low and high values recommended for use in Section 812 analysis (Neumann, et al. 1994)
Shortness of Breath	$5.30	From Ostro, et al. 1995. This is the mean of the median estimates from two studies to avoid a day of shortness of breath, Dickie et al. 1991 (0.00) and Loehman et al., 1979 (13.00).
Restricted Activity and Work Loss Days		
Work Loss Days (WLDs)	Variable	Regionally adjusted median weekly wage for 1990 divided by 5 (adjusted to 1997$) (U.S. Bureau of the Census, 1992).
Minor Restricted Activity Days (MRADs)	$47	Median WTP estimate to avoid 1 MRRAD – minor respiratory restricted activity day -- from Tolley et al.(1986) .

a. Premature Mortality: Quantification

Both acute and chronic exposures to ambient levels of air pollution have been associated with increased risk of premature mortality. Because of the extreme nature of this endpoint and the high monetary value associated with risks to life, reductions in the risk of premature mortality are the most important health endpoint quantified in this analysis, accounting for over 90 percent of the total monetized benefits. However, considerable uncertainty exists, both among economists and policymakers, as to the appropriate way to value reductions in mortality risks. Because of these factors, we include a more detailed discussion for premature mortality than for other health effects.

Health researchers have consistently linked air pollution, especially PM, with increases in premature mortality. A substantial body of published scientific literature recognizes a correlation between elevated PM concentrations and increased mortality rates. Much of this literature is summarized in the 1996 PM Criteria Document (U.S. EPA, 1996a). There is much about this relationship that is still uncertain, however, as stated in preamble to the 1997 PM National Ambient Air Quality Standards (U.S. EPA. 40 CFR 50, 1997), “the consistency of the results of the epidemiological studies from a large number of different locations and the coherent nature of the observed effects are suggestive of a likely causal role of ambient PM in contributing to the reported effects,” which include premature mortality. The National Academy of Sciences, in their report on research priorities for PM (National Academy of Sciences, 1998), indicate that “there is a great deal of uncertainty about the implications of the findings [of an association between PM and premature mortality] for risk management, due to the limited scientific information about the specific types of particles that might cause adverse health effects, the contributions of particles of outdoor origin to actual human exposures, the toxicological mechanisms by which the particles might cause adverse health effects, and other important

questions." EPA acknowledges these uncertainties, however, for this analysis, we assume a causal relationship between exposure to elevated PM and premature mortality, based on the consistent evidence of a correlation between PM and mortality reported in the scientific literature (U.S. EPA, 1996a).

It is currently unknown whether there is a time lag (a delay between changes in PM exposures and changes in mortality rates) in the chronic PM/premature mortality relationship. The existence of such a lag is important for the valuation of premature mortality incidences because economic theory suggests that benefits occurring in the future should be discounted. Although there is no specific scientific evidence of the existence or structure of a PM effects lag, current scientific literature on adverse health effects, such as those associated with PM (e.g., smoking-related disease) and the difference in the effect size between chronic exposure studies and daily mortality studies suggest that all incidences of premature mortality reduction associated with a given incremental change in PM exposure probably would not occur in the same year as the exposure reduction. This same smoking-related literature implies that lags of up to a few years are plausible. Adopting the lag structure used in a illustrative calculation for the Tier 2 Proposal RIA and endorsed by the SAB (EPA-SAB-COUNCIL-ADV-00-001, 1999), we assume a five-year lag structure, with 25 percent of premature deaths occurring in the first year, another 25 percent in the second year, and 16.7 percent in each of the remaining three years. To explore the uncertainty surrounding this lag structure, Appendix VII-A contains a sensitivity analysis showing how different lag structures affect the estimated value of reductions in premature mortality.

Two types of exposure studies (short-term and long-term) have been used to estimate a PM/premature mortality relationship. Short-term exposure studies attempt to relate short-term (often day-to-day) changes in PM concentrations and changes in daily mortality rates up to several days after a period of elevated PM concentrations. Long-term exposure studies examine the potential relationship between longer-term (e.g., annual) changes in exposure to PM and annual mortality rates. Researchers have found significant correlations using both types of studies (U.S. EPA, 1996a); however, for this analysis, following SAB advice (EPA-SAB-COUNCIL-ADV-99-005, 1999) we rely exclusively on long-term studies to quantify PM mortality effects.

Following guidance from the SAB (EPA-SAB-COUNCIL-ADV-99-005, 1999), we prefer studies to use long-term studies that employ a prospective cohort design over those that use an ecologic or population-level design. Prospective cohort studies follow individuals forward in time for a specified period, periodically evaluating each individual's exposure and health status. While the long-term study design is preferred, they are expensive to conduct and consequently there are relatively few well designed long-term studies. For PM, there have been

only a few, and the SAB has explicitly recommended use of only one — the Pope, et al. (1995) prospective cohort study in estimating avoided premature mortality from reductions in ambient PM concentrations (EPA-SAB-COUNCIL-ADV-99-005, 1999). We follow this recommendation and are consistent with the modeling of mortality effects of PM in both the Section 812 Retrospective and Prospective Reports to Congress. The Pope et al. study is recommended 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.

Although we use the Pope study exclusively to derive our primary estimates of avoided premature mortality, the C-R function based on Dockery et al. (1993) may provide a reasonable alternative estimate (EPA-SAB-COUNCIL-ADV-99-012, 1999). While the Dockery et al. study used a smaller sample of individuals from fewer cities than the study by Pope et al., it features improved exposure estimates, a slightly broader study population (adults aged 25 and older), and a follow-up period nearly twice as long as that of Pope et al. The Dockery et al. (1993) study finds a larger effect of PM on premature mortality. We present an alternative estimate of premature adult mortality associated with long-term PM exposure based on Dockery et al. (1993) in Table VII-18. We emphasize, however, that based on SAB advice, the Pope et al. (1995) derived estimate is our primary estimate of the effect of the final Tier 2/Gasoline Sulfur rule on this important health effect**.**

b. Premature Mortality: Valuation

We estimate the monetary benefit of reducing premature mortality risk using the "value of statistical lives saved" (VSL) approach, even though the actual valuation is of small changes in mortality risk experienced by a large number of people. The VSL approach applies information from several value-of-life studies to determine a reasonable benefit of preventing premature mortality. The mean value of avoiding one statistical death is estimated to be $5.9 million in 1997 dollars. This represents an intermediate value from a variety of estimates that appear in the economics literature, and is a value EPA has frequently used in RIAs for other rules and in the Section 812 reports to Congress. This estimate is the mean of a distribution fitted to the estimates from 26 value-of-life studies identified in the Section 812 reports 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 as 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-11. As indicated in the previous section on quantification of premature mortality benefits, we assume for

this analysis that some of the incidences of premature mortality related to PM exposures occur in a distributed fashion over the five years following exposure. To take this into account in the valuation of reductions in premature mortality, we apply an annual five percent discount rate to the value of premature mortality occurring in future years.

The economics literature concerning the appropriate method for valuing reductions in premature mortality risk is still developing. Some of the alternative approaches that have been proposed for valuing reductions in mortality risk are discussed in Text Box 1. There is general agreement that the value to an individual of a reduction in mortality risk can vary based on several factors, including the age of the individual, the type of risk, the level of control the individual has over the risk, the level of risk aversion, and the health status of the individual. While the empirical basis for adjusting the $5.9 million VSL for many of these factors does not yet exist, a thorough discussion of these factors is contained in the benefits TSD for this RIA (Abt Associates, 1999). EPA recognizes the need for investigation by the scientific community to develop additional empirical support for adjustments to VSL for the factors mentioned above.

Table VII-11. Summary of Mortality Valuation Estimates[a]

Study	*Type of Estimate*	*Valuation per Statistical Life (millions of 1997 $)*
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).

Text Box 1
Alternative Approaches for Assessing the Value of Reduced Mortality Risk

Stated preference studies – These studies use survey responses to estimate WTP to avoid risks. *Strengths:* flexible approach allowing for appropriate risk context, good data on WTP for individuals. *Weaknesses:* Risk information may not be well-understood by respondents and questions may be unfamiliar.

Consumer market studies – These studies use consumer purchases and risk data (e.g. smoke detectors) to estimate WTP to avoid risks. *Strengths:* uses revealed preferences and is a flexible approach. *Weaknesses:* very difficult to estimate both risk and purchase variables.

Value of statistical life year – Provides an annual equivalent to value of statistical life estimates. *Strengths:* provides financially accurate adjustment for age at death. *Weaknesses:* adjustment may not reflect how individuals consider life-years; assumes equal value for all remaining life-years.

Quality adjusted life year – Applies quality of life adjustment to life-extension data, uses cost-effectiveness data to value. *Strengths:* widely used in public health literature to assess private medical interventions. *Weaknesses:* lack of data on health state indices and life quality adjustments that are applicable to an air pollution context.

WTP for a change in survival curve – Reflects WTP for change in risk, potentially incorporates age-specific nature of risk reduction. *Strengths:* theoretically preferred approach that most accurately reflects risk reductions from air pollution control. *Weaknesses:* almost no empirical literature available; difficulty in obtaining reliable values.

WTP for a change in longevity – Uses stated preference approach to generate WTP for longevity or longer life expectancy. *Strengths:* life expectancy is a familiar term to most individuals. *Weaknesses:* does not incorporate age-specific risk information; problems in adapting to air pollution context.

Cost-effectiveness – Determines the implicit cost of saving a life or life-year. *Strengths:* widely used in public health contexts. *Weaknesses:* health context is for private goods, dollar values do not necessarily reflect individual preferences.

One important factor in Text Box 1 for which the impact on total benefits can be illustrated is the difference in age distribution between the population affected by air pollution and the population for which most of the VSL estimates were developed. To address this factor we use the "value of statistical life-years lost" (VSLY) approach, recommended by the SAB as an appropriate alternative to the VSL approach (EPA-SAB-COUNCIL-ADV-98-003, 1998). To employ the value of statistical life-year (VSLY) approach, we first estimated the age distribution of those lives projected to be saved by reducing air pollution. Based on life expectancy tables, we calculate the life-years saved from each statistical life saved within each age and gender cohort. To value these statistical life-years, we hypothesized a conceptual model which depicted the

relationship between the value of life and the value of life-years. The average number of life-years saved across all age groups for which data were available is 14 for PM-related mortality. The average for PM, in particular, differs from the 35-year expected remaining lifespan derived from existing wage-risk studies. Using the same distribution of value of life estimates used above, we estimated a distribution for the value of a life-year and combined it with the total number of estimated life-years lost. The details of these calculations are presented in the TSD for this RIA (Abt Associates, 1999).

c. Chronic Bronchitis: Quantification

Chronic bronchitis is characterized by mucus in the lungs and a persistent wet cough for at least three months a year for several years in a row. Chronic bronchitis affects an estimated five percent of the U.S. population (American Lung Association, 1999). There are a limited number of studies that have estimated the impact of air pollution on chronic bronchitis. 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 Section 812 Prospective Report (U.S. EPA, 1999a), our analysis pools the estimates from these studies 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*. Following the §812 Prospective Report, we assume that it is appropriate 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 this percentage change applies to a baseline incidence rate obtained from another source. For example, 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..

d. Chronic Bronchitis: Valuation

The best available estimate of WTP to avoid a case of chronic bronchitis (CB) comes from Viscusi et al. (1991)[19]. The Viscusi et al. study, however, describes a severe case of CB to the survey respondents. We therefore employ an estimate of WTP to avoid a pollution-related case of CB, based on adjusting an adjustment of the Viscusi et al. (1991) estimate of the WTP to avoid a sever case. This is done to account for the likelihood that an average case of pollution-related CB is not as severe. The adjustment is made by applying the elasticity of WTP with respect to severity reported in the Krupnick and Cropper (1992) study. Details of this adjustment procedure are provided in the benefits TSD for this RIA (Abt Associates, 1999).

We use the mean of a distribution of WTP estimates as the central tendency estimate of WTP to avoid a pollution-related case of CB in this analysis. The distribution incorporates uncertainty from three sources: (1) the WTP to avoid a case of severe CB, as described by Viscusi et al.; (2) the severity level of an average pollution-related case of CB (relative to that of the case described by Viscusi et al.; and (3) the elasticity of WTP with respect to severity of the illness. Based on assumptions about the distributions of each of these three uncertain components, we derive a distribution of WTP to avoid a pollution-related case of CB by statistical uncertainty analysis techniques. The expected value (i.e., mean or average) of this distribution, which is about $320,000 (1997$), is taken as the central tendency estimate of WTP to avoid a PM-related case of CB. We describe the three underlying distributions, and the generation of the resulting distribution of WTP, in the benefits TSD for this RIA (Abt Associates, 1999).

e. Chronic Asthma: Quantification

Chronic asthma is characterized by repeated incidences of inflammation of the lungs. This causes restriction in the airways and results in shortness of breath, wheezing, and coughing. Asthma is also characterized by airway hyper responsiveness to stimuli. Chronic asthma affects over seven percent of the U.S. population (U.S. Centers for Disease Control, 1999b). Most studies have not identified an association between air quality and asthma. However, a recent study by McDonnell et al. (1999) provides a statistical association between ozone and the development of asthma in adult white, non-Hispanic males. Following the advice of the EPA

[19]The Viscusi et al. (1991) study was an experimental study intended to examine new methodologies for eliciting values for morbidity endpoints. Although these studies were not specifically designed for policy analysis, the EPA Science Advisory Board (EPA-SAB-COUNCIL-ADV-00-002, 1999) has indicated that the severity adjusted values from this study 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.

Science Advisory Board (EPA-SAB-COUNCIL-ADV-00-001, 1999) and the Section 812 Prospective Report, we have added this significant health effect to our benefit analysis since the proposal RIA. However, it should be noted that it is not clear that the intermittent, short-term, and relatively small changes in annual average ozone concentrations resulting from this rule are likely to measurably change long-term risks of asthma. The McDonnell et al. study is a prospective cohort analysis, measuring the association between long-term exposure to ambient concentrations of ozone and development of chronic asthma in adults. The study found a statistically significant effect for adult males, but none for adult females.

Some commentors have raised questions about the statistical validity of the associations found in this study and the appropriateness of transferring the estimated C-R function from the study populations (white, non-Hispanic males) to other male populations (i.e. African-American males). Some of these concerns include 1) no significant association was observed for female study participants also exposed to ozone; 2) the estimated C-R function is based on a cross-sectional comparison of ozone levels, rather than incorporating information on ozone levels over time; 3) information on the accuracy of self-reported incidence of chronic asthma was collected but not used in estimating the C-R function; 4) the study may not be representative of the general population because it included only those individuals living 10 years or longer within 5 miles of their residence at the time of the study; and 5) the study had a significant number of study participants drop out, either through death, loss of contact, or failure to provide complete or consistent information.

EPA believes that while these issues may result in increased uncertainty about this effect, none can be identified with a specific directional bias in the estimates. In addition, the study has been reviewed by the SAB and has been specifically recommended for inclusion in benefits analyses of changes in ozone concentrations (EPA-SAB-COUNCIL-ADV-00-001, 1999). EPA also believes it to be appropriate to apply the C-R function to all adult males over age 27 because no evidence exists to suggest that non-white adult males have a lower responsiveness to air-pollution. For other health effects such as shortness of breath, where the study population was limited to a specific group potentially more sensitive to air pollution than the general population (Ostro, et al., 1995), EPA has applied the C-R function only to the limited population. EPA recognizes the need for further investigation by the scientific community to confirm the statistical association identified in the McDonnell et al. study.

f. Chronic Asthma: Valuation

Similar to the valuation of chronic bronchitis, WTP to avoid chronic asthma is presented as the net present value of what would potentially be a stream of costs and lower well-being incurred over a lifetime. Estimates of WTP to avoid asthma are provided in two studies, one by Blumenschein and Johannesson (1998) and one by O'Conor and Blomquist (1997). Both studies use the contingent valuation method to solicit annual WTP estimates from individuals

who have been diagnosed as asthmatics. The central estimate of lifetime WTP to avoid a case of chronic asthma among adult males, approximately $31,000, is the average of the present discounted value from the two studies. Details of the derivation of this central estimate from the two studies is provided in the benefits TSD for this RIA (Abt Associates, 1999).

g. Hospital Admissions: Quantification

There is a wealth of epidemiological information on the relationship between air pollution and hospital admissions for various respiratory and cardiovascular diseases; in addition, some studies have examined the relationship between air pollution and emergency room (ER) visits. Because most emergency room visits do not result in an admission to the hospital (the majority of people going to the ER are treated and return home) we treat hospital admissions and ER visits separately, taking account of the fraction of ER visits that do get admitted to the hospital.

Hospital admissions require the patient to be examined by a physician, and on average may represent more serious incidents than ER visits. The two main groups of hospital admissions estimated in this analysis are respiratory admissions and cardiovascular admissions. There is not much evidence linking ozone or PM with other types of hospital admissions. The only type of ER visits that have been linked to ozone and PM in the U.S. or Canada are asthma-related visits. To estimate the number of hospital admissions for respiratory illness, cardiovascular illness, and asthma ER visits, we pool the incidence estimates from a variety of U.S. and Canadian studies, using a random effects weighting procedure[20]. Details of the pooling procedure and a complete listing of the hospital admission studies used in our estimates can be found in the benefits TSD for this RIA (Abt Associates, 1999).

h. Hospital Admissions: Valuation

An individual's WTP to avoid a hospital admission will include, at a minimum, the amount of money he or she pays for medical expenses (i.e., payment towards the hospital charge and the associated physician charge) and the loss in earnings. In addition, an individual is likely to be willing to pay some amount to avoid the pain and suffering associated with the illness itself.

[20]Because we are estimating ER visits as well as hospital admissions for asthma, we must avoid counting twice the ER visits for asthma that are subsequently admitted to the hospital. To avoid double-counting, the baseline incidence rate for emergency room visits is adjusted by subtracting the percentage of patients that are admitted into the hospital. The reported incidence rates suggest that ER visits for asthma occur 2.7 times as frequently as hospital admissions for asthma. The baseline incidence of asthma ER visits is therefore taken to be 2.7 times the baseline incidence of hospital admissions for asthma. To avoid double-counting, however, only 63% of the resulting change in asthma ER visits associated with a given change in pollutant concentrations is counted in the ER visit incidence change.

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.

In the absence of estimates of WTP to avoid hospital admissions for specific illnesses, estimates of total cost-of-illness (COI) are typically used as conservative estimates. These estimates are biased downward because they do not include the value of avoiding the illness itself. 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. Consistent with the guidance offered by the EPA Science Advisory Board, the COI values used in this benefits analysis will not be adjusted to better reflect the total WTP (EPA-SAB-COUNCIL-ADV-98-003, 1998).

For the valuation of avoided hospital admissions, the current literature provides well-developed and detailed cost estimates of hospitalization by health effect or illness. Using illness-specific estimates of avoided medical costs and avoided costs of lost work-time that Elixhauser (1993) developed, we construct COI estimates specific to the suite of health effects defined by each C-R function. For example, we use twelve distinct C-R functions to quantify the expected change in respiratory admissions. Consequently in this analysis, we develop twelve separate COI estimates, each reflecting the unique composition of health effects considered in the individual studies. Details of the derivation of the values of avoided hospital admissions for respiratory and cardiovascular illnesses and asthma-related ER visits are provided in the benefits TSD for this RIA (Abt Associates, 1999).

i. Other Health Effects: Quantification

As indicated in Table VII-1, in addition to mortality, chronic illness, and hospital admissions, there are a number of acute health effects not requiring hospitalization that are associated with exposure to ambient levels of ozone and PM. The sources for the C-R functions used to quantify these effects are described below. A more complete description of these estimates is provided in the benefits TSD for this RIA (Abt Associates, 1999).

Around five percent of U.S. children between ages five and seventeen experience episodes of acute bronchitis annually (Adams, et al., 1995). Acute bronchitis is characterized by coughing, chest discomfort, and extreme tiredness. Incidences of acute bronchitis in children between the ages of five and seventeen are estimated using a C-R function developed from Dockery et al. (1996).

Incidences of lower respiratory symptoms (i.e., wheezing, deep cough) in children aged seven to fourteen are estimated using a C-R function developed from Schwartz et al. (1994). Because asthmatics have greater sensitivity to stimuli (including air pollution), children with

asthma can be more susceptible to a variety of upper respiratory symptoms (i.e., runny or stuffy nose; wet cough; and burning, aching, or red eyes). Incidences of upper respiratory symptoms in asthmatic children aged nine to eleven are estimated using a C-R function developed from Pope et al. (1991).

Health effects from air pollution can also result in missed days of work (either from personal symptoms or from caring for a sick family member). Work loss days are estimated using a C-R function developed from Ostro (1987).

The endpoint minor restricted activity days (MRAD), which is also represented by the occurrence of any of 19 acute respiratory symptoms as defined by Krupnick et al. (1990), is a pooled estimate using estimates of C-R functions derived from Ostro and Rothschild (1989) and Krupnick et al. (1990).

As noted above, asthma affects over seven percent of the U.S. population. Air pollution is sometimes linked to development of asthma and occurrences of asthma symptoms (McDonnell, et al, 1999; Ostro, et al., 1991; Whittemore and Korn, 1980). Incidences of shortness of breath (in African American asthmatics[21]) are estimated using a C-R function derived from Ostro, et al. (1995). Other asthma related symptoms are included in the incidences of MRAD and any of 19 acute respiratory symptoms. Inclusion of separate estimates for these endpoints would result in double-counting of these benefits. Supplemental calculations for separate asthma only endpoints are included in Appendix VII-A.

In addition to the health effects discussed above, human exposure to PM and ozone is believed to be linked to health effects such as ozone-related premature mortality (Ito and Thurston, 1996; Samet, et al. 1997), PM-related infant mortality (Woodruff, et al., 1997), cancer (U.S. EPA, 1996b), increased emergency room visits for non-asthma respiratory causes (U.S. EPA, 1996a; 1996b), impaired airway responsiveness (U.S. EPA, 1996a), increased susceptibility to respiratory infection (U.S. EPA, 1996a), acute inflammation and respiratory cell damage (U.S. EPA, 1996a), premature aging of the lungs and chronic respiratory damage (U.S. EPA, 1996a; 1996b). An improvement in ambient PM and ozone air quality may reduce the number of incidences within each effect category that the U.S. population would experience. Although these health effects are believed 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 lends a downward bias to the monetized benefits presented in this analysis.

Another category of potential effects that may change in response to ozone strategies

[21]Shortness of breath due to PM exposure is not necessarily limited to African-American asthmatics. However, the Ostro, et al. study was based on a sample of African-American children, who may be more sensitive to air pollution than the general population so we chose not to extrapolate the findings to the general population.

results from the shielding provided by ozone against the harmful effects of ultraviolet radiation (UV-B) derived from the sun. The great majority of this shielding results from naturally occurring ozone in the stratosphere, but the 10% of total "column"ozone present in the troposphere also contributes (NAS, 1991). A variable portion of this tropospheric fraction of UV-B shielding is derived from ground level or "smog" ozone related to anthropogenic air pollution. Therefore, strategies that reduce ground level ozone will, in some small measure, increase exposure to UV-B from the sun.

While it is possible to provide quantitative estimates of benefits associated with globally based strategies to restore the far larger and more spatially uniform stratospheric ozone layer, the changes in UV-B exposures associated with ground level ozone reduction strategies are much more complicated and uncertain. Smog ozone strategies, such as mobile source controls, are focused on decreasing peak ground level ozone concentrations, and it is reasonable to conclude that they produce a far more complex and heterogeneous spatial and temporal pattern of ozone concentration and UV-B exposure changes than do stratospheric ozone protection programs. In addition, the changes in long-term total column ozone concentrations are far smaller from ground-level programs. To properly estimate the change in exposure and impacts, it would be necessary to match the spatial and temporal distribution of the changes in ground-level ozone to the spatial and temporal distribution of exposure to ground level ozone and sunlight. More importantly, it is long-term exposure to UV-B that is associated with effects. Intermittent, short-term, and relatively small changes in ground-level ozone and UV-B are not likely to measurably change long-term risks of these adverse effects.

For all of these reasons, we were unable to provide reliable estimates of the changes in UV-B shielding associated with ground-level ozone changes. This inability lends an upward bias to the net monetized benefits presented in this analysis. It is likely that the adverse health effects associated with increases in UV-b exposure from decreased tropospheric ozone will, however, be relatively small because 1) the expected long-term ozone change resulting from this rule is small relative to total anthropogenic tropospheric ozone, which in turn is small in comparison to total column natural stratospheric and tropospheric ozone; 2) air quality management strategies are focused on decreasing peak ozone concentrations and thus may change exposures over limited areas for limited times, 3) people often receive peak exposures to UV-B in coastal areas where sea or lake breezes reduce ground level pollution concentrations regardless of strategy, and 4) ozone concentration changes are greatest in urban areas and areas immediately downwind of urban areas. In these areas, people are more likely to spend most of their time indoors or in the shade of buildings, trees or vehicles.

j. Other Health Effects: Valuation

The valuation of a specific short-term morbidity endpoint is generally estimated by representing the illness as a cluster of acute symptoms. For each symptom, the WTP is calculated. These values, in turn, are aggregated to arrive at the WTP to avoid a specific short term condition. For example, the endpoint lower respiratory symptoms (LRS) is represented by two or more of the following symptoms: runny or stuffy nose; coughing; and eye irritation. The WTP to avoid one day of LRS is the sum of values associated with these symptoms. The primary advantage of this approach is that is provides some flexibility in constructing estimates to represent a variety of health effects.

Valuation estimates for individual minor health effects are listed in Table 11-10. Derivation of the individual valuation estimates is provided in the benefits TSD for this RIA. Mean estimates range from $5.30 for an avoided incidence of shortness of breath to $45 for an avoided incidence of acute bronchitis. The value of work loss days varies depending on the location of an affected population. Using the median daily wage, the value of a work loss day is $83.

k. Lost Worker Productivity: Quantification and Valuation

While not technically a health effect, lost worker productivity related to pollution exposure is presumably linked to reductions in the physical capabilities of workers in outdoor jobs. The value of lost worker productivity due to ozone exposure is directly estimated based on a study of California citrus workers (Crocker and Horst, 1981 and U.S. EPA, 1994). 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 (or the percentage change in income for a one percent change in ambient ozone concentration). The reported elasticity translates a ten percent reduction in ozone to a 1.4 percent increase in income.

l. Estimated Reductions in Incidences of Health Endpoints and Associated Monetary Values

Applying the C-R and valuation functions described above to the estimated changes in ozone and PM yields estimates of the number of avoided incidences (i.e. premature mortalities, cases, admissions, etc.) and the associated monetary values for those avoided incidences. These estimates are presented in Table VII-12. All of the monetary benefits are in constant 1997 dollars.

Not all known PM and ozone related health effects could be quantified or monetized. These unmonetized benefits are indicated by place holders, labeled B_1 and B_2. Unquantified

physical effects are indicated by U_1 and U_2. The estimate of total monetized health benefits is thus equal to the subset of monetized PM and ozone related health benefits plus $\mathbf{B_H}$, the sum of the unmonetized health benefits.

The largest monetized health benefit is associated with reductions in the risk of premature mortality. The next largest benefit is for chronic bronchitis reductions, although this value is more than an order of magnitude lower than for premature mortality. Minor restricted activity days, work loss days, and worker productivity account for the majority of the remaining benefits. The remaining categories account for less than $10 million each, however, they represent a large number of avoided incidences affecting many individuals.

Alternative calculations for premature mortality incidences and valuation are presented in Table VII-18. An alternative calculation is also provided in that table for chronic bronchitis incidences.

Table VII-12. Estimated Annual Health Benefits Associated With Air Quality Changes Resulting from the Tier 2/Gasoline Sulfur Rule in 2030

Endpoint	Avoided Incidence[c] (cases/year)	Monetary Benefits[d] (millions 1997$)
PM-related Endpoints[a]		
Premature mortality[b] (adults, 30 and over)	4,300	$23,380
Chronic bronchitis	2,300	$730
Hospital Admissions from Respiratory Causes	1,200	$10
Hospital Admissions from Cardiovascular Causes	500	$10
Emergency Room Visits for Asthma	900	$<1
Acute bronchitis (children, 8-12)	7,900	$<1
Lower respiratory symptoms (LRS) (children, 7-14)	87,100	$<5
Upper respiratory symptoms (URS) (asthmatic children, 9-11)	86,500	$<5
Shortness of breath (African American asthmatics, 7-12)	17,400	$<1
Work loss days (WLD) (adults, 18-65)	682,900	$70
Minor restricted activity days (MRAD)/Acute respiratory symptoms	3,628,500	$170
Other PM-related health effects[e]	U_1	B_1
Ozone-related Endpoints		
Chronic asthma (adult males, 27 and over)	400	$10
Hospital Admissions from Respiratory Causes	1,000	$10
Hospital Admissions from Cardiovascular Causes	300	$<5
Emergency Room Visits for Asthma	400	$<1
Minor restricted activity days (MRAD)/Acute respiratory symptoms	2,226,500	$100
Decreased worker productivity (adult working population)	—	$140
Other ozone-related health effects[e]	U_2	B_2
CO-related health effects[e]	U_3	B_3
HAPS-related health effects[e]	U_4	B_4
Monetized Total Health-related Benefits[f]	—	$24,630+$\mathbf{B_H}$

[a] PM reductions are due to reductions in NOx and SO_2 resulting from the Tier 2/Gasoline Sulfur rule.
[b] Premature mortality associated with ozone is not separately included in this analysis. It is assumed that the Pope, et al. C-R function for premature mortality captures both PM mortality benefits and any mortality benefits associated with other air pollutants. Also note that the estimated value assumes the 5 year distributed lag structure described earlier.
[c] Incidences are rounded to the nearest 100. [d] Dollar values are rounded to the nearest 10 million.
[e] A detailed listing of unquantified PM, ozone, CO, and HAPS related heatlh effects is provided in Table VII-1.
[f] $\mathbf{B_H}$ is equal to the sum of all unmonetized categories, i.e. B_1+B_2

E. Assessment of Human Welfare Benefits

Particulate matter and ozone have numerous documented effects on environmental quality that affect human welfare. These welfare effects include direct damages to property, either through impacts on material structures or by soiling of surfaces, direct economic damages in the form of lost productivity of crops and trees, indirect damages through alteration of ecosystem functions, and indirect economic damages through the loss in value of recreational experiences or the existence value of important resources. EPA's criteria documents for ozone and PM list numerous physical and ecological effects known to be linked to ambient concentrations of these pollutants (U.S. EPA, 1996a, 1996b). This section describes individual effects and how we quantify and monetize them. These effects include changes in crop yields, visibility, and nitrogen deposition to estuaries.

In section 1, we describe how we quantify and value changes in visibility, both in federal Class I areas (national parks and wilderness areas) and in the areas where people live and work. In section 2, we describe how we value the benefits of increased agricultural and commercial forest yields resulting from decreased levels of ambient ozone. In section 3, we describe the damage to materials caused by particulate matter. In section 4, we discuss the effects of nitrogen deposition on ecosystems (especially estuarine ecosystems) and describe how we quantify changes in nitrogen loadings. Finally, in section 6, we summarize the monetized estimates for welfare effects.

1. Visibility Benefits

Changes in the level of ambient particulate matter caused by the final Tier 2/Gasoline Sulfur rule will change the level of visibility in much of the U.S. Visibility directly affects people's enjoyment of a variety of daily activities. Individuals value visibility both in the places they live and work, in the places they travel to for recreational purposes, and at sites of unique public value, such as the Grand Canyon. This section discusses the measurement of the economic benefits of visibility.

It is difficult to quantitatively define a visibility endpoint that can be used for valuation. Increases in PM concentrations cause increases in light extinction. Light extinction is a measure of how much the components of the atmosphere absorb light. More light absorption means that the clarity of visual images and visual range is reduced, *ceteris paribus*. Light absorption is a variable that can be accurately measured. Sisler (1996) created a unitless measure of visibility based directly on the degree of measured light absorption called the *deciview*. Deciviews are standardized for a reference distance in such a way that one deciview corresponds to a change of about 10 percent in available light. Sisler characterized a change in light extinction of one deciview as "a small but perceptible scenic change under many circumstances." Air quality models were used to predict the change in visibility, measured in deciviews, of the areas affected

by the final Tier 2/Gasoline Sulfur rule[22].

EPA considers benefits from two categories of visibility changes: residential visibility and recreational visibility. In both cases economic benefits are believed to consist of both use values and non-use values. The use values include the aesthetic benefits of better visibility, improved road and air safety, and enhanced recreation in activities like hunting and birdwatching. The non-use values are based on people's beliefs that the environment ought to exist free of human-induced haze. Non-use values may be a more important component of value for recreational areas, particularly national parks and monuments.

Residential visibility benefits are those that occur from visibility changes in urban, suburban, and rural areas, and also in recreational areas **not** listed as federal Class I areas[23]. Recreational visibility improvements are those that occur specifically in federal Class I areas. A key distinction is that only those people living in residential areas are assumed to receive benefits from residential visibility, while all households in the U.S. are assumed to derive some benefit from improvements in Class I areas. Values are assumed to be higher if the Class I area is located close to their home.[24]

The results of air quality modeling of the Tier 2/Gasoline Sulfur rule show consistent improvements in visibility in all areas of the country. The mean improvement across all U.S. counties was 0.24 deciviews. The biggest improvements in visibility were most often found in heavily populated urban areas. Of the central counties of metropolitan areas with more than one million in population in 1993, 21 percent show an improvement of 0.5 deciviews or more. For suburban counties of these same regions, 11 percent are predicted to have visibility improvements of 0.5 deciview or more. For the 21 percent of metropolitan areas showing an improvement of 0.5 deciviews or more, the baseline visibility is 25.3. For the 11 percent of suburban counties in these regions, the baseline visibility is 23.3. And, baseline visibility in the 10 percent of counties with the largest improvements in visibility (baseline = 24.4 deciviews) is much worse than baseline visibility in those counties with no change in visibility (baseline = 18.1 deciviews). This suggests that the Tier 2/Gasoline Sulfur rule has the potential to provide large improvements in visibility in those areas with the worst baseline visibility conditions.

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[22]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. Some of the average regional changes in visibility are 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.

[23] The Clean Air Act designates 156 national parks and wilderness areas as Class I areas for visibility protection.

[24] For details of the visibility estimates discussed in this chapter, please refer to the benefits technical support document for this RIA (Abt Associates).

Only two existing studies provide defensible monetary estimates of the value of visibility changes. One is a study on residential visibility conducted in 1990 (McClelland, et. al., 1993) and the other is a 1988 survey on recreational visibility value (Chestnut and Rowe, 1990a, 1990b). Both utilize the contingent valuation method. There has been a great deal of controversy and significant development of both theoretical and empirical knowledge about how to conduct CVM surveys in the past decade. In EPA's judgment, the Chestnut and Rowe study contains many of the elements of a valid CVM study and is sufficiently reliable to serve as the basis for monetary estimates of the benefits of visibility changes in recreational areas[25]. This study serves as an essential input to our estimates of the benefits of recreational visibility improvements in the primary benefits estimates. Based on SAB advice (EPA-SAB-COUNCIL-ADV-00-002, 1999), EPA has designated the McClelland et al. study as significantly less reliable for regulatory benefit-cost analysis, but it does provide useful estimates on the order of magnitude of residential visibility benefits. Residential visibility benefits are therefore only included as an alternative calculation in Table VII-18. The methodology for this alternative calculation, explained below, is similar to the procedure for recreational benefits.

The Chestnut and Rowe study measured the demand for visibility in Class I areas managed by the National Park Service (NPS) in three broad regions of the country: California, the Southwest, and the Southeast. Respondents in five states were asked about their willingness to pay to protect national parks or NPS-managed wilderness areas within a particular region. The survey used photographs reflecting different visibility levels in the specified recreational areas. The visibility levels in these photographs were later converted to deciviews for the current analysis. The survey data collected were used to estimate a willingness-to-pay equation for improved visibility. In addition to the visibility change variable, the estimating equation also included household income as an explanatory variable.

The Chestnut and Rowe study did not measure values for visibility improvement in Class I areas outside the three regions. Their study covered 86 of the 156 Class I areas in the U.S. We can infer the value of visibility changes in the other Class I areas by transferring values of visibility changes at Class I areas in the study regions. However, these values are not as defensible and are thus presented only as an alternative calculation in Table VII-18. A complete description of the benefits transfer method used to infer values for visibility changes in Class I areas outside the study regions is provided in the benefits TSD for this RIA (Abt Associates, 1999).

The estimated relationship from the Chestnut and Rowe study is only directly applicable

[25]An SAB advisory letter (EPA-SAB-COUNCIL-ADV-00-002, 1999) indicates that "many members of the Council believe that the Chestnut and Rowe study is the best available," however, the council did not formally approve use of these estimates because of concerns about the peer-reviewed status of the study. EPA believes the study has received adequate review and has been cited in numerous peer-reviewed publications (Chestnut and Dennis, 1997).

to the populations represented by survey respondents. EPA used benefits transfer methodology to extrapolate these results to the population affected by the final Tier 2/Gasoline Sulfur rule. A general willingness to pay equation for improved visibility (measured in deciviews) was developed as a function of the baseline level of visibility, the magnitude of the visibility improvement, and household income. The behavioral parameters of this equation were taken from analysis of the Chestnut and Rowe data. These parameters were used to calibrate WTP for the visibility changes resulting from the final Tier 2/Gasoline Sulfur rule. The method for developing calibrated WTP functions is based on the approach developed by Smith, et al. (1999). Available evidence indicates that households are willing to pay more for a given visibility improvement as their income increases (Chestnut 1997). The benefits estimates here incorporate Chestnut's estimate that a one percent increase in income is associated with a 0.9 percent increase in WTP for a given change in visibility.

Using the methodology outlined above, EPA estimates that the total willingness to pay for the visibility improvements in Class I areas brought about by the final Tier 2/Gasoline Sulfur rule is $371 million. This value includes the value to households living in the same state as the Class I area as well as values for all households in the U.S. living outside the state containing the Class I area. A complete presentation of this method can be found in the benefits TSD for this RIA (Abt Associates, 1999).

For the alternative calculation for residential visibility, the McClelland study's results were used to calculate the parameter for the effect of deciview changes on WTP. The WTP equation was then run for the population affected by the final Tier 2/Gasoline Sulfur rule. The results indicate that improvements to residential visibility provide an economic benefit of $581 million dollars for the continental U.S.[26] A complete presentation of this method can be found in the benefits TSD for this RIA (Abt Associates, 1999).

One major source of uncertainty for the visibility benefit estimate is the benefits transfer process used. Judgments used to choose the functional form and key parameters of the estimating equation for willingness to pay for the affected population could have significant effects on the size of the estimates. Assumptions about how individuals respond to changes in visibility that are either very small, or outside the range covered in the Chestnut and Rowe study, could also affect the results.

[26] The McClelland et al. (1990) study examined visibility changes in two Eastern cities, Chicago and Atlanta. Transferring these values to residential visibility changes in the Western U.S. may introduce greater uncertainty than transferring the values to other Eastern cities. As such, an additional alternate calculation showing the value of residential visibility just for the Eastern U.S. is included in Table VII-18.

2. Agricultural and Forestry Benefits

Reduced levels of ground-level ozone resulting from the final Tier 2/Gasoline Sulfur rule will have generally beneficial results on agricultural crop yields and commercial forest growth. Well-developed techniques exist to provide monetary estimates of these benefits to agricultural producers and to consumers. These techniques use models of farmers' planting decisions, yield response functions, and agricultural supply and demand. The resulting welfare measures are based on predicted changes in market prices and production costs.

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 final Tier 2/Gasoline Sulfur rule) that affect commodity crop yields or production costs[27]. The benefits TSD for this RIA also provides further details on AGSIM© (Abt Associates, 1999).

The measure of benefits calculated by the model is the net change in consumer and producer 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 consumer and producer surplus on a crop-by-crop basis[28]. 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 final Tier 2/Gasoline Sulfur rule.

The model employs biological exposure-response information derived from controlled experiments conducted by the National Crop Loss Assessment Network (NCLAN, 1996). For the purpose of our analysis, we analyze changes for the six most economically significant crops for which dose-response functions are available: corn, cotton, peanuts, sorghum, soybean, and winter wheat.[29] For some crops there are multiple dose-response functions, some more sensitive to ozone and some less. Our primary estimate assumes that crops are evenly mixed between relatively sensitive and relatively insensitive varieties. The primary estimate of the net change in economic surplus resulting from changes in ozone associated with the Tier 2/Gasoline Sulfur rule

[27] AGSIM© is designed to forecast agricultural supply and demand out to 2010. We were not able to adapt the model to forecast out to 2030. Instead, we apply percentage increases in yields from decreased ambient ozone levels in 2030 to 2010 yield levels, and input these into a agricultural sector model held at 2010 levels of demand and supply. It is uncertain what impact this assumption will have on net changes in surplus.

[28] 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.

[29] The total value for these crops in 1997 was $57 billion.

is $217 million.

Similar models exist for forest products. Ozone also has been shown conclusively to cause discernible injury to forest trees (Fox and Mickler, 1996). Once the effects of changes in ozone concentrations on tree growth are predicted, econometric models of forest product supply and demand can be used to estimate changes in prices, producer profits and consumer surplus. Our analysis does not attempt to quantify commercial forestry benefits due to difficulties in obtaining C-R functions relating ozone exposure and tree growth. An additional welfare benefit expected to accrue as a result of reductions in ambient ozone concentrations in the United States is the economic value the public receives from reduced aesthetic injury to forests. There is sufficient scientific information available to reliably establish that ambient ozone levels cause visible injury to foliage and impair the growth of some sensitive plant species (U.S. EPA, 1996c, p. 5-521). However, present analytic tools and resources preclude EPA from quantifying the benefits of improved forest aesthetics.

Urban ornamentals represent an additional vegetation category likely to experience some degree of negative effects associated with exposure to ambient ozone levels and likely to impact large economic sectors. In the absence of adequate exposure-response functions and economic damage functions for the potential range of effects relevant to these types of vegetation, no direct quantitative 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. This is therefore a potentially important welfare effects category. However, information and valuation methods are not available to allow for plausible estimates of the percentage of these expenditures that may be related to impacts associated with ozone exposure.

The final Tier 2/Gasoline Sulfur rule, by reducing NO_X emissions, will also reduce nitrogen deposition on agricultural land and forests. There is some evidence that nitrogen deposition may have positive effects on agricultural output through passive fertilization. Holding all other factors constant, farmers' use of purchased fertilizers or manure may increase as deposited nitrogen is reduced. Estimates of the potential value of this possible increase in the use of purchased fertilizers are not available, but it is likely that the overall value is very small relative to other health and welfare effects. The share of nitrogen requirements provided by this deposition is small, and the marginal cost of providing this nitrogen from alternative sources is quite low. In some areas, agricultural lands suffer from nitrogen over-saturation due to an abundance of on-farm nitrogen production, primarily from animal manure. In these areas, reductions in atmospheric deposition of nitrogen from PM represent additional agricultural benefits.

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.

3. Benefits from Reductions in Materials Damage

The final Tier 2/Gasoline Sulfur rule is expected to produce economic benefits in the form of reduced materials damage. There are two important categories of these benefits. Household soiling refers to the accumulation of dirt, dust, and ash on exposed surfaces. Criteria pollutants also have corrosive effects on commercial/industrial buildings and structures of cultural and historical significance. The effects on historic buildings and outdoor works of art are of particular concern because of the uniqueness and irreplaceability of many of these objects.

Previous EPA benefit analyses including that for the Tier 2 Proposal RIA, have been able to provide quantitative estimates of household soiling damage. Following an SAB recommendation (EPA-SAB-Council-ADV-003, 1998), EPA has determined that the existing data (based on consumer expenditures from the early 1970's) is too out of date to provide a reliable enough estimate of current household soiling damages. However, a calculation is made for inclusion in the alternative calculations table (Table VII-18).

EPA is unable to estimate any benefits to commercial and industrial entities from reduced materials damage. Nor is EPA able to estimate the benefits of reductions in PM-related damage to historic buildings and outdoor works of art. Existing studies of damage to this latter category in Sweden (Grosclaude and Soguel, 1994) indicate that these benefits could be an order of magnitude larger than household soiling benefits.

4. Benefits from Reduced Ecosystem Damage

The effects of air pollution on the health and stability of ecosystems are potentially very important, but are at present poorly understood and difficult to measure. The reductions in NO_X caused by the final rule could produce significant benefits. Excess nutrient loads, especially 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 (Haire et al., 1992).

Reductions in nitrogen loadings are estimated for twelve eastern estuaries (including two on the Gulf Coast). These estimated reductions are described earlier in this Chapter. Four of these estuaries have established consensus goals for reductions in annual nitrogen loads, indicating an intention of reaching these goals through implementation of controls on nitrogen sources. These four estuaries and their reduction goals are listed in Table VII-13.

Table VII-13. Reduction Goals and Nitrogen Loads to Selected Eastern Estuaries (tons per year)

Estuary	*Total Nitrogen Loadings*	*Nitrogen Loadings from Atmospheric Deposition*	*Overall Reduction Goal*
Albemarle/Pamlico Sound	25,300	11,000	7,600
Chesapeake Bay	185,000	49,500	35,600
Long Island Sound	53,700	13,200	31,460
Tampa Bay	3,900	2,100	100

Source: U.S. EPA, 1998

Estimated reductions in deposition of atmospheric nitrogen to these four estuaries are listed in Table VII-14, along with the percentage of the reduction goal accounted for by these reductions. These figures suggest that the reductions in nitrogen deposition resulting from the final Tier 2/Gasoline Sulfur rule will provide significant progress towards meeting nitrogen reduction goals in several of these estuaries.

Table VII-14. Estimated Annual Reductions in Nitrogen Loadings in Selected Eastern Estuaries for the Final Tier 2/Gasoline Sulfur Rule in 2030 (tons per year)

Estuary	*Change in Nitrogen Loadings*	*% of Estuary Nitrogen Reduction Goal*
Albemarle/Pamlico Sound	-2,013	26.5%
Chesapeake Bay	-3,080	8.7%
Long Island Sound	-1,144	3.6%
Tampa Bay[a]	-484	over 100%

[a] Tampa Bay had a very low nitrogen loadings reduction goal. As such, the Tier 2 rule provides more reductions than are necessary to achieve the stated goal.

Direct C-R functions relating changes in nitrogen loadings to changes in estuarine benefits are not available. The preferred WTP 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 value of changes in water quality exist at present, calculation of a WTP measure is not possible. As stated earlier, an alternative is to use an avoided cost approach to estimate the welfare effects of PM on estuarine ecosystems. The use of the avoided cost approach to establish the value of a reduction in nitrogen deposition is problematic if there is not a direct link between reductions in air deposited nitrogen and the abandonment of a costly regulatory program. However, there are currently no readily available alternatives to this approach.

Based on the advice of the EPA Science Advisory Board, we use the avoided cost approach only to derive an alternative calculation of the value of reductions in atmospheric nitrogen loadings to estuaries (EPA-SAB-COUNCIL-ADV-00-002, 1999). The SAB believes that the avoided cost approach for nitrogen loadings is valid only if the state and local governments have established firm pollution reduction targets, and that displaced costs measured in the study represent measures not taken because of the CAAA (EPA-SAB-COUNCIL-ADV-00-002, 1999). Because the nitrate reduction targets in the studied estuaries are not firm targets, and there is not assurance that planned measures would be undertaken in the absence of the CAAA, we are currently unable to provide a meaningful primary estimate. However, the avoided cost estimate is presented in the table of alternative calculations (Table VII-18).

If better models of ecological effects can be defined, EPA believes that progress can be made in estimating WTP measures for ecosystem functions. These estimates would be superior to avoided cost estimates in placing economic values on the welfare changes associated with air pollution damage to ecosystem health. For example, if nitrogen or sulfate loadings can be linked to measurable and definable changes in fish populations or definable indexes of biodiversity,

then CVM studies can be designed to elicit individuals' willingness to pay for changes in these effects. This is an important area for further research and analysis, and will require close collaboration among air quality modelers, natural scientists, and economists.

5. Estimated Values for Welfare Endpoints

Applying the valuation methods described above to the estimated changes in ozone and PM in 2030 yields estimates of the value of changes in visibility and agricultural yields. These estimates are presented in Table VII-15. All of the monetary benefits are in constant 1997 dollars.

We are unable to provide primary monetized estimates of residential visibility, household soiling, materials damage, nitrogen deposition and commercial forestry benefits, in addition to the other welfare effects listed in Table VII-1. These unmonetized benefits are indicated by placeholders, labeled B_3 to B_9. The estimate of total monetized welfare benefits is thus equal to the subset of monetized welfare benefits plus $\mathbf{B_W}$, the sum of the unmonetized welfare benefits.

Total monetized welfare related benefits are around $590 million. Monetized welfare benefits are roughly one fortieth the magnitude of monetized health benefits. However, due to the difficulty in quantifying and monetizing welfare benefits, a higher proportion of welfare benefits

Table VII-15. Estimated Annual Monetary Values for Welfare Effects Associated With Improved Air Quality Resulting from the Tier 2/Gasoline Sulfur Rule in 2030

Endpoint	*Monetary Benefits (millions 1997$)*[a]
PM-related Endpoints	
Recreational Visibility (86 Class I areas in California, the Southeast and the Southwest)	$370
Residential Visibility	B_5
Household Soiling	B_6
Materials Damage	B_7
Nitrogen Deposition to Estuaries	B_8
Other PM-related welfare effects[b]	B_9
Ozone-related Endpoints	
Commercial Agricultural Benefits (6 major crops)	$220
Commercial Forestry Benefits	B_{10}
Other ozone-related welfare effects[b]	B_{11}
CO-related welfare effects[b]	B_{12}
HAPS-related welfare effects[b]	B_{13}
Total Monetized Welfare-related Benefits[c]	$590+$\mathbf{B_W}$

[a] Rounded to the nearest 10 million.
[b] A detailed listing of unquantified PM, ozone, CO, and HAPS related welfare effects is provided in Table VII-1.
[c] $\mathbf{B_W}$ is equal to the sum of all unmonetized welfare categories, i.e. $B_5+B_6+...+B_{13}$.

are not monetized. It is thus inappropriate to conclude that welfare benefits are unimportant just by comparing the estimates of the monetized benefits.

Alternative calculations for recreational visibility, residential visibility, household soiling, and nitrogen deposition are presented in Table VII-18 later in this chapter.

F. Total Benefits

We provide our preferred estimate of benefits for each health and welfare endpoint and the resulting preferred estimate of total benefits. To obtain this estimate, we aggregate 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 is the sum of the

separate effects estimates. Total monetized benefits associated with the final Tier 2/Gasoline Sulfur rule are listed in Table VII-16, along with a breakdown of benefits by endpoint. Note that the value of endpoints known to be affected by ozone and/or PM that we are not able to monetize are assigned a placeholder value, e.g. B_1, B_2, etc. Unquantified physical effects are indicated by a U. The estimate of total benefits is thus the sum of the monetized benefits and a constant, B, equal to the sum of the unmonetized benefits, $B_1+B_2+...+B_n$.

A comparison of the incidence column to the monetary benefits column reveals that there is not always a close correspondence between the number of incidences avoided for a given endpoint and the monetary value associated with that endpoint. This reflects the fact that many of the less severe health effects, while more common, are valued at a lower level than the more severe health effects.

Our preferred estimate of total monetized benefits for the final Tier 2/Gasoline Sulfur rule is $25 billion, of which $23 billion is the benefits of reduced premature mortality risk from PM exposure. Total monetized benefits are dominated by the benefits of reduced mortality risk. Mortality related benefits account for over 90 percent of total monetized benefits followed by chronic bronchitis (3 percent). However, the adoption of a value for the projected reduction in the risk of premature mortality is the subject of continuing discussion within the economic and public policy analysis community within and outside the Administration. In response to the sensitivity on this issue, we provide estimates reflecting two alternative approaches. The first approach -- supported by some in the above community and preferred by EPA -- uses a Value of a Statistical Life (VSL) approach developed for the Clean Air Act Section 812 benefit-cost studies. This VSL estimate of $5.9 million (1997$) was derived from a set of 26 studies identified by EPA using criteria established in Viscusi (1992), as those most appropriate for environmental policy analysis applications.

An alternative, age-adjusted approach is preferred by some others in the above community both within and outside the Administration. This approach was also developed for the Section 812 studies and addresses concerns with applying the VSL estimate –reflecting a valuation derived mostly from labor market studies involving healthy working-age manual laborers– to PM-related mortality risks that are primarily associated with older populations and those with impaired health status. This alternative approach leads to an estimate of the value of a statistical life year (VSLY), which is derived directly from the VSL estimate. It differs only in incorporating an explicit assumption about the number of life years saved and an implicit assumption that the valuation of each life year is not affected by age.[30] The mean VSLY is

[30] Specifically, the VSLY estimate is calculated by amortizing the $5.9 million mean VSL estimate over the 35 years of life expectancy associated with subjects in the labor market studies. The resulting estimate, using a 5 percent discount rate, is $360,000 per life-year saved in 1997 dollars. This annual average value of a life-year is then multiplied times the number of years of remaining life expectancy for the affected population (in the case of PM-related premature mortality, the average number of $ life-years saved is 14.

$360,000 (1997$); combining this number with a mean life expectancy of 14 years yields an age-adjusted VSL of $3.6 million (1997$).

Both approaches are imperfect, and raise difficult methodological issues which are discussed in depth in the recently published Section 812 Prospective Study, the draft EPA Economic Guidelines, and the peer-review commentaries prepared in support of each of these documents. For example, both methodologies embed assumptions (explicit or implicit) about which there is little or no definitive scientific guidance. In particular, both methods adopt the assumption that the risk versus dollars trade-offs revealed by available labor market studies are applicable to the risk versus dollar trade-offs in an air pollution context.

EPA currently prefers the VSL approach because, essentially, the method reflects the direct, application of what EPA considers to be the most reliable estimates for valuation of premature mortality available in the current economic literature. While there are several differences between the labor market studies EPA uses to derive a VSL estimate and the particulate matter air pollution context addressed here, those differences in the affected populations and the nature of the risks imply both upward and downward adjustments. For example, adjusting for age differences may imply the need to adjust the $5.9 million VSL downward as would adjusting for health differences, but the involuntary nature of air pollution-related risks and the lower level of risk-aversion of the manual laborers in the labor market studies may imply the need for upward adjustments. In the absence of a comprehensive and balanced set of adjustment factors, EPA believes it is reasonable to continue to use the $5.9 million value while acknowledging the significant limitations and uncertainties in the available literature. Furthermore, EPA prefers not to draw distinctions in the monetary value assigned to the lives saved even if they differ in age, health status, socioeconomic status, gender or other characteristic of the adult population.

Those who favor the alternative, age-adjusted approach (i.e. the VSLY approach) emphasize that the value of a statistical life is not a single number relevant for all situations. Indeed, the VSL estimate of $5.9 million (1997 dollars) is itself the central tendency of a number of estimates of the VSL for some rather narrowly defined populations. When there are significant differences between the population affected by a particular health risk and the populations used in the labor market studies - as is the case here - they prefer to adjust the VSL estimate to reflect those differences. While acknowledging that the VSLY approach provides an admittedly crude adjustment (for age though not for other possible differences between the populations), they point out that it has the advantage of yielding an estimate that is not presumptively biased. Proponents of adjusting for age differences using the VSLY approach fully concur that enormous uncertainty remains on both sides of this estimate - upwards as well as downwards - and that the populations differ in ways other than age (and therefore life expectancy). But rather than waiting for all relevant questions to be answered, they prefer a process of refining estimates by incorporating new information and evidence as it becomes

available.

The estimates of benefits for the final Tier 2/Gasoline Sulfur rule using the different approaches for premature mortality valuation are presented in Table VII-17. The VSL approach –the approach EPA prefers – yields a monetized benefit estimate of $25.5 billion. The alternative, age-adjusted approach yields monetary benefits of $14 billion. The final Tier 2/Gasoline Sulfur rule is expected to affect populations in the entire continental U.S[31]. Given a projected U.S. population in 2030 of 300 million, annual monetized per capita benefits (using EPA's preferred approach for valuing reductions in premature mortality) are over $84 in 2030. Assuming an average household size of 2.6 persons, this translates to over $218 per household in 2030.

[31] The Tier 2/Gasoline Sulfur standards will not apply to vehicles in California, however, populations in California are expected to receive some benefits from the Tier 2/Gasoline Sulfur standards due to reductions in pollutants transported into the state from other regions.

Table VII-16. EPA Preferred Estimate of Annual Quantified and Monetized Benefits Associated With Improved Air Quality Resulting from the Tier 2/Gasoline Sulfur Rule in 2030

Endpoint	*Pollutant*	*Avoided Incidence[c,d] (cases/year)*	*Monetary Benefits[e] (millions 1997$)*
Premature mortality[a,h] (adults, 30 and over)	PM[b]	4,300	$23,380
Chronic asthma (adult males, 27 and over)	Ozone	400	$10
Chronic bronchitis	PM	2,300	$730
Hospital Admissions from Respiratory Causes	Ozone and PM	2,200	$20
Hospital Admissions from Cardiovascular Causes	Ozone and PM	800	$10
Emergency Room Visits for Asthma	Ozone and PM	1,200	$<1
Acute bronchitis (children, 8-12)	PM	7,900	$<1
Lower respiratory symptoms (children, 7-14)	PM	87,100	$<5
Upper respiratory symptoms (asthmatic children, 9-11)	PM	86,500	$<5
Shortness of breath (African American asthmatics, 7-12)	PM	17,400	$<1
Work loss days (adults, 18-65)	PM	682,900	$70
Minor restricted activity days /Acute resp. symptoms	Ozone and PM	5,855,000	$270
Other health effects[d]	Ozone, PM, CO, HAPS	$U_1+U_2+U_3+U_4$	$B_1+B_2+B_3+B_4$
Decreased worker productivity	Ozone	—	$140
Recreational visibility (86 Class I Areas)	PM	—	$370
Residential visibility	PM	—	B_5
Household soiling damage	PM	—	B_6
Materials damage	PM	—	B_7
Nitrogen Deposition to Estuaries	Nitrogen	—	B_8
Agricultural crop damage (6 crops)	Ozone	—	$220
Commercial forest damage	Ozone	—	B_9
Other welfare effects[f]	Ozone, PM, CO, HAPS	—	$B_{10}+B_{11}+B_{12}+B_{13}$
Monetized Total[g,h]			$25,220+**B**

[a] Premature mortality associated with ozone is not separately included in this analysis. It is assumed that the Pope, et al. C-R function for premature mortality captures both PM mortality benefits and any mortality benefits associated with other air pollutants. Also note that the valuation assumes the 5 year distributed lag structure described earlier.
[b] PM reductions are due to reductions in NOx and SO_2 resulting from the Tier 2/Gasoline Sulfur rule.
[c] Incidences are rounded to the nearest 100.
[d] The U_i are the incidences for the unquantified category i.

[e] Dollar values are rounded to the nearest 10 million.
[f] A detailed listing of unquantified PM, ozone, CO, and HAPS related heatlh and welfare effects is provided in Table VII-1.
[g] **B** is equal to the sum of all unmonetized categories, i.e. $B_1+B_2+...+B_{13}$.
[h] These estimates are based on the EPA preferred approach for valuing reductions in premature mortality, the VSL approach. This approach and an alternative, age-adjusted approach – the VSLY approach – are discussed more fully in section F.

Table VII-17. Final Tier 2/Gasoline Sulfur Rule: 2030 Monetized Benefits Estimates for Alternative Premature Mortality Valuation Approaches (Billions of 1997 dollars)

Premature Mortality Valuation Approach	*PM Mortality Benefits*	*Total Monetized Benefits*
Value of statistical life (VSL) ($5.9 million per life saved)[a]	$23.4	$25.2 + **B**
Value of statistical life-years (VSLY) ($360,000 per life-year saved, which implies $3.6 million per life saved, based on the mean of 14 life-years saved)[a, b]	$11.9	$13.7 + **B**

[a] Premature mortality estimates are determined assuming a 5 year distributed lag, which applies 25 percent of the incidence in year 1 and 2, and then 16.7 percent of the incidence in years 3, 4, and 5.
[b] The VSLY estimate is calculated by amortizing the $5.9 million mean VSL estimate over the 35 years of life expectancy associated with subjects in the labor market studies used to obtain the VSL estimate. The resulting estimate, using a 5 percent discount rate, is $360,000 per life-year saved in 1997 dollars. This approach is discussed more fully in section F above.

In addition to the preferred estimate, in Table VII-18 we present alternative calculations representing how the value for individual endpoints or total benefits would change if we were to make a different assumption about an element of the benefits analysis. For example, this table can be used to answer questions like "What would total benefits be if we were to use the Dockery, et al. C-R function to estimate avoided premature mortality?" This table provides alternative calculations both for valuation issues (e.g. the correct value for a statistical life saved) and for physical effects issues (e.g., how reversals in chronic illnesses are treated). This table is not meant to be comprehensive. Rather, it reflects some of the key issues identified by EPA or commentors as likely to have a significant impact on total benefits. Accompanying Table VII-18 is a brief discussion of each of the alternative calculations.

While Table VII-18 provides alternative calculations for specific alternative assumptions, there are some parameters to which total benefits may be sensitive but for which no or limited credible scientific information exists to determine plausible values. Sensitivity analyses for these parameters are presented in Appendix VII-A. Issues examined in this appendix include alternative specifications for the lag structure of PM related premature mortality and impacts of assumed thresholds on the estimated incidence of avoided premature mortality. Also, this appendix contains several illustrative endpoint calculations for which the scientific uncertainty is too great to provide a reasonable estimate for which inclusion would lead to double-counting of benefits. These include premature mortality associated with daily fluctuations in PM, infant

mortality associated with PM, and premature mortality associated with daily fluctuations in ozone.

We have simulated a distribution around our preferred estimate to characterize uncertainty in the total benefit estimate due to measurement uncertainty (i.e. variance of estimated C-R functions and valuation functions) holding all other potentially uncertain inputs constant. Based on the simulated distribution, we have included calculations of the 5th and 95th percentiles of the distribution of benefits in Table VII-18. This provides an estimate of how sensitive the preferred estimate of total benefits would be to measurement errors (i.e. statistical uncertainty around C-R and valuation functions) if all other factors could be treated as certain. However, these do not represent the actual range of benefits, given the large number of uncertain factors for which we are not able to provide uncertainty estimates. 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).

Table VII-18. Alternative Benefits Calculations for the Tier 2/Gasoline Sulfur Rule in 2030

Alternative Calculation	*Description of Estimate*	*Impact on Preferred Benefit Estimate (million 1997$)*
5th percentile of "measurement" uncertainty distribution	Estimate of total monetized benefits at the 5th percentile of a distribution generated using Monte Carlo simulation assuming measurement error is the only source of uncertainty in the benefits estimates.	-$20,300 (-81%)
95th percentile of "measurement" uncertainty distribution	Estimate of total monetized benefits at the 95th percentile of a distribution generated using Monte Carlo simulation assuming measurement error is the only source of uncertainty in the benefits estimates.	+$33,900 (+134%)
PM-related premature mortality based on Dockery et al.	The Dockery et al. study provides an alternative estimate of the relationship between chronic PM exposure and mortality. The number of avoided mortality incidences increases from 4,300 to 9,800 (128%)	+$30,200 (+120%)
Value of avoided premature mortality incidences based on statistical life years.	Calculate the incremental number of life-years lost from exposure to changes in ambient PM and use the value of a statistical life year based on a $5.9 million value of a statistical life	-$11,500 (-46%)
Reversals in chronic bronchitis treated as lowest severity cases	Instead of omitting those cases of chronic bronchitis that reverse after a period of time, they are treated as being cases with the lowest severity rating. The number of avoided chronic bronchitis incidences increases from 2,300 to 4,300 (87%)	+$280 (+1%)
Value of visibility changes in all Class I areas	Values of visibility changes at Class I areas in California, the Southwest, and the Southeast are transferred to visibility changes in Class I areas in other regions of the country.	+$180 (+1%)
Value of visibility changes in Eastern U.S. residential areas	Value of visibility changes outside of Class I areas are estimated for the Eastern U.S. based on the reported values for Chicago and Atlanta from McClelland, et al. (1990)	+$420 (+2%)
Value of visibility changes in Western U.S. residential areas	Values of visibility changes outside of Class I areas are estimated for the Western U.S. based on the reported values for Chicago and Atlanta derived from McClelland et al. (1990)	+$130 (+1%)
Household soiling damage	Value of decreases in expenditures on cleaning are estimated using values derived from Manuel, et al. (1983)	+$110 (+1%)

Alternative Calculation	*Description of Estimate*	*Impact on Preferred Benefit Estimate (million 1997$)*
Avoided costs of reducing nitrogen loadings in east coast estuaries	Estuarine benefits in 12 east coast estuaries from reduced atmospheric nitrogen deposition are approximated using the avoided costs of removing or preventing loadings from terrestrial sources.	+$160 (+1%)

The 5th and 95th percentile alternative calculations (rows 1 and 2 of Table VII-18) are estimated by holding air quality changes, population estimates, and other factors, including the parameters examined in Table VII-18, constant and determining the distribution of total benefits that would be generated by a large number of random draws from the distributions of C-R functions and economic valuation functions. These alternative calculations thus show how the preferred estimate of benefits changes in response to uncertainty in the measurement of C-R and valuation functions.

The Dockery, et al. estimate of the relationship between PM exposure and premature mortality (row 3 of Table VII-18) is a plausible alternative to the Pope, et al. The SAB has noted that "the study had better monitoring with less measurement error than did most other studies" (EPA-SAB-COUNCIL-ADV-99-012, 1999). However, the Dockery study had a more limited geographic scope (and a smaller study population) than the Pope, et al. study. The demographics of the Pope,et al. study population, i.e. largely white and middle-class, may also produce a downward bias in the Pope PM mortality coefficient, because short-term studies indicate that the effects of PM tend to be significantly greater among groups of lower socioeconomic status. The Dockery study also covered a broader age category (25 and older compared to 30 and older in the Pope study) and followed the cohort for a longer period (15 years compared to 8 years in the Pope study). For these reasons, the Dockery study is considered to be a plausible alternative estimate of the avoided premature mortality incidences associated with the final Tier 2/Gasoline Sulfur rule.

The value of statistical life years alternative calculation (row 4 of Table VII-18) recognizes that individuals who die from air pollution related causes tend to be older than the average age of individuals in the VSL studies used to develop the $5.9 million value.

The treatment of reversals in chronic bronchitis incidences is addressed in row 5 of Table VII-18. Reversals are defined as those cases where an individual reported having chronic bronchitis at the beginning of the study period but reported not having chronic bronchitis in follow-up interviews at a later point in the study period. Since, by definition, chronic diseases are long-lasting or permanent, if the disease goes away it is not chronic. However, we have not captured the benefits of reducing incidences of bronchitis that are somewhere in-between acute and chronic. One way to address this is to treat reversals as cases of chronic bronchitis that are at

the lowest severity level. These cases thus get the lowest value for chronic bronchitis.

The alternative calculation for recreational visibility (row 6 of Table VII-18) is an estimate of the full value of visibility in the entire region affected by the final Tier 2/Gasoline Sulfur rule. The Chestnut and Rowe study from which the primary valuation estimates are derived only examined WTP for visibility changes in the southeastern portion of the affected region. In order to obtain estimates of WTP for visibility changes in the northeastern and central portion of the affected region, we have to transfer the southeastern WTP values. This introduces additional uncertainty into the estimates. However, we have taken steps to adjust the WTP values to account for the possibility that a visibility improvement in parks in one region, is not necessarily the same environmental quality good as the same visibility improvement at parks in a different region. This may be due to differences in the scenic vistas at different parks, uniqueness of the parks, or other factors, such as public familiarity with the park resource. To take this potential difference into account, we adjusted the WTP being transferred by the ratio of visitor days in the two regions[20] A complete discussion of the benefits transfer method used to generate this alternative estimate is provided in the benefits TSD for this RIA (Abt Associates, 1999)

The alternative calculation for residential visibility (row 7 of Table VII-18) is based on the McClelland, et al. study of WTP for visibility changes in Chicago and Atlanta. As discussed in section F.1, the residential visibility estimates from the available literature have been determined by the SAB to be inadequate for use in a primary estimate in a benefit-cost analysis. However, EPA recognizes that residential visibility is likely to have some value and the McClelland, et al. estimates are the most useful in providing an estimate of the likely magnitude of the benefits of residential visibility improvements.

The alternative calculation for household soiling (row 8 of Table VII-18) is based on the Manuel et al. study of consumer expenditures on cleaning and household maintenance. This study has been cited as being “the only study that measures welfare benefits in a manner consistent with economic principals (Desvouges et al., 1998). However, the data used to estimate household soiling damages in the Manuel, et al. study is from a 1972 consumer expenditure survey and as such may not accurately represent consumer preferences in 2007. EPA recognizes this limitation, but believes the Manuel, et al. estimates are still useful in providing an estimate of the likely magnitude of the benefits of reduced household soiling by particulate matter.

The alternative calculation for the avoided costs of reductions in nitrogen loadings (row 9 of Table VII-18) is constructed by examining the avoided costs to surrounding communities of reduced nitrogen loadings for three case study estuaries (EPA, 1998).[21] The three case study estuaries are chosen because they have agreed upon nitrogen reduction goals and the necessary nitrogen control cost data. The values of atmospheric nitrogen reductions are determined on the basis of avoided costs associated with agreed upon controls of nonpoint water pollution sources. Benefits are estimated 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. The avoided cost measure is likely to be an underestimate of the value of reduced nitrogen loadings in eastern estuaries because: 1) the twelve estuaries represent only about fifty percent of the total watershed area in the eastern U.S.; and 2) costs avoided are not good proxies for willingness-to-pay. The details of the nitrogen deposition benefits calculation are provided in the benefits TSD for this RIA (Abt Associates, 1999).

G. Summary of Cost Results

Since the benefits assessment has been performed on the basis of a 2030 fleet of Tier 2 vehicles, consistent costs were developed using the same basis. 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 2030 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 to multiply the cost effectiveness ratio (dollars per ton) times the emission reduction estimates for the benefits assessment.

The cost-effectiveness value that was used in our calculation of applicable costs was calculated as the ratio of the net present value of vehicle and fuel costs divided by the net present value of emission reductions for an average vehicle meeting our Tier 2 standards, as described in Section VI. However, the cost-effectiveness value used for our benefit-cost analysis differed in several ways from those in Table VI-8. These differences ensured that the cost-effectiveness value represented the same set of assumptions that were used when we developed the emission inventories for use in the air quality modeling that formed the basis of the benefits analysis. Specifically, we did not include the larger LDT4 trucks weighing greater than 8500 lb GVWR, and we did not include any effects of catalyst irreversibility. We also focused on the "long-term" cost-effectiveness as described above, since this value best represents the cost-effectiveness in

2030.

Finally, adjustments for two factors relating to fuel consumption needed to be made to enable us to arrive at a final value for the adjusted cost. First the cost effectiveness value we calculated did not account for the approximately 20 percent drop in the per-gallon fuel cost occurring about 2020 (due to the lowering cost of desulfurization technology discussed in Chapter V). Second, our cost effectiveness value also did not include the effects of expected improvements in fleet fuel economy prior to 2020, also discussed in Chapter V. Improvements in light duty truck and passenger car fuel economy are expected to reduce 2020 and beyond per-mile fuel consumption by a little over 10 percent compared to that used in our cost effectiveness calculation. Adjustments to account for the impact of these factors on total cost are included in the table below.

There is one factor related to calculation of the adjusted cost which we were not able to quantitatively account for in this analysis. This relates to the increasing rate of mileage accumulation per vehicle over time. Fleet wide VMT is generally growing faster than vehicle sales, indicating a gradual growth in VMT per vehicle. However, our per-vehicle cost effectiveness is based on the current distribution of VMT with age of the vehicle, providing a conservative basis for our cost-effectiveness calculations. By 2030, this assumption is likely to yield substantially higher cost-effectiveness values than are appropriate. At this time we have no specific estimate of the impact of this growth in per-vehicle VMT, so no adjustment has been made to account for its existence. The adjusted cost would be lower if this factor were accounted for.

The resulting adjusted costs are somewhat greater than the actual annual cost of the program, reflecting the time value adjustment and lack of correction for the increase in VMT per vehicle. Thus, the costs presented in this section do not represent actual annual costs of the Tier 2/gasoline sulfur program for 2030. Rather, they represent an approximation of the steady-state cost per ton that would likely prevail in that time period. Except for the VMT adjustment, 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 per-vehicle costs are larger in the early years of the program while the benefits are smaller. The resulting adjusted cost value is given in Table VII-19.

Table VII - 19. Adjusted Cost for Comparison to Benefits

Cost per ton ratio	*fuel cost adjustment*	*fuel economy adjustment*	*Tons of NOx + NMHC*	*Adjusted Cost (billions of 1997 dollars)*
$2,107	0.87	0.9	3,204,600	$5.3

I. Comparison of Costs and Benefits

Benefit-cost analysis provides a valuable framework for organizing and evaluating information on the effects of environmental programs. When used properly, benefit-cost analysis helps illuminate important potential effects of alternative policies and helps set priorities for closing information gaps and reducing uncertainty. According to economic theory, the efficient alternative policy maximizes net benefits to society (i.e., social benefits minus social costs). However, not all relevant costs and benefits can be captured in any analysis. Executive Order 12866 clearly indicates that unquantifiable or nonmonetizable categories of both costs and benefits should not be ignored. There are many important unquantified and unmonetized costs and benefits associated with reductions in emissions, including many health and welfare effects. Potential benefit categories that have not been quantified and monetized are listed in Table VII-1 of this chapter.

In addition to categories that cannot be included in the calculated net benefits, there are also practical limitations for the comparison of benefits to costs in this analysis, which have been discussed throughout this chapter. Several specific limitations deserve to be mentioned again here:

- The state of atmospheric modeling is not sufficiently advanced to provide a workable "one atmosphere" model capable of characterizing ground-level pollutant exposure for all pollutants of interest (e.g., ozone, particulate matter, carbon monoxide, nitrogen deposition, etc). Therefore, the EPA must employ several different pollutant models to characterize the effects of alternative policies on relevant pollutants. Also, not all atmospheric models have been widely validated against actual ambient data. In particular, since a broad-scale monitoring network does not yet exist for fine particulate matter ($PM_{2.5}$), atmospheric models designed to capture the effects of alternative policies on $PM_{2.5}$ are not fully validated. Additionally, significant shortcomings exist in the data that are available to perform these analyses. While containing identifiable shortcomings and uncertainties, EPA believes the models and assumptions used in the analysis are reasonable based on the available evidence.

- Another dimension adding to the uncertainty of this analysis is time. Thirty years is a very long time over which to carry assumptions. Projected growth in population and VMT over the 30-year period may have a significant effect on the benefits estimates. Pollution control technology has advanced considerably in the last 10 years and can be expected to continue to advance in the future. Yet there is no clear way to model this advance for use in this analysis. In addition, there is no clear way to predict future meteorological conditions, or the growth in emissions from other sources over time. Again, EPA believes that the assumptions to capture these elements are reasonable based on the available evidence.

- Qualitative and more detailed discussions of the above and other uncertainties and limitations are included in detail in earlier sections. Where information and data exist, quantitative characterizations of these uncertainties are included (in this chapter and in Appendix VII-A). However, data limitations prevent an overall quantitative estimate of the uncertainty associated with final estimates. Nevertheless, the reader should keep all of these uncertainties and limitations in mind when reviewing and interpreting the results.

- The preferred benefit estimate does not include the monetary value of several known ozone and PM-related welfare effects, including commercial forest growth, residential visibility, household soiling and materials damage, and deposition of nitrogen to sensitive estuaries.

Nonetheless, if one is mindful of these limitations, the relative magnitude of the benefit-cost comparison presented here can be useful information. Thus, this section summarizes the benefit and cost estimates that are potentially useful for evaluating the efficiency of the final Tier 2 rulemaking.

The estimated adjusted cost of implementing the final Tier 2 program is **$5.3 billion (1997$)**, while the estimate of monetized benefits using EPA's preferred approach for monetizing reductions in PM-related premature mortality – the VSL approach – are **$25.2 billion (1997$).** Monetized net benefits using EPA's preferred method for valuing avoided incidences of premature mortality are approximately **$19.9 billion (1997$).** Using the alternative, age-adjusted approach – the VSLY approach – total monetized benefits are projected to be around **$13.8 billion (1997$)**. Monetized net benefits using this approach are approximately **$8.5 billion (1997$)**. Therefore, implementation of the Tier 2 program will provide society with a net gain in social welfare. Tables VII-20 and VII-21 summarize the costs, benefits, and net benefits for the two alternative valuation approaches.

Table VII-20. 2030 Annual Monetized Costs, Benefits, and Net Benefits for the Final Tier 2/Gasoline Sulfur Rule: EPA Preferred Estimates Using the Value of Statistical Lives Saved Approach to Value Reductions in Premature Mortality[a]

	Billion 1997$
Adjusted compliance costs	$5.3
Monetized PM-related benefits[b,d]	$24.7+$\mathbf{B_{PM}}$
Monetized Ozone-related benefits[b]	$0.5+$\mathbf{B_{Ozone}}$
Monetized net benefits[c,d]	$19.9+**B**

[a] For this section , all costs and benefits are rounded to the nearest 100 million. Thus, figures presented in this chapter may not exactly equal benefit and cost numbers presented in earlier sections of the chapter.
[b] Not all possible benefits or disbenefits are quantified and monetized in this analysis. Potential benefit categories that have not been quantified and monetized are listed in **Table VII-1.** Unmonetized PM- and ozone-related benefits are indicated by B_{PM}. And B_{Ozone}, respectively.
[c] **B** is equal to the sum of all unmonetized benefits, including those associated with PM, ozone, CO, and HAPS.
[d] These estimates are based on the EPA preferred approach for valuing reductions in premature mortality, the VSL approach. This approach and an alternative, age-adjusted approach – the VSLY approach – are discussed more fully in section F.

Table VII-21. 2030 Annual Monetized Costs, Benefits, and Net Benefits for the Final Tier 2/Gasoline Sulfur Rule: Alternative Estimates Using the Value of Statistical Life Years Saved Approach to Value Reductions in Premature Mortality[a]

	Billion 1997$
Adjusted compliance costs	$5.3
Monetized PM-related benefits[b,d]	$13.3+$\mathbf{B_{PM}}$
Monetized Ozone-related benefits[b]	$0.5+$\mathbf{B_{Ozone}}$
Monetized net benefits[c,d]	$8.5+**B**

[a] For this section , all costs and benefits are rounded to the nearest 100 million. Thus, figures presented in this chapter may not exactly equal benefit and cost numbers presented in earlier sections of the chapter.
[b] Not all possible benefits or disbenefits are quantified and monetized in this analysis. Potential benefit categories that have not been quantified and monetized are listed in **Table VII-1.** Unmonetized PM- and ozone-related benefits are indicated by B_{PM}. And B_{Ozone}, respectively.
[c] **B** is equal to the sum of all unmonetized benefits, including those associated with PM, ozone, CO, and HAPS.
[d] The VSLY estimate is calculated by amortizing the $5.9 million mean VSL estimate over the 35 years of life expectancy associated with subjects in the labor market studies used to obtain the VSL estimate. The resulting estimate, using a 5 percent discount rate, is $360,000 per life-year saved in 1997 dollars. This approach is discussed more fully in section F above.

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Appendix VII-A
Supplementary Benefit Estimates and Sensitivity Analyses of Key Parameters in the Benefits Analysis

A. Introduction and Overview

In chapter VII, we estimated the benefits of the final Tier 2/gasoline sulfur rule using the most comprehensive set of endpoints available. For some health endpoints, this meant using a dose-response function that linked a larger set of effects to a change in pollution, rather than using dose-response functions for individual effects. For example, the minor restricted activity days/any of 19 acute respiratory symptoms endpoint covers most of the symptoms used to characterize asthma attacks and days of moderate or worse asthma. For premature mortality, we selected a dose-response function that captured reductions in incidences due to both long and short-term exposures to ambient concentrations of particulate matter (PM). In addition, the premature mortality dose-response function is expected to capture at least some of the mortality effects associated with exposure to ozone. This effect is described more fully below in section A.2.

In order to provide the reader with a fuller understanding of the health effects associated with reductions in air pollution associated with the final Tier 2/gasoline sulfur rule, this appendix provides estimates for those health effects which, if included in the primary estimate, could result in double-counting of benefits. For some endpoints, such as ozone mortality, additional research is needed to provide separate estimates of the effects for different pollutants, i.e. PM and ozone. These supplemental estimates should not be considered as additive to the primary estimate of benefits. Supplemental estimates included in this appendix include premature mortality associated with short-term exposures to PM and ozone, asthma attacks, and occurrences of moderate or worse asthma symptoms. In addition, an estimate of the avoided incidences of premature mortality in infants is provided. Because the Pope, et al. estimate applies only to adults, avoided incidences of infant mortality are additive to the primary benefits estimate.

Table VII-19 in Chapter VII reports the results of alternative calculations based on plausible alternatives to the assumptions used in deriving the primary estimate of benefits. In addition to these calculations, two important parameters, the length and structure of the potential lag in mortality effects and thresholds in PM health effects, have been identified as key to the analysis, and are explored in this appendix through the use of sensitivity analyses.

B. Supplementary Benefit Estimates

In the primary estimate, we use the Pope et al. study to provide the C-R function relating premature mortality to long-term PM exposure. In the primary analysis, we assume that

this mortality occurs over a five year period, with 25 percent of the deaths occurring in the first year, 25 percent in the second year, and 16.7 percent in each of the third, fourth, and fifth years. Studies examining the relationship between short-term exposures and premature mortality can reveal what proportion of premature mortality is due to immediate response to daily variations in PM. There is only one short-term study (presenting results from 6 separate U.S. cities) that uses $PM_{2.5}$ as the metric of PM (Schwartz et al., 1996). As such, the supplemental estimate for premature mortality related to short-term PM exposures is based on the pooled city-specific, short-term $PM_{2.5}$ results from Schwartz, et al.

In the Tier 2 Proposal RIA, we estimated avoided incidences of ozone-related premature mortality for the primary benefits estimate. Based on recent advice from the SAB (EPA-SAB-Council-ADV-99-012, 1999), we have converted this endpoint to a supplemental estimate to avoid potential double-counting of benefits captured by the Pope, et al. PM premature mortality endpoint[32]. There are many studies of the relationship between ambient ozone levels and daily mortality levels. The supplemental estimate is calculated using results from only four U.S. studies (Ito and Thurston, 1996; Kinney et al., 1995; Moolgavkar et al., 1995; and Samet et al., 1997), based on the assumption that demographic and environmental conditions on average would be more similar between these studies and the conditions prevailing when the Tier 2/gasoline sulfur rule is implemented. 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. We combined these studies using probabilistic sampling methods 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). The estimated incidences of short-term premature mortality are valued using the value of statistical lives saved method, as described in Chapter VII.

The estimated effect of PM exposure on premature mortality in infants (post neo-natal) is based on a single U.S. study (Woodruff, et al, 1997) which, on recommendation of the Science Advisory Board, was deemed too uncertain to include in the primary analysis. Adding this endpoint to the primary benefits estimate would result in an increase in total benefits.

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[32]While the growing body of epidemiological studies suggests that there may be a positive relationship between ozone and premature mortality, there is still substantial uncertainty about this relationship. Because the evidence linking premature mortality and particulate matter is currently stronger than the evidence linking premature mortality and ozone, it is important that models of the relationship between ozone and mortality include a measure of particulate matter as well. Because of the lack of monitoring data on fine particulates or its components, however, the measure of particulate matter used in most studies was generally either PM10 or TSP or, in some cases, Black Smoke. If a component of PM, such as PM 2.5 or sulfates, is more highly correlated with ozone than with PM or TSP, and if this component is also related to premature mortality, then the apparent ozone effects on mortality could be at least partially spurious. Even if there is a true relationship between ozone and premature mortality, after taking particulate matter into account, there would be a potential problem of double counting in this analysis if the ozone effects on premature mortality were added to the PM effects estimated by Pope et al., 1995, because, as noted above, the Pope study does not include ozone in its model.

As noted in Chapter VII, asthma affects over seven percent of the U.S. population. One study identifies a statistical association between air pollution and the development of asthma in some non-smoking adult men. Other studies identify a relationship between air quality and occurrences of acute asthma attacks or worsening of asthma symptoms. Supplemental estimates are provided for two asthma related endpoints. Occurrence of moderate or worse asthma symptoms in adults is estimated using a C-R function derived from Ostro, et al. (1991). Asthma attacks in children are estimated using a C-R function derived from Whittemore and Korn (1980). Both asthma attacks and occurrence of moderate or worse asthma symptoms are valued at $39 per incidence, based on the mean of average WTP estimates for the four severity definitions of a “bad asthma day,” described in Rowe and Chestnut (1986), a study which surveyed asthmatics to estimate WTP for avoidance of a "bad asthma day,” as defined by the subjects.

Table VII-A-1 presents estimated incidences and values for the supplemental endpoints listed above. The supplemental estimate of 1,200 avoided incidences of premature mortality from short-term exposures to PM indicates that these incidences are approximately 25 percent of the total premature mortality incidences estimated using the Pope, et al., study (4,300). This lends support for the assumption that 25 percent of the premature deaths predicted to be avoided in the first year using the Pope study should be assigned to the first year after a reduction in exposure.

The infant mortality estimate indicates that exclusion of this endpoint does not have a large impact, either in terms of incidences (13) or monetary value (approximately $80 million). Estimates of the value for separate asthma endpoints are well under the estimate of the value of all respiratory symptoms. All of these supplemental estimates support the set of endpoints and assumptions chosen as the basis of the primary benefits estimate described in Chapter VII.

Table VII-A-1
Supplemental Benefit Estimates for the Final Tier 2 Rule for the 2030 Analysis Year

Endpoint	*Pollutant*	*Avoided Incidence[a] (cases/year)*	*Monetary Benefits[b] (millions 1997$)*
Premature mortality (short-term exposures)	PM	1,200	$6,320
Premature mortality (short-term exposures)[c]	Ozone	500	$2,670
Premature mortality in infant population	PM	<100	$80
Asthma attacks	PM	77,000	$<10
Asthma attacks [c]	Ozone	188,100	$10
Moderate or Worse Asthma	PM	79,500	$<10

[a] Incidences are rounded to the nearest 100.
[b] Dollar values are rounded to the nearest 10.

C. Sensitivity Analyses

As discussed in Chapter VII, there are two key parameters of the benefits analysis for which there are no specific values recommended in the scientific literature. These parameters, the lag between changes in exposure to PM and reductions in premature mortality and the threshold in PM-related health effects, are investigated in this section through the use of sensitivity analyses, we perform an analysis of the sensitivity of benefits valuation to the lag structure by considering a range of assumptions about the timing of premature mortality. To examine the threshold parameter, we show how the estimated avoided incidences of PM-related premature mortality are distributed with respect to the threshold.

1. Alternative Lag Structures

As noted by the SAB (EPA-SAB-COUNCIL-ADV-00-001, 1999), “some of the mortality effects of cumulative exposures will occur over short periods of time in individuals with compromised health status, but other effects are likely to occur among individuals who, at baseline, have reasonably good health that will deteriorate because of continued exposure. No animal models have yet been developed to quantify these cumulative effects, nor are there epidemiologic studies bearing on this question.” However, they also note that “Although there is substantial evidence that a portion of the mortality effect of PM is manifest within a short period of time, i.e., less than one year, it can be argued that, if no a lag assumption is made, the entire mortality excess observed in the cohort studies will be analyzed as immediate effects, and this will result in an overestimate of the health benefits of improved air quality. Thus some time lag is appropriate for distributing the cumulative mortality effect of PM in the population.” In the

primary analysis, based on SAB advice, we assume that mortality occurs over a five year period, with 25 percent of the deaths occurring in the first year, 25 percent in the second year, and 16.7 percent in each of the third, fourth, and fifth years. Readers should note that the selection of a 5 year lag is not supported by any scientific literature on PM-related mortality. Rather it is intended to be a best guess at the appropriate distribution of avoided incidences of PM-related mortality.

Although the SAB recommended the five-year distributed lag be used for the primary analysis, the SAB has also recommended (EPA-SAB-COUNCIL-ADV-00-001, 1999) that alternative lag structures be explored as a sensitivity analysis. Specifically, they recommended an analysis of 0, 8, and 15 year lags. The 0 year lag is representative of EPA's assumption in previous RIAs. The 8 and 15 year lags are based on the study periods from the Pope and Dockery studies, respectively[33]. However, neither the Pope or Dockery studies assumed any lag structure when estimating the relative risks from PM exposure. In fact, the Pope and Dockery studies do not contain any data either supporting or refuting the existence of a lag. Therefore, any lag structure applied to the avoided incidences estimated from either of these studies will be an assumed structure. The 8 and 15 year lags implicitly assume that all premature mortalities occur at the end of the study periods, i.e. at 8 and 15 years. We also present two additional lags: a 15 year distributed lag with the distribution skewed towards the early years and a 15 year distributed lag with the distribution skewed towards the later years. This is to demonstrate how sensitive the results are not only to the length of the lag, but also to the shape of the distribution of incidences over the lag period. It is important to keep in mind that changes in the lag assumptions do not change the total number of estimated deaths, but rather the timing of those deaths.

The estimated impacts of alternative lag structures on the monetary benefits associated with reductions in PM-related premature mortality (estimated with the Pope, et al. C-R function) are presented in Table VII-A-2. These estimates are based on the value of statistical lives saved approach, i.e. $5.9 million per incidence, and assume a 5 percent discount rate over the lag period. The results using the primary 5-year lag are repeated here for comparison. The table reveals that the length of the lag period is not as important as the distribution of incidences within the lag period. A 15 year distributed lag with most of the incidences occurring in the early years reduces monetary benefits less than an 8 year lag with all incidences occurring at the eighth year. Even with an extreme lag assumption of 15 years, benefits are reduced by less than half relative to the no lag and primary (5 year distributed lag) benefit estimates.

[33]Although these studies were conducted for 8 and 15 years, respectively, the choice of the duration of the study by the authors was not likely due to observations of a lag in effects, but is more likely due to the expense of conducting long-term studies or the amount of satisfactory data that could be collected during this time period.

Table VII-A-2
Sensitivity Analysis of Alternative Lag Structures for PM-related Premature Mortality

Lag	*Description*	*Monetary Benefit (millions 1997$)*	*Percent of Primary Estimate*
5-year distributed	Primary estimate, incidences are distributed with 25% in the 1st and 2nd years, and 16.7% in the remaining 3 years.	$23,400	100%
None	Incidences all occur in the first year	$25,400	109%
8 year	Incidences all occur in the 8th year	$18,000	77%
15 year	Incidences all occur in the 15th year	$12,800	55%
15 year distributed - skewed early	Incidences are distributed with 30% in the 1st year, 25% in the 2nd year, 15% in the 3rd year, 6% in the 4th year, 4% in the 5th year, and the remainder 20% distributed over the last 10 years.	$22,700	97%
15 year distributed - skewed late	Incidences are distributed with 4% in the 11th year, 6% in the 12th year, 15% in the 13th year, 25% in the 14th year, and 30% in the 15th year, with the remaining 20 % distributed over the first 10 years.	$14,800	63%

2. PM Health Effect Threshold

In developing its primary estimate of benefits for previous analyses, EPA has assumed a PM health effects threshold equal to the lowest observed level in a given epidemiological study or anthropogenic background when no lowest observed level is reported (Hubbell, 1998). Recent advice from the SAB (EPA-SAB-Council-ADV-99-012, 1999) is that there is currently no scientific basis for selecting a threshold of 15 $\mu g/m^3$ or any other specific threshold for the PM related health effects considered in this analysis. The most important health endpoint that would be impacted by a PM threshold is premature mortality, as measured by the Pope, et al. (1995) C-R function. Pope et al. did not explicitly include a threshold in their analysis. However, if the true mortality C-R relationship has a threshold, then Pope et al.'s slope coefficient would likely have been underestimated for that portion of the C-R relationship above the threshold. This would likely lead to an underestimate of the incidences of avoided cases above any assumed

threshold level. It is difficult to determine the size of the underestimate without data on a likely threshold and without re-analyzing the Pope et al. data. Nevertheless, it is illustrative to show at what threshold levels benefits are significantly affected.

Any of the PM-related health effects estimated in the primary analysis could have a threshold; however a threshold for PM-related mortality would have the greatest impact on the overall benefits analysis. Figure A-1 shows the effect of incorporating a range of possible thresholds, using 2030 PM levels and the Pope et al. (1995) study.

The distribution of premature mortality incidences in Figure A-1 indicates that over ninety percent of the premature mortality related benefits of the final Tier 2/gasoline sulfur rule are due to changes in PM concentrations occurring above 10 $\mu g/m^3$, and around seventy-five percent are due to changes above 12 $\mu g/m^3$, the lowest observed level in the Pope, et al. study. Over fifty percent of avoided incidences are due to changes occurring above the $PM_{2.5}$ standard of 15 $\mu g/m^3$.

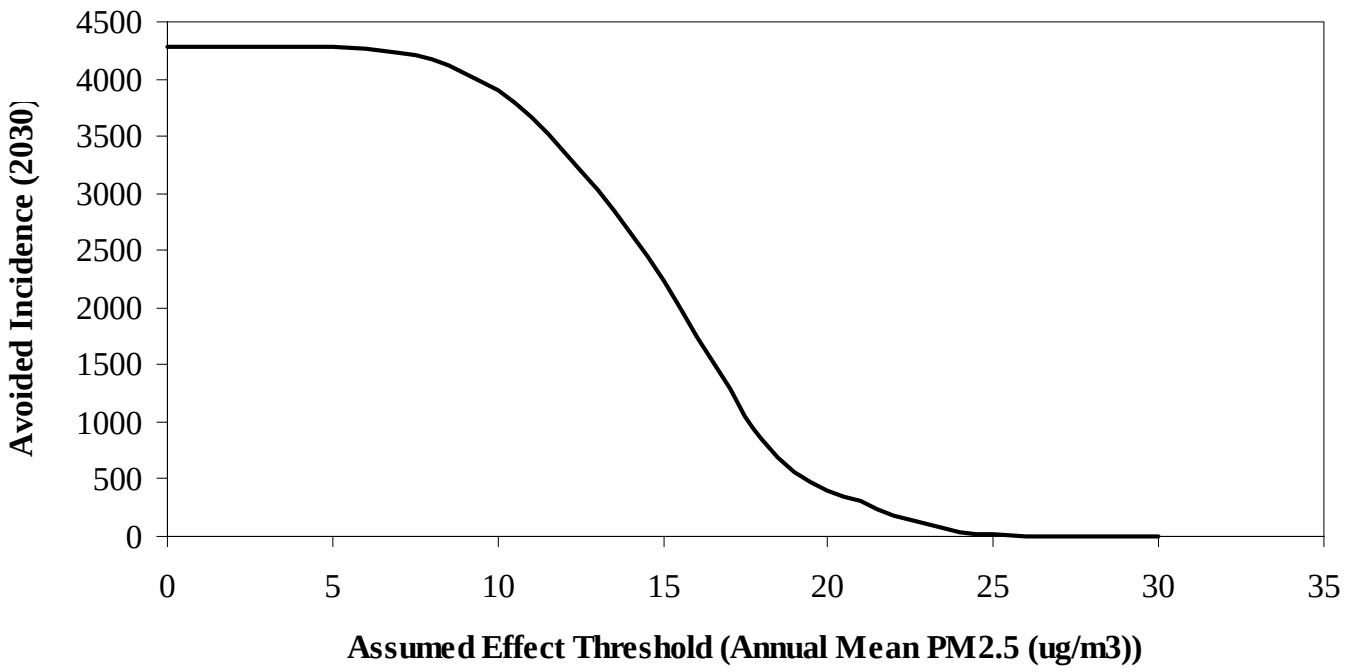

Figure VII-A-1
Impact of PM Health Effects Threshold on Avoided Incidences of Premature Mortality Estimated with the Pope Concentration-Response Function

D. References

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Chapter VIII: Regulatory Flexibility

This chapter presents our Final Regulatory Flexibility Analysis (FRFA) which evaluates the impacts of our Tier 2 and gasoline sulfur standards on small businesses. Prior to issuing our proposal last May, we analyzed the potential impacts of our program on small businesses. As a part of this analysis, we convened a Small Business Advocacy Review Panel, as required under the Regulatory Flexibility Act as amended by the Small Business Regulatory Enforcement Fairness Act of 1996 (SBREFA). Through the Panel process, we gathered advice and recommendations from small entity representatives (SERs) who would be affected by our proposed vehicle and fuel standards. The report of the Panel has been placed in the rulemaking record.[1] A month after our proposal was published in the Federal Register, we held four public hearings to obtain feedback on it. The small business provisions of today's action reflect changes to the proposed program based upon updated analyses as well as comments heard at the public hearings and those submitted in writing during the comment period.

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 FRFA 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 RFA was amended by SBREFA to ensure that concerns regarding small entities are adequately considered during the development of new regulations that affect them. Although we are not required by the CAA to provide special treatment to small businesses, the RFA requires us to carefully consider the economic impacts that our rules will have on small entities. Specifically, the RFA requires us to determine, to the extent feasible, our rule's economic impact on small entities, explore regulatory options for reducing any significant economic impact on a substantial number of such entities, and explain our ultimate choice of regulatory approach.

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.

B. Description of Affected Entities

Our Tier 2/gasoline sulfur program will primarily affect manufacturers of LDVs, LDTs, 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 corporate-wide to qualify as a SBA small business. Based on our small business analysis, we believe that some small refiners will 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 are more affected by our gasoline sulfur control program than any other industry, some marketers of gasoline, many of which are small by SBA's definition[1], may also be impacted. However, this impact appears to be limited to new or expanded requirements for reporting the sulfur content of gasoline samples.

3. Small Certifiers of Covered Vehicles

In addition to the major vehicle manufacturers, three distinct categories of businesses relating to LDVs and LDTs exist that are 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 (ICIs) 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

[1]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.

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 will 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 will be relatively more difficult for small manufacturers to achieve than larger manufacturers because 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	1.47	3	14
PADD IV	2.58	6	28

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 15
Small Gasoline Marketers	Several Hundred
Small Certifiers of Covered Vehicles	Approximately 15

We have estimated that small refiners produce approximately four percent of all gasoline in the U.S., excluding California. In most cases, gasoline produced by small refiners is mixed with substantial amounts of other gasoline prior to retail distribution (due to the nature of the gasoline distribution system).

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 requiring 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 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 requiring 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 is relatively short and will require only the minimum information necessary to demonstrate compliance with the applicable sulfur standards. Parties are 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 are also 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

Our Tier 2 emission standards and gasoline sulfur control regulations 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, we are not aware of any area where the new regulations would duplicate, overlap, or conflict with any existing federal, state, or local regulations.

G. Regulatory Alternatives

We considered a wide range of options and regulatory alternatives for providing small businesses flexibility in complying with the Tier 2 vehicle emission and gasoline sulfur standards. The regulatory flexibilities we are providing for small businesses are described below.

1. Small Refiner Interim Sulfur Standards

Upon careful review of the comments received on the proposal as well as the recommendations of the Small Business Advocacy Review Panel, we have determined that regulatory relief in the form of delayed compliance dates is appropriate to allow small refiners, both foreign and domestic, to comply with our regulations without disproportionate burdens. From 2004-2007, when other refiners must meet the 30/80 standards (or the standards listed in Table IV.C-1 of the preamble if they are participating in our ABT program), refiners meeting the corporate employee and capacity limits are allowed to comply with somewhat less stringent requirements. These interim annual-average standards, beginning in 2004, for qualifying small refiners are shown in Table VIII-4 below.

Table VIII-4. Temporary Gasoline Sulfur Requirements for Small Refiners in 2004-2007

Refinery Baseline Sulfur Level (ppm)	*Temporary Sulfur Standards (ppm)*	
	Average	*Cap*
0 to 30	30 ppm	300 ppm
31 to 200	Baseline Level	300 ppm
201 to 400	200 ppm	300 ppm
401 to 600	50% of baseline	Factor of 1.5 times the average standard
601 and above	300	450

The cap standards for the first two "bins" of refineries (that is those with baseline sulfur levels from zero to 30 and 31 to 200) have been relaxed somewhat based on comments that the proposed standards for these two bins were more stringent than the options under discussion for all other refiners. We believe that small refiners should be able to meet the average standards without much, if any, change to their operations but the more lenient cap will give them some flexibility for turnarounds or unexpected equipment shutdowns. In addition, small refiners may also use credits or allotments in 2004-2007 to comply with their average standards.

Compliance with these standards is based on a refiner's demonstration that it meets our specific small refiner criteria. Refiners who qualify as a small refiner under our definition must establish a sulfur baseline for each of their participating refineries. Section IV.C.2. of the preamble explains these requirements in more detail.

Based on comments received on the proposal, we are also making four other changes to our small refiner program.

1. We are revising the employee number criterion.
2. We are adopting a cap on the corporate crude oil capacity for a refining company to qualify as a small business under today's regulations.
3. We are allowing small refiners to use credits and allotments to meet their average standard (as specified in Table VIII-1) in addition to allowing them to generate credits (from 2000 through 2007) and allotments (2003 only).
4. We are requiring that small refiners expecting to apply for a hardship extension establish a compliance plan to demonstrate their commitment to produce low sulfur gasoline (described in subsection a below).

In regard to the employee number criterion, we are modifying how the employee number is determined, based on comments received from SBA. As mentioned above, our proposed definition applied to any petroleum refining company having no more than 1,500 employees throughout the corporation as of January 1, 1999. We selected that date to prevent companies from "gaming" the system. However, as SBA pointed out in its comments, the Small Business Act regulations specify that, where the number of employees is used as a size standard, as we proposed for small refiners, size determination is based on the average number of employees for all pay periods during the preceding 12 months. Since we intended to use SBA's size standard in our proposal, we are incorporating that definition correctly in today's action. It is also worth mentioning that SBA shares our concerns about preventing companies from gaming the system and that it solved this problem specifically by using the average employment over 12 months. In addition, the averaging concept was designed to properly address firms with seasonal fluctuations, according to SBA.

Second, we're amending the small refiner definition to include a corporate capacity cap. We believe such a corporate capacity limitation is necessary to ensure that only truly small businesses benefit from the relaxed interim standards. Furthermore, we received many comments we should adopt a threshold based on crude capacity as specified in the Clean Air Act and used in past EPA fuel programs.

As proposed, small refiners will be permitted to generate and trade sulfur credits and allotments if they reduce sulfur levels early in 2000-2003. In today's action, we are also allowing them to generate credits in 2004-2007. Furthermore, they may use credits that they generate in 2000-2007 and/or purchase credits from another refinery to meet their average standard during 2004-2007. A small refiner may sell credits in 2004 and beyond provided they honor the credit life provisions explained in the ABT section (Section IV.C.1.c., above) while at the same time meeting the small refinery standards.

a. Extensions Beyond 2007 for Qualifying Small Refiners

We are also finalizing our proposed hardship relief provision for qualifying small refiners with some added detail based on the feedback we received during the public comment period. Beginning January 1, 2008, all small companies' refineries must meet the national sulfur standard of 30 ppm on average and the 80 ppm cap, except small refineries that apply for and receive an extension of their 2007 standards. An extension will provide a given small refinery up to an additional two years to comply with the national standards. An extension must be requested in writing and must specify the factors that demonstrate a significant economic hardship to qualify the refinery for such an extension. Factors considered for an extension could include, but are not limited to, the refinery's financial position; its efforts to procure necessary equipment and to obtain design and engineering services and construction contractors; the

availability of desulfurization equipment, and any other relevant factors.

In order for us to consider an extension, a refiner must submit a detailed request for an extension by January 1, 2007 demonstrating that it has made best efforts to obtain necessary financing, and must provide detailed information regarding any lack of success in obtaining financing. In addition, the refiner must meet the compliance plan requirements described below. If we determine that the refiner has made the best efforts possible to achieve compliance with the national standards by January 1, 2008, but has been unsuccessful for reasons beyond its control, we will consider granting the hardship extension initially for the 2008 averaging period. If further relief is appropriate for good reasons, we will consider a further extension through the 2009 averaging period but in no case will this relief be provided unless the refiner can demonstrate conclusively that it has financing in place and that it will be able to complete construction and meet the national gasoline sulfur standards no later than December 31, 2009.

b. Compliance Plans for Demonstrating a Commitment to Produce Low Sulfur Gasoline

This final rule includes a compliance plan provision for those refiners who may seek a hardship extension of their approved interim standards. This provision requires that those refiners with approved interim standards who seek a hardship extension must submit a series of reports to EPA discussing and describing their progress toward producing gasoline that meets the 30/80 ppm standards by January 1, 2008. We expect that small refiners will need to begin preparations to meet the national standards in 2008 by 2004. However, we understand that the potential exists for some small refiners to face additional hardship circumstances that will warrant more time to meet the standards. For this reason, we have adopted provisions (see above) allowing refiners subject to the interim standards to petition us and make a showing that additional time is needed to meet the national standards. To properly evaluate hardship applications, we are requiring demonstrations of good faith efforts towards assessing the economic feasibility, along with the business and technical practicality of ultimately producing low sulfur gasoline. Such progress reports must be submitted for a refiner to receive consideration in any future determinations regarding hardship extensions. However, these reports are not required from refiners who will not be seeking a hardship extension.

By June 1, 2004, such refiners would need to submit preliminary information in the form of a report outlining its time line for compliance and a project plan discussing areas such as permits, engineering plans (e.g., design and construction), and capital commitments for making the necessary modifications to produce low sulfur gasoline. Documents showing activities and progress in these areas should be provided if available.

By no later than June 1, 2005, these small refiners would need to submit a report to us

stating in detail progress to date based on their time line and project plan. This should include copies of approved permits for construction of the equipment, contracts for design and construction, and any available evidence of having secured the necessary financing to complete the required construction. If any difficulties in meeting this requirement are anticipated, the refiner must submit a detailed report of all efforts to date and the factors that may cause delay, including costs, specification of engineering or other design work still needed and reasons for delay, specification of equipment needed and any reasons for delay, potential equipment suppliers and history of negotiations, and any other relevant information. If unavailability of equipment is a factor, the report must include a discussion of other options considered, and the reasons these other options are not feasible.

In addition, the small refiner would need to provide evidence by June 1, 2006, that on-site construction has begun at its refinery(s) and that absent unforeseen circumstances or problems, they will be producing complying gasoline (30/80 ppm) by January 1, 2008. While the submission of these progress reports is evidence of a refiner's good faith efforts to comply by 2008, it does not bind the refiner to make gasoline in 2008. There are several reasons why a refiner may choose to exit the gasoline-production business in 2008 that go beyond the low sulfur gasoline requirement.

As a result of a refiner's efforts in moving toward compliance with the 2008 standards, for market, economic, business, or technical reasons, the company could choose not to make gasoline in 2008. Although we do not believe this will be the likely outcome for small refiners, we cannot preclude it. Any refiner that makes such a determination in its progress reports will have until 2008 to transition out of gasoline production, but will not be considered for a hardship extension.

2. Small Certifiers of Covered Vehicles

During the SBREFA process and in the Tier 2 proposal, we discussed compliance flexibilities for small certifiers of cars and light trucks who are subject to the Tier 2 standards. The final rule includes several provisions that should ease the compliance burden for some, if not all, of these companies.

Small certifiers will benefit from the provisions we are finalizing for all SVMs, not just those that are also small entities according to the SBA definition (primarily ICIs and alternative fuel converters). One of these provisions allows SVMs to opt-out of the interim standards during the phase-in years and to then comply with the final standards with 100 percent of their vehicles at the end of the phase-in period. Another aspect of the final rule is a one-year hardship provision for SVMs that will allow these manufacturers to apply for an additional year to meet any of the 100 percent phase-in requirements. Finally, SVMs will be allowed to participate in the

averaging, banking, and trading (ABT) program. (Although our proposal did not include ICIs in the ABT program, the final rule includes them, albeit with slightly different requirements because of the unique nature of their business). See Section V of the Preamble of this rule for more information on the treatment of small certifiers.

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. Summary of Emission Inventories for 47 States and for Four Urban Areas

In this appendix, emissions are summarized for the 47 States and for four urban areas: New York, Chicago, Atlanta, and Charlotte. VOC, NOx, SOx, PM10, and PM2.5 emissions are summarized in Tables A-3 to A-7. Abbreviations used in these tables are written out in Table A-2. The emissions presented here are mass emissions inventories. These are distinct from the emissions input files that are used by the UAM-V and REMSAD modeling systems, which generate air quality estimates from emissions and meteorological inputs. Those emissions input files contain hour-by-hour emissions produced under the specific meteorological conditions of the ozone episode being modeled. The mass emissions files, on the other hand, which are summarized in this appendix, represent average or typical conditions for the whole year and for an "ozone season day". Detailed information on how both these sets of files were prepared is in the "Procedures for Developing Base Year and Future Year Mass and Modeling Inventories for the Tier 2 Final Rulemaking," September 1999, which is in Air Docket A-97-10.

As indicated in the titles of the tables, emissions of VOC and NOx are presented as "annualized ozone season tons," which were generated by multiplying the "ozone season day" variable in each mass emissions file by 365. For highway mobile sources, ozone season day emissions represent a typical July day. The electrical generation mass emissions files contain June, July, and August ozone season days; for consistency with the highway mobile sources, the July day was chosen. The other mass emissions files contain only a single ozone-season-day variable.

The urban areas coincide closely with ozone nonattainment or maintenance areas, as described on EPA's Greenbook website (http://www.epa.gov/oar/oaqps/greenbk/oindex.html). They depart slightly from the nonattainment/maintenance definitions where partial counties are included in those definitions. For the emissions analysis presented here, only whole counties are summarized. In general, if only part of a county is included in a nonattainment/maintenance area, the whole county is included in the emissions analysis. However, if a county is in two nonattainment/maintenance areas, it is assigned to the nonattainment/maintenance area containing most of the county's population. Counties included in each urban area are listed in Table 1.

Table A-1. Counties included in the emissions for four urban areas.

Chicago		**New York**	
Cook Co	IL	Fairfield Co	CT
Du Page Co	IL	Bergen Co	NJ
Grundy Co	IL	Essex Co	NJ
Kane Co	IL	Hudson Co	NJ
Kendall Co	IL	Hunterdon Co	NJ
Lake Co	IL	Middlesex Co	NJ
McHenry Co	IL	Monmouth Co	NJ
Will Co	IL	Morris Co	NJ
Lake Co	IN	Ocean Co	NJ
Porter Co	IN	Passaic Co	NJ
		Somerset Co	NJ
Atlanta		Sussex Co	NJ
Cherokee Co	GA	Union Co	NJ
Clayton Co	GA	Bronx Co	NY
Cobb Co	GA	Kings Co	NY
Coweta Co	GA	Nassau Co	NY
De Kalb Co	GA	New York Co	NY
Douglas Co	GA	Orange Co	NY
Fayette Co	GA	Queens Co	NY
Forsyth Co	GA	Richmond Co	NY
Fulton Co	GA	Rockland Co	NY
Gwinnett Co	GA	Suffolk Co	NY
Henry Co	GA	Westchester Co	NY
Paulding Co	GA		
Rockdale Co	GA	**Charlotte**	
		Gaston Co	NC
		Mecklenburg Co	NC

Table A-2. Full description of abbreviated entries in the emissions tables in this appendix.

Table Entry	***Full description***
Stationary and Area	Stationary and area sources including natural and miscellaneous categories.
S & A w/o Nat. and Misc.	Stationary and area sources without the natural and miscellaneous categories
Nonroad	Nonroad mobile sources.
HD & MC Highway	Heavy-duty highway vehicles and motorcycles.
LD Highway	Light-duty highway vehicles.
Total Highway	Emissions of all highway vehicles
Total Inventory	
Total without Natural and Misc.	The total inventory without the natural and miscellaneous categories.
% LD of Total	The percentage of the total inventory that light-duty highway vehicles emit
% LD of Total w/o Nat. & Misc.	The percentage that light-duty highway vehicles emit of the total inventory without the natural and miscellaneous categories.

Table A-3. 47-State non-attainment area, FRM inventory, annualized ozone season tons.
VOC and NOx are in annualized ozone season tons. SOx and PM are in true annual tons.

47-State VOC	Base Case			Control Case			
Category	1996	2007	2030	2007	% Red.	2030	% Red.
Stationary and Area	11,948,272	11,030,732	13,632,729	11,030,732		13,632,729	
S & A w/o Nat. and Misc.	11,094,679	10,028,585	12,608,048	10,028,585		12,608,048	
Nonroad	3,536,201	2,487,618	2,218,832	2,487,618		2,218,832	
HD & MC Highway	537,939	370,071	473,224	365,537		470,697	
LD Highway	3,577,079	2,026,945	2,108,765	1,883,438	7.080	1,707,797	19.014
Total Highway	4,115,018	2,397,016	2,581,988	2,248,975		2,178,494	
Total Inventory	19,599,492	15,915,366	18,433,549	15,767,326	0.930	18,030,055	2.189
Total without Natural and Misc.	18,745,898	14,913,219	17,408,868	14,765,178	0.993	17,005,374	2.318
% LD of Total	18.251	12.736	11.440	11.945		9.472	
% LD of Total w/o Nat. & Misc.	19.082	13.592	12.113	12.756		10.043	

47-State NOx	Base Case			Control Case			
Category	1996	2007	2030	2007	% Red.	2030	% Red.
Stationary and Area	11,768,720	8,690,766	8,765,165	8,690,766		8,765,165	
S & A w/o Nat. and Misc.	11,483,283	8,279,298	8,339,423	8,279,298		8,339,423	
Nonroad	6,215,200	5,950,291	5,675,190	5,950,291		5,675,190	
HD & MC Highway	2,372,476	1,484,071	1,286,233	1,452,462		1,251,626	
LD Highway	3,908,147	3,095,698	3,704,747	2,239,227	27.667	909,196	75.459
Total Highway	6,280,624	4,579,769	4,990,979	3,691,688		2,160,821	
Total Inventory	24,264,544	19,220,826	19,431,335	18,332,746	4.620	16,601,177	14.565
Total without Natural and Misc.	23,979,107	18,809,358	19,005,593	17,921,277	4.721	16,175,435	14.891
% LD of Total	16.106	16.106	19.066	12.214		5.477	
% LD of Total w/o Nat. & Misc.	16.298	16.458	19.493	12.495		5.621	

47-State SOx	Base Case			Control Case			
Category	1996	2007	2030	2007	% Red.	2030	% Red.
Stationary and Area	18,374,124	16,599,944	15,172,033	16,599,944		15,172,033	
S & A w/o Nat. and Misc.	18,362,566	16,585,319	15,156,406	16,585,319		15,156,406	
Nonroad	923,392	1,132,670	1,589,760	1,111,538		1,562,831	
HD & MC Highway	82,226	103,036	166,550	92,700		149,592	
LD Highway	197,754	216,626	313,998	22,847	89.453	32,982	89.496
Total Highway	279,980	319,662	480,548	115,547		182,574	
Total Inventory	19,577,496	18,052,276	17,242,341	17,827,028	1.248	16,917,439	1.884
Total without Natural and Misc.	19,565,938	18,037,651	17,226,714	17,812,404	1.249	16,901,811	1.886
% LD of Total	1.010	1.200	1.821	0.128		0.195	
% LD of Total w/o Nat. & Misc.	1.011	1.201	1.823	0.128		0.195	

Table A-3. 47-State non-attainment area, FRM inventory, annualized ozone season tons.
VOC and NOx are in annualized ozone season tons. SOx and PM are in true annual tons.

47-State PM10	Base Case			Control Case			
Category	1996	2007	2030	2007	% Red.	2030	% Red.
Stationary and Area	30,941,836	30,917,199	32,270,152	30,917,199		32,270,152	
S & A w/o Nat. and Misc.	2,319,354	2,244,054	2,530,559	2,244,054		2,530,559	
Nonroad	428,101	479,433	657,057	479,433		657,057	
HD & MC Highway	160,473	87,063	106,758	86,107		105,603	
LD Highway	92,160	97,269	137,077	74,574	23.332	103,169	24.736
Total Highway	252,633	184,332	243,835	160,682		208,773	
Total Inventory	31,622,569	31,580,964	33,171,043	31,557,314	0.075	33,135,981	0.106
Total without Natural and Misc.	3,000,087	2,907,819	3,431,450	2,884,169	0.813	3,396,388	1.022
% LD of Total	0.291	0.308	0.413	0.236		0.311	
% LD of Total w/o Nat. & Misc.	3.072	3.345	3.995	2.586		3.038	

47-State PM2.5	Base Case			Control Case			
Category	1996	2007	2030	2007	% Red.	2030	% Red.
Stationary and Area	7,233,601	7,665,679	8,420,947	7,665,679		8,420,947	
S & A w/o Nat. and Misc.	1,611,450	1,736,330	2,074,096	1,736,330		2,074,096	
Nonroad	379,532	426,976	589,326	426,976		589,326	
HD & MC Highway	140,393	72,544	86,436	71,783		85,451	
LD Highway	57,452	56,939	80,818	35,340	37.933	48,388	40.127
Total Highway	197,846	129,484	167,253	107,123		133,839	
Total Inventory	7,810,978	8,222,138	9,177,527	8,199,778	0.272	9,144,112	0.364
Total without Natural and Misc.	2,188,827	2,292,789	2,830,675	2,270,429	0.975	2,797,261	1.180
% LD of Total	0.736	0.693	0.881	0.431		0.529	
% LD of Total w/o Nat. & Misc.	2.625	2.483	2.855	1.557		1.730	

Table A-4. Atlanta non-attainment area, FRM inventory, annualized ozone season tons. VOC and NOx are in annualized ozone season tons. SOx and PM are in true annual tons.

Atlanta VOC	Base Case			Control Case			
Category	1996	2007	2030	2007	% Red.	2030	% Red.
Stationary and Area	105,393	103,128	137,039	103,128		137,039	
S & A w/o Nat. and Misc.	101,924	99,710	133,614	99,710		133,614	
Nonroad	34,776	22,828	23,391	22,828		23,391	
HD & MC Highway	10,535	6,598	8,725	6,485		8,658	
LD Highway	85,071	26,719	28,751	23,964	10.308	20,157	29.893
Total Highway	95,606	33,317	37,477	30,449		28,815	
Total Inventory	235,775	159,273	197,906	156,405	1.800	189,244	4.377
Total without Natural and Misc.	232,305	155,855	194,481	152,987	1.840	185,820	4.454
% LD of Total	36.081	16.775	14.528	15.322		10.651	
% LD of Total w/o Nat. & Misc.	36.620	17.143	14.784	15.664		10.847	

Atlanta NOx	Base Case			Control Case			
Category	1996	2007	2030	2007	% Red.	2030	% Red.
Stationary and Area	41,959	31,275	29,887	31,275		29,887	
S & A w/o Nat. and Misc.	41,309	30,485	29,093	30,485		29,093	
Nonroad	59,541	58,261	57,388	58,261		57,388	
HD & MC Highway	35,900	25,048	23,404	24,339		22,573	
LD Highway	80,446	58,592	75,723	40,605	30.698	13,372	82.340
Total Highway	116,346	83,639	99,126	64,945		35,945	
Total Inventory	217,846	173,176	186,401	154,481	10.795	123,220	33.895
Total without Natural and Misc.	217,196	172,386	185,607	153,691	10.845	122,426	34.040
% LD of Total	36.928	33.834	40.623	26.285		10.852	
% LD of Total w/o Nat. & Misc.	37.038	33.989	40.797	26.420		10.923	

Atlanta SOx	Base Case			Control Case			
Category	1996	2007	2030	2007	% Red.	2030	% Red.
Stationary and Area	49,955	81,482	75,655	81,482		75,655	
S & A w/o Nat. and Misc.	49,871	81,397	75,570	81,397		75,570	
Nonroad	10,726	14,056	21,056	13,848		20,765	
HD & MC Highway	1,260	1,721	2,973	1,500		2,586	
LD Highway	4,079	5,566	8,591	504	90.936	778	90.945
Total Highway	5,339	7,287	11,564	2,004		3,364	
Total Inventory	66,021	102,825	108,275	97,334	5.340	99,784	7.842
Total without Natural and Misc.	65,937	102,740	108,190	97,249	5.345	99,699	7.848
% LD of Total	6.179	5.413	7.934	0.518		0.780	
% LD of Total w/o Nat. & Misc.	6.187	5.417	7.941	0.519		0.780	

Table A-4. Atlanta non-attainment area, FRM inventory, annualized ozone season tons. VOC and NOx are in annualized ozone season tons. SOx and PM are in true annual tons.

Atlanta PM10	Base Case			Control Case			
Category	1996	2007	2030	2007	% Red.	2030	% Red.
Stationary and Area	218,941	239,672	285,950	239,672		285,950	
S & A w/o Nat. and Misc.	7,933	8,745	10,076	8,745		10,076	
Nonroad	5,808	6,945	10,028	6,945		10,028	
HD & MC Highway	2,474	1,530	1,877	1,509		1,852	
LD Highway	1,947	2,147	3,204	1,602	25.391	2,355	26.484
Total Highway	4,420	3,677	5,080	3,111		4,207	
Total Inventory	229,169	250,295	301,058	249,729	0.226	300,185	0.290
Total without Natural and Misc.	18,162	19,368	25,185	18,802	2.922	24,312	3.467
% LD of Total	0.849	0.858	1.064	0.641		0.785	
% LD of Total w/o Nat. & Misc.	10.719	11.086	12.721	8.520		9.688	

Atlanta PM2.5	Base Case			Control Case			
Category	1996	2007	2030	2007	% Red.	2030	% Red.
Stationary and Area	47,873	54,594	68,015	54,594		68,015	
S & A w/o Nat. and Misc.	6,738	7,956	9,803	7,956		9,803	
Nonroad	5,183	6,222	9,041	6,222		9,041	
HD & MC Highway	2,160	1,278	1,516	1,262		1,496	
LD Highway	1,219	1,254	1,899	740	41.025	1,079	43.177
Total Highway	3,379	2,532	3,415	2,001		2,574	
Total Inventory	56,435	63,347	80,472	62,817	0.838	79,631	1.045
Total without Natural and Misc.	15,300	16,710	22,259	16,179	3.176	21,418	3.777
% LD of Total	2.160	1.980	2.359	1.177		1.355	
% LD of Total w/o Nat. & Misc.	7.966	7.505	8.530	4.571		5.037	

Table A-5. Charlotte non-attainment area, FRM inventory.
VOC and NOx are in annualized ozone season tons. SOx and PM are in true annual tons.

Charlotte VOC	Base Case			Control Case			
Category	1996	2007	2030	2007	% Red.	2030	% Red.
Stationary and Area	34,288	33,411	44,570	33,411		44,570	
S & A w/o Nat. and Misc.	32,956	32,087	43,234	32,087		43,234	
Nonroad	11,807	7,463	7,844	7,463		7,844	
HD & MC Highway	1,413	1,255	1,672	1,235		1,661	
LD Highway	12,535	7,506	7,177	6,723	10.431	4,873	32.103
Total Highway	13,949	8,761	8,849	7,958		6,534	
Total Inventory	60,044	49,635	61,263	48,832	1.618	58,947	3.780
Total without Natural and Misc.	58,712	48,311	59,927	47,508	1.662	57,611	3.864
% LD of Total	20.877	15.122	11.715	13.768		8.267	
% LD of Total w/o Nat. & Misc.	21.351	15.537	11.977	14.151		8.459	

Charlotte NOx	Base Case			Control Case			
Category	1996	2007	2030	2007	% Red.	2030	% Red.
Stationary and Area	27,348	17,022	18,358	17,022		18,358	
S & A w/o Nat. and Misc.	27,141	16,814	18,150	16,814		18,150	
Nonroad	18,720	18,526	18,954	18,526		18,954	
HD & MC Highway	6,530	4,510	4,569	4,388		4,418	
LD Highway	14,151	12,406	15,143	8,632	30.422	2,719	82.044
Total Highway	20,681	16,915	19,712	13,019		7,137	
Total Inventory	66,749	52,463	57,024	48,567	7.426	44,450	22.051
Total without Natural and Misc.	66,541	52,256	56,816	48,360	7.456	44,242	22.132
% LD of Total	21.200	23.646	26.556	17.773		6.117	
% LD of Total w/o Nat. & Misc.	21.266	23.740	26.653	17.849		6.146	

Charlotte SOx	Base Case			Control Case			
Category	1996	2007	2030	2007	% Red.	2030	% Red.
Stationary and Area	56,355	71,844	61,130	71,844		61,130	
S & A w/o Nat. and Misc.	56,355	71,844	61,130	71,844		61,130	
Nonroad	2,848	3,899	6,100	3,833		6,010	
HD & MC Highway	258	340	579	296		503	
LD Highway	859	1,147	1,716	104	90.936	155	90.945
Total Highway	1,117	1,487	2,295	400		658	
Total Inventory	60,320	77,230	69,526	76,078	1.492	67,798	2.484
Total without Natural and Misc.	60,320	77,230	69,526	76,077	1.492	67,798	2.484
% LD of Total	1.424	1.485	2.468	0.137		0.229	
% LD of Total w/o Nat. & Misc.	1.424	1.485	2.468	0.137		0.229	

Table A-5. Charlotte non-attainment area, FRM inventory.
VOC and NOx are in annualized ozone season tons. SOx and PM are in true annual tons.

Charlotte PM10	Base Case			Control Case			
Category	1996	2007	2030	2007	% Red.	2030	% Red.
Stationary and Area	43,590	52,887	69,383	52,887		69,383	
S & A w/o Nat. and Misc.	2,858	2,928	3,029	2,928		3,029	
Nonroad	1,486	1,841	2,850	1,841		2,850	
HD & MC Highway	429	238	367	235		362	
LD Highway	386	442	643	330	25.342	471	26.651
Total Highway	815	680	1,010	565		834	
Total Inventory	45,891	55,407	73,244	55,292	0.208	73,067	0.241
Total without Natural and Misc.	5,159	5,449	6,889	5,334	2.110	6,713	2.558
% LD of Total	0.842	0.797	0.878	0.596		0.645	
% LD of Total w/o Nat. & Misc.	7.490	8.106	9.330	6.183		7.023	

Charlotte PM2.5	Base Case			Control Case			
Category	1996	2007	2030	2007	% Red.	2030	% Red.
Stationary and Area	10,963	13,389	17,563	13,389		17,563	
S & A w/o Nat. and Misc.	2,186	2,535	2,996	2,535		2,996	
Nonroad	1,355	1,679	2,603	1,679		2,603	
HD & MC Highway	373	195	297	193		293	
LD Highway	238	258	379	152	40.962	216	43.167
Total Highway	611	453	676	345		508	
Total Inventory	12,929	15,520	20,842	15,412	0.696	20,674	0.805
Total without Natural and Misc.	4,152	4,666	6,275	4,558	2.316	6,107	2.675
% LD of Total	1.843	1.660	1.819	0.987		1.042	
% LD of Total w/o Nat. & Misc.	5.739	5.520	6.043	3.336		3.529	

Table A-6. Chicago non-attainment area, FRM inventory.
VOC and NOx are in annualized ozone season tons. SOx and PM are in true annual tons.

Chicago VOC	Base Case			Control Case			
Category	1996	2007	2030	2007	% Red.	2030	% Red.
Stationary and Area	409,386	384,462	475,490	384,462		475,490	
S & A w/o Nat. and Misc.	408,536	383,598	474,604	383,598		474,604	
Nonroad	97,946	64,689	61,501	64,689		61,501	
HD & MC Highway	10,479	6,507	7,887	6,452		7,837	
LD Highway	91,524	26,895	28,181	25,029	6.940	20,250	28.145
Total Highway	102,003	33,402	36,069	31,480		28,086	
Total Inventory	609,334	482,553	573,059	480,631	0.398	565,077	1.393
Total without Natural and Misc.	608,484	481,689	572,174	479,767	0.399	564,191	1.395
% LD of Total	15.020	5.574	4.918	5.207		3.584	
% LD of Total w/o Nat. & Misc.	15.041	5.584	4.925	5.217		3.589	

Chicago NOx	Base Case			Control Case			
Category	1996	2007	2030	2007	% Red.	2030	% Red.
Stationary and Area	257,347	195,557	209,579	195,557		209,579	
S & A w/o Nat. and Misc.	257,243	195,453	209,475	195,453		209,475	
Nonroad	155,390	149,783	144,669	149,783		144,669	
HD & MC Highway	43,072	27,950	25,858	27,605		25,332	
LD Highway	107,714	62,072	73,150	47,980	22.703	15,414	78.928
Total Highway	150,786	90,023	99,008	75,585		40,746	
Total Inventory	563,523	435,363	453,257	420,925	3.316	394,994	12.854
Total without Natural and Misc.	563,419	435,259	453,152	420,821	3.317	394,890	12.857
% LD of Total	19.114	14.258	16.139	11.399		3.902	
% LD of Total w/o Nat. & Misc.	19.118	14.261	16.142	11.402		3.903	

Chicago SOx	Base Case			Control Case			
Category	1996	2007	2030	2007	% Red.	2030	% Red.
Stationary and Area	283,888	331,893	342,165	331,893		342,165	
S & A w/o Nat. and Misc.	283,888	331,892	342,164	331,892		342,164	
Nonroad	17,378	23,142	35,152	22,555		34,386	
HD & MC Highway	1,662	1,885	2,989	1,791		2,838	
LD Highway	5,983	2,910	4,082	669	77.021	937	77.041
Total Highway	7,645	4,796	7,071	2,460		3,775	
Total Inventory	308,911	359,830	384,388	356,908	0.812	380,326	1.057
Total without Natural and Misc.	308,911	359,829	384,388	356,908	0.812	380,326	1.057
% LD of Total	1.937	0.809	1.062	0.187		0.246	
% LD of Total w/o Nat. & Misc.	1.937	0.809	1.062	0.187		0.246	

Table A-6. Chicago non-attainment area, FRM inventory.
VOC and NOx are in annualized ozone season tons. SOx and PM are in true annual tons.

Chicago PM10	Base Case			Control Case			
Category	1996	2007	2030	2007	% Red.	2030	% Red.
Stationary and Area	259,792	274,604	314,362	274,604		314,362	
S & A w/o Nat. and Misc.	62,898	65,902	76,380	65,902		76,380	
Nonroad	9,188	11,025	16,309	11,025		16,309	
HD & MC Highway	2,902	1,508	2,078	1,496		2,060	
LD Highway	2,671	2,820	3,867	2,370	15.970	3,200	17.265
Total Highway	5,573	4,329	5,945	3,866		5,260	
Total Inventory	274,553	289,957	336,616	289,494	0.160	335,931	0.204
Total without Natural and Misc.	77,658	81,256	98,634	80,793	0.569	97,949	0.695
% LD of Total	0.973	0.973	1.149	0.819		0.952	
% LD of Total w/o Nat. & Misc.	3.440	3.471	3.921	2.933		3.267	

Chicago PM2.5	Base Case			Control Case			
Category	1996	2007	2030	2007	% Red.	2030	% Red.
Stationary and Area	88,998	94,550	109,471	94,550		109,471	
S & A w/o Nat. and Misc.	44,137	46,377	53,563	46,377		53,563	
Nonroad	8,474	10,093	14,938	10,093		14,938	
HD & MC Highway	2,525	1,238	1,677	1,228		1,662	
LD Highway	1,634	1,603	2,212	1,184	26.129	1,590	28.123
Total Highway	4,159	2,841	3,889	2,412		3,252	
Total Inventory	101,631	107,484	128,297	107,055	0.399	127,660	0.496
Total without Natural and Misc.	56,770	59,311	72,389	58,882	0.723	71,753	0.880
% LD of Total	1.608	1.491	1.724	1.106		1.245	
% LD of Total w/o Nat. & Misc.	2.878	2.703	3.056	2.011		2.216	

Table A-7. New York non-attainment area, FRM inventory.
VOC and NOx are in annualized ozone season tons. SOx and PM are in true annual tons.

New York VOC	Base Case			Control Case			
Category	1996	2007	2030	2007	% Red.	2030	% Red.
Stationary and Area	517,305	459,828	529,668	459,828		529,668	
S & A w/o Nat. and Misc.	514,215	456,656	526,465	456,656		526,465	
Nonroad	151,282	96,183	92,176	96,183		92,176	
HD & MC Highway	16,893	10,794	12,683	10,707		12,612	
LD Highway	149,763	37,125	40,442	34,591	6.826	29,008	28.273
Total Highway	166,656	47,918	53,125	45,297		41,619	
Total Inventory	835,243	603,930	674,968	601,309	0.434	663,463	1.705
Total without Natural and Misc.	832,153	600,758	671,765	598,137	0.436	660,260	1.713
% LD of Total	17.930	6.147	5.992	5.753		4.372	
% LD of Total w/o Nat. & Misc.	17.997	6.180	6.020	5.783		4.393	

New York NOx	Base Case			Control Case			
Category	1996	2007	2030	2007	% Red.	2030	% Red.
Stationary and Area	165,367	122,713	120,317	122,713		120,317	
S & A w/o Nat. and Misc.	165,006	122,298	119,900	122,298		119,900	
Nonroad	218,910	220,952	231,676	220,952		231,676	
HD & MC Highway	77,788	48,094	42,383	47,471		41,487	
LD Highway	177,258	88,878	113,645	68,366	23.079	24,089	78.803
Total Highway	255,047	136,973	156,028	115,837		65,576	
Total Inventory	639,324	480,638	508,021	459,502	4.397	417,569	17.805
Total without Natural and Misc.	638,963	480,223	507,604	459,087	4.401	417,152	17.819
% LD of Total	27.726	18.492	22.370	14.878		5.769	
% LD of Total w/o Nat. & Misc.	27.742	18.508	22.389	14.892		5.775	

New York SOx	Base Case			Control Case			
Category	1996	2007	2030	2007	% Red.	2030	% Red.
Stationary and Area	323,294	257,903	265,644	257,903		265,644	
S & A w/o Nat. and Misc.	323,290	257,900	265,640	257,900		265,640	
Nonroad	70,567	77,015	97,854	76,065		96,559	
HD & MC Highway	2,925	3,257	5,008	3,087		4,743	
LD Highway	10,288	5,044	6,829	1,115	77.891	1,503	77.996
Total Highway	13,213	8,301	11,836	4,202		6,245	
Total Inventory	407,074	343,220	375,335	338,170	1.471	368,448	1.835
Total without Natural and Misc.	407,071	343,216	375,331	338,166	1.471	368,444	1.835
% LD of Total	2.527	1.470	1.819	0.330		0.408	
% LD of Total w/o Nat. & Misc.	2.527	1.470	1.819	0.330		0.408	

Table A-7. New York non-attainment area, FRM inventory.
VOC and NOx are in annualized ozone season tons. SOx and PM are in true annual tons.

New York PM10	Base Case			Control Case			
Category	1996	2007	2030	2007	% Red.	2030	% Red.
Stationary and Area	466,339	497,623	575,429	497,623		575,429	
S & A w/o Nat. and Misc.	49,070	42,324	44,825	42,324		44,825	
Nonroad	19,127	22,525	32,535	22,525		32,535	
HD & MC Highway	5,045	2,603	3,455	2,581		3,426	
LD Highway	4,614	4,723	6,215	3,952	16.317	5,120	17.622
Total Highway	9,659	7,326	9,670	6,534		8,546	
Total Inventory	495,126	527,474	617,634	526,681	0.150	616,510	0.182
Total without Natural and Misc.	77,857	72,175	87,031	71,382	1.098	85,906	1.292
% LD of Total	0.932	0.895	1.006	0.750		0.830	
% LD of Total w/o Nat. & Misc.	5.926	6.544	7.142	5.537		5.960	

New York PM2.5	Base Case			Control Case			
Category	1996	2007	2030	2007	% Red.	2030	% Red.
Stationary and Area	128,173	131,512	151,036	131,512		151,036	
S & A w/o Nat. and Misc.	36,042	30,438	32,426	30,438		32,426	
Nonroad	15,308	19,599	28,781	19,599		28,781	
HD & MC Highway	4,386	2,141	2,789	2,123		2,764	
LD Highway	2,824	2,700	3,569	1,980	26.665	2,546	28.671
Total Highway	7,211	4,841	6,359	4,103		5,310	
Total Inventory	150,692	155,951	186,176	155,213	0.473	185,127	0.563
Total without Natural and Misc.	58,561	54,877	67,565	54,139	1.345	66,517	1.551
% LD of Total	1.874	1.731	1.917	1.276		1.375	
% LD of Total w/o Nat. & Misc.	4.823	4.920	5.283	3.657		3.828	

Appendix B: Evidence Supporting the Irreversibility of Sulfur's Emission Impact

Fuel sulfur impacts vehicle emissions in two basic ways. One is a significant, 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.[11] 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), on average, by 40 percent for NMHC and 134 percent for NOx emissions compared to 30 ppm sulfur fuel. New data generated since the NPRM on similar LEVs and ULEVs show that when these vehicles were driven on high sulfur (330 ppm) fuel for a few thousand miles, the NMHC and NOx emission increase due to high sulfur fuel increased by 149 percent and 47 percent, respectively. In other words, instead of the previous estimated 40 percent and 134 percent increases in NMHC and NOx emissions, respectively, the newer estimates would be 100 percent and 197 percent, respectively.

In this section, we are concerned with the impact of sulfur under a broader range of 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 irreversibility). The third describes the vehicle testing programs which have attempted to measure the irreversibility of the sulfur impact. The fourth presents criteria for evaluating the wide range of sulfur irreversibility data which are available. Finally, the fifth describes EPA's projections of the degree of sulfur irreversibility for various vehicle types (e.g., Tier 1 vehicle, LEVs, and Tier 2 vehicles).

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[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.

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. In the NPRM we estimated that, based on data from test programs conducted by EPA and the automotive and oil industries, LEV and ULEV vehicles could experience, on average, a 40 percent increase in NMHC and 134 percent increase in NOx emissions when operated on 330 ppm sulfur fuel (our estimate in the NPRM of the current national average sulfur level) compared to 30 ppm sulfur fuel. New data generated since the NPRM on similar LEVs and ULEVs show that when these vehicles were driven on high sulfur (330 ppm) fuel for a few thousand miles, the NMHC and NOx emission increase due to high sulfur fuel increased by 149 percent and 47 percent, respectively. In other words, instead of the previous estimated 40 percent and 134 percent increases in NMHC and NOx emissions, respectively, more realistic estimates would be 100 percent and 197 percent, respectively. The calculations resulting in these sensitivity values are described below in this section. Also, new data generated since the NPRM for late model LEV and ULEV vehicles that meet the Federal and California supplemental federal test procedure (SFTP) standards and also have very low FTP emission levels, indicate that, on average, a 51 percent increase in NMHC and a 242 percent increase in NOx emissions when operated for a short period of time on 330 ppm compared to 30 ppm could be realized.

Table A-1 lists new sulfur sensitivity data for several late model LEV and ULEV vehicles that meet the Federal and California supplemental federal test procedure (SFTP) standards and also have very low FTP emission levels when sulfur is increased from 30 ppm to 350 ppm.

Table B-1. Sulfur Sensitivity: New Data Between 30 ppm and 350 ppm

Vehicle	NMHC	NOx
DaimlerChrysler Caravan	87%	333%
Ford Expedition	81%	42%
Ford Windstar	12%	238%
Ford F-150	30%	249%
Average	51%	242%

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. We examined the sulfur sensitivity for vehicles in our sulfur database that were at or below Tier 2 levels with those that were above Tier 2 standards. What we found was that those vehicles meeting Tier 2 standards showed a higher degree of sensitivity to sulfur than those with higher emission levels. However, at a 95 percent confidence level, there was no statistical difference in sulfur sensitivity between the vehicles at or below Tier 2 emission standards and those above Tier 2 standards. Thus, we have only projected that Tier 2 vehicles will be just as sensitive as LEV and ULEV LDVs and not more so. Therefore, these should be considered conservative estimates for Tier 2 vehicles.

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"[2] 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

[2] "EPA Staff Paper on Gasoline Sulfur Issues," U.S. EPA, May 1998, EPA420-R-98-005

surface more thoroughly at lower catalyst temperatures (approximately 450 C to 500 C) 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 450 C, 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 450 C.

A second concern about the estimates of sulfur sensitivity used in the NPRM is that all of the vehicles in the test programs used to develop the NPRM projections of sulfur sensitivities were only exposed to high sulfur fuel for a few miles of driving prior to emission testing. This is referred to as “short-term” sulfur exposure. 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. The short-term exposure in the test programs typically consisted of only running several emission tests (FTP or LA4). Since each FTP is approximately 18 miles in length, short-term exposure usually amounted to just under 100 miles of operation, all of which was in a controlled laboratory environment.

To address this concern, API and EPA each conducted test programs testing a combined total of six light-duty vehicles for sulfur sensitivity after short-term and long-term exposure to sulfur. The vehicles were randomly selected by both API and EPA. The long-term exposure consisted of between 1,500 and 3,000 miles of in-use operation over urban, rural and highway roads. Two of the vehicles were 1999 models, while the other four were 1998 models. All six were either LEV or ULEV vehicles. Three of the vehicles were equipped with catalyst systems aged to either 50,000 or 100,000 miles. The other three vehicles had low mileage catalyst systems aged to only 4,000 miles. Table A-2 describes the vehicles tested:

Table B-2. Vehicles Tested After Short-Term vs. Long-Term Exposure to Higher Sulfur Fuel

Make/Model	Model Year	Emission Level	Catalyst Aging (miles)
EPA Test Program			
Honda Accord	1999	ULEV	50,000
Chevrolet Cavalier	1999	LEV	50,000
API Test Program			
Nissan Altima	1998	LEV	100,000
Ford Taurus	1998	LEV	4,000
Honda Accord	1998	ULEV	4,000
Toyota Avalon	1998	LEV	4,000

All of the vehicles were tested for short-term exposure first. Each vehicle was FTP baseline[3] tested on low sulfur fuel (30 or 40 ppm). The number of tests used to establish the baseline varied from two to four. The vehicles were then tested with the high sulfur fuel (EPA at 350 ppm, API at 540 ppm). Again the number of tests ranged from two to four. Upon completion of the short-term program, each vehicle was preconditioned several times with the EPEFE sulfur purge cycle prior to beginning the long-term exposure program. Only the 1999 Honda Accord of the EPA test program reestablished a new baseline for the long-term program–the other vehicles used the original short-term baseline. All of the vehicles were then operated on the road with the high sulfur fuel from anywhere between 1,500 to 3,000 miles and tested over the FTP to establish long-term high sulfur emission levels.

Sulfur sensitivity was determined by calculating the percent increase in average emissions with the high sulfur fuel compared to the average emissions with the low sulfur fuel. For NOx emissions, all six vehicles showed greater sulfur sensitivity after long-term exposure to high sulfur fuel than after short-term exposure. For NMHC emissions, all of the vehicles except the Altima and Avalon experienced greater sensitivity for long-term exposure. Only the Altima showed lower sulfur sensitivity for CO emissions after long-term exposure. Table A-3 lists the sulfur sensitivity results for all six vehicles:

[3] Prior to baseline testing, each vehicle was preconditioned with a purge cycle based on the European Programme for Emission, Fuels, and Engine Technologies (EPEFE) sulfur purge cycle, which uses a series of ten wide-open throttle accelerations from 30 to 70 mph, in order to ensure there was no sulfur contamination prior to baseline testing.

Table B-3. Vehicle-by-Vehicle Short-Term vs. Long-Term Sulfur Sensitivity

Vehicle	*Cat. Age*	*Sulfur Aging*	*Sulfur Level*	*Tailpipe Emissions (g/mi)*			*Sulfur Sensitivity (%)*		
				NMHC	*CO*	*NOx*	*NMHC*	*CO*	*NOx*
Accord (EPA Vehicle)	50K	Short	30 ppm	0.031	0.351	0.092	12.0	36.3	69.4
			350 ppm	0.035	0.478	0.155			
	50K	Long	30 ppm	0.033	0.330	0.090	21.7	121.1	158.5
			350 ppm	0.040	0.731	0.234			
Cavalier	50K	Short	30 ppm	0.070	1.778	0.068	49.3	127.7	347.0
			350 ppm	0.105	4.048	0.303			
	50K	Long	30 ppm	0.0.70	1.778	0.068	216.6	306.4	411.8
			350 ppm	0.223	7.224	0.324			
Altima	100K	Short	40 ppm	0.041	0.788	0.061	43.9	34.3	83.6
			540 ppm	0.059	1.058	0.112			
	100K	Long	40 ppm	0.041	0.788	0.061	39.0	25.3	116.4
			540 ppm	0.057	0.987	0.132			
Taurus	4K	Short	40 ppm	0.033	0.522	0.075	54.5	59.4	34.7
			540 ppm	0.051	0.832	0.101			
	4K	Long	40 ppm	0.033	0.522	0.075	121.2	151.0	56.0
			540 ppm	0.073	1.310	0.117			
Accord (API	4K	Short	40 ppm	0.029	0.285	0.100	10.3	4.9	92.0
			540	0.032	0.299	0.192			

Vehicle	*Cat. Age*	*Sulfur Aging*	*Sulfur Level*	*Tailpipe Emissions (g/mi)*			*Sulfur Sensitivity (%)*		
				NMHC	*CO*	*NOx*	*NMHC*	*CO*	*NOx*
	4K	Long	40 ppm	0.029	0.285	0.100	41.4	63.2	145.0
			540 ppm	0.041	0.465	0.245			
Avalon	4K	Short	40 ppm	0.040	0.406	0.068	52.5	33.3	70.6
			540 ppm	0.061	0.541	0.116			
	4K	Long	40 ppm	0.040	0.406	0.068	50.0	80.8	108.8
			540 ppm	0.060	0.734	0.142			

In order to quantify the difference between short-term and long-term exposure, we averaged the low and high sulfur emissions for each pollutant for all of the vehicles and determined a straight linear fleet average emissions for both low sulfur and high sulfur fuels. The ratio of the long-term sensitivity to the short-term sulfur sensitivity was then determined. As can be seen in table A-4, the percent increases from short-term to long-term are quite significant, especially for NMHC emissions. The three vehicles with catalysts aged to 50,000 or 100,000 miles had, on average, long-term sensitivities greater than the three vehicles with 4,000 mile catalysts. Therefore, the effects of long-term exposure to sulfur presented here may be underestimated.

Table B-4. Percent Difference Between Short-Term vs. Long-Term Sulfur Sensitivity

Average	*Sulfur Sensitivity (%)*			*Ratio of the Sensitivities (long-term to short-term , in %)*		
	NMHC	*CO*	*NOx*	*NMHC*	*CO*	*NOx*
Short-Term	40.2	75.7	111.3	149.2	136.0	46.8
Long-Term	100.3	178.7	163.4			

To test whether this observed increase in sulfur sensitivity was statistically valid, we calculated the ratio of short-term sulfur sensitivity (in percent) to long-term sulfur sensitivity (in percent) for each vehicle. We then calculated the average and standard deviation of these ratios and calculated 90percent and 95percent confidence intervals. At a 95percent confidence level,

the lower limits of the confidence intervals for NMHC and NOx pollutants exceeded 1.0. This indicates that at least a 95percent confidence exists that the long-term sulfur sensitivity exceeds that for short-term exposure. The same was true for CO emissions at a 90percent confidence level.

We multiplied the short term sulfur sensitivities from the larger vehicle database by the ratio of the long to short term sensitivities from the 6 vehicle database. This resulted in a sulfur sensitivity of 100 percent for NMHC and 197 percent for NOx emissions when measured at 330 ppm fuel sulfur compared to 30 ppm.

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.

[4] "EPA Staff Paper on Gasoline Sulfur Issues," U.S. EPA, May 1998, EPA420-R-98-005.

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 no information on 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. 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.

Results from our Tier 2 technology assessment program indicate that there will be trade-offs between NMOG and NOx control in order to meet Tier 2 emission standards, especially for larger vehicles. For example, significant reductions in NOx can be achieved by improved EGR strategies that don't necessarily rely on improvements to the catalyst, whereas reductions in NMOG may rely more heavily on strategies to reduce catalyst light-off time as well as catalyst light-off performance. Since sulfur doesn't affect emissions coming out of the engine, an emission control strategy that focuses less on catalyst performance may not experience sulfur

problems as readily as systems that depend more on the catalyst. Since these trade-offs will be very model-specific, it is very difficult to determine the impact emission control strategies needed to meet strict Tier 2 emission standards will have on sulfur reversibility tolerance.

Thus, the two changes in emission control design necessary to reverse sulfur, 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 evaluates the available sulfur irreversibility data from numerous sulfur irreversibility test programs.

C. Results of Sulfur Irreversibility Test Programs

We have received data from seven test programs which evaluate the irreversibility of sulfur's impact on vehicle emissions. These programs are summarized in the following seven sections.

1. Pre-SFTP LEVs

All of the data generated for the NPRM was for Tier 1, LEV, and ULEV vehicles that were not designed to meet the Federal, or California SFTP standards. The potential effect of the SFTP standards on sulfur reversibility has already been discussed above. Therefore, we are going to divide the data from the various test programs into two categories: pre-SFTP LEVs and SFTP-compliant LEV and Tier 2 vehicles. The following is a summary of the programs in the pre-SFTP category. Two of the programs were discussed in the RIA for the proposed rule. There are also two new programs that were run after the NPRM.

a. Coordinating Research Council (CRC) Sulfur Irreversibility Program

The CRC sulfur irreversibility 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-5. 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 irreversibility test program.

Table B-6. Sulfur Irreversibility: CRC Test Program (%)

		NMHC		***NOx***	
		Purge Cycle		*Purge Cycle*	
Vehicle Manufac	Models	LA4	US06	LA4	US06
Ford	Taurus	31.0	17.0	30.0	5.0
Ford	Escort	0.0	0.0	5.0	0.0
Honda	Civic	6.0	1.0	4.0	3.0
Nissan	Sentra	1.0	0.0	15.0	12.0
Toyota	Camry	0.0	2.0	50.0	0.0
Suzuki	Metro	0.0	0.0	14.0	13.0
Fleet Estimate		**3.0**	**0.0**	**16.0**	**5.0**

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 irreversibility for NMHC, especially with the LA4 purge cycle (31 percent). The results for NOx indicate that with the LA4 purge cycle, the average level of irreversibility is 16 percent with the Toyota Camry having irreversibility as high as 50 percent. When using the US06 purge cycle, NOx emissions were far more reversible with an average irreversibility of 5 percent. The Nissan Sentra and Suzuki Metro showed almost the exact same level of irreversibility with both purge cycles.

b. American Petroleum Institute Sulfur Irreversibility Program

The API program[5] 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

[5] 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. This will underestimate reversibility since other programs have shown that emissions on low sulfur fuel after exposure to high sulfur fuel continue to decrease after two tests. Thus, statistically speaking, the API program is weaker than the CRC program. Examination of individual emission test results shows significant variability occurred.

Table B-7 lists the vehicle tested in the API program.

Table B-7. 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 assumption will be discussed further below.

Table B-8 shows the sulfur irreversibility emission results for all of the vehicles when tested with low mileage (4,000 mile) catalysts.

Table B-8. Sulfur Irreversibility: 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	0.0	n/a *	3.8	n/a
Honda	98 Accord (ULEV)	76.9	0.0	21.7	2.2
Toyota	98 Avalon	28.6	57.1	47.9	0.0
Nissan	98 Altima	0.0	n/a*	0.0	n/a
Ford	98 Gr. Mar	0.0	19.4	15.5	28.2
Ford	98 Town Car (Tier1)	53.7	40.0	5.0	0.0
Chevrolet	97 S-10 (Tier1)	33.3	0.0	29.7	0.0
Fleet Estimate		**32.4**	**54.1**	**16.7**	**7.7**

* Vehicle not tested with US06 purge cycle.

The most obvious difference between the irreversibilities measured by API and those found by CRC is that API's average NMHC irreversibility rate when using the LA4 as a purge cycle is 32 percent, while CRC's average NMHC reversibility rate shows nearly full reversibility at three percent irreversibility. The measured NOx irreversibilities (with the LA4 purge cycle) were almost identical in the two programs, 17 percent for API compared to 16 percent for CRC. However, it should be pointed out that API only performed two tests on low sulfur fuel.

API found much lower irreversibility using the US06 cycle as a purge cycle for NOx (7.7

percent). However, the opposite was true for NMHC (54.1 percent). This 54.1 percent irreversibility is considerably higher 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 irreversibilities 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 irreversibility.

Table B-9 shows measured irreversibility 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 irreversibility with the US06 cycle. Irreversibility 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-9. Sulfur Irreversibility: 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	32.5	0.0	2.4	0.0	0.0	n/a *	3.8	n/a
98 Accord (ULEV)	n/a	0.0	n/a	5.5	76.9	0.0	21.7	2.2
98 Avalon	n/a	25.0	n/a	0.0	28.6	57.1	47.9	0.0
98 Grand Marquis	n/a	54.5	n/a	0.0	0.0	19.4	15.5	28.2
Fleet Estimate	**32.5**	**12.0**	**2.4**	**0.0**	**6.0**	**31.0**	**22.3**	**11.6**

Table B-9 shows measured irreversibility for vehicles with catalysts bench aged to represent 100,000 miles 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. Irreversibility 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-10. Sulfur Irreversibility: 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	0.0	0.0	11.3	14.6
98 Altima	15.1	0.0	21.1	10.8
Fleet estimate	**0.0**	**0.0**	**12.7**	**12.7**
2,000 Mile Exposure to High Sulfur Fuel				
98 Altima	n/a	0.0	n/a	6.1

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 irreversibility increased from 3.8 percent with the low mileage catalyst to 11.3 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 reversible for both NMHC and NOx emissions with the LA4 purge cycle. The second Altima, which had a 100,000 mile catalyst showed more irreversibility, only 15.1 percent for NMHC emissions and 21.1 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.

Table B-11. 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

c. Ford Sulfur Irreversibility Program

Ford tested two vehicles, a 1999 LEV Taurus and a 1999 LEV Explorer. Both vehicles were equipped with 4K mile aged catalysts. Neither vehicle was designed to meet SFTP emission standards. The vehicles were initially tested over the FTP cycle using low sulfur fuel (35 ppm) to establish a baseline. A total of three FTPs were run. This was followed by testing another three FTPs on a high sulfur fuel (450 ppm). Then, the fuel was switched back to the low sulfur fuel and the vehicles ran a LA4 cycle immediately followed by a FTP. The LA4 cycle was used to purge sulfur from the catalyst. Ford ran between three to five of these LA4/FTP combinations for each vehicle. Ford repeated the entire procedure with the US06 cycle in place of the LA4 cycle as a purge cycle. The following table lists the results of the Ford sulfur irreversibility test program.

Table B-12. Sulfur Irreversibility: Ford Test Program (%)

		NMHC		***NOx***	
		Purge Cycle		*Purge cycle*	
Model	Vehicle Type	LA4	US06	LA4	US06
Taurus	LDV	12.0	0.0	7.0	0.0
Explorer	LDT3	91.0	70.0	n/a	n/a

The Ford results were somewhat sporadic. The Taurus was mostly reversible over the LA4 and fully reversible over the US06, whereas the Explorer was highly irreversible over the LA4 cycle. They were unable to perform any tests over the US06 for the Explorer. Our biggest concerns with the Ford data was that the vehicles were mistakenly equipped and tested with 4K catalyst systems instead of 50K or 100K aged catalysts, and the data showed an enormous amount of variability.

d. EPA Sulfur Irreversibility Test Program

After publication of the NPRM, we tested two 1999 LDVs which were supplied to us by their manufacturer. One was a LEV Chevrolet Cavalier and the other was a ULEV Honda Accord. Both vehicles were equipped 50K aged catalysts. The vehicles were initially tested over the FTP cycle using low sulfur fuel (30 ppm) to establish a baseline. We tested until the emission results stabilized, typically three to four FTPs (approximately 60 to 80 miles). This was followed by FTP testing on a high sulfur fuel (350 ppm). Again, tests were run until emission levels were stable. Upon completion of high sulfur testing, the fuel was switched back to the low sulfur fuel and the vehicles ran a combination of LA4 cycle immediately followed by a FTP. These tests were also run until emissions stabilized, not exceeding eight LA4 + FTP cycles. Since neither vehicle was SFTP-compliant, we did not perform any tests with the US06 cycle as a purge cycle.

In addition to short-term sulfur testing, we also tested the vehicles with long-term exposure to sulfur. After completion of the short-term testing, the vehicles were driven over several EPEFE purge cycles to ensure that any sulfur from the short-term testing was removed from the catalysts. The vehicles were baseline tested on low sulfur fuel as before and then driven for 2,000 to 3,000 miles on the road with high sulfur (350 ppm) fuel. FTP tests were performed at 500 mile intervals. Upon the completion of high sulfur road aging, the vehicles ran a combination of LA4 cycle immediately followed by a FTP, exactly as in the short-term testing. Again, no US06 purge cycle testing was performed.

The following Table lists the results from our test program.

Table B-13. Sulfur Irreversibility: EPA Test Program, Short-Term and Long-Term Exposure (%)

		NMHC		***NOx***	
Short-Term		*Purge Cycle*		*Purge cycle*	
Model	Vehicle Type	LA4	US06	LA4	US06
Cavalier	LEV LDV	67.0	n/a	42.0	n/a
Accord	ULEV LDV	0.0	n/a	26.0	n/a
Long-Term					
Cavalier	LEV LDV	0.0	n/a	27.0	n/a
Accord	ULEV LDV	0.0	n/a	14.0	n/a

The results for short-term exposure suggest that both vehicles were highly irreversible, especially the Cavalier. The NMHC results for the Accord are most likely an anomaly since the vehicle mistakenly had only one test performed on high sulfur fuel. The results for long-term sulfur exposure are counter-intuitive, since NMHC emissions were fully reversible compared to the low level of reversibility for the vehicles when tested after short-term exposure. NOx emissions were slightly more reversible than for short-term exposure. However, even with long-term exposure to sulfur, NOx emissions were still only partially reversible.

e. ATL Sulfur Irreversibility Program

ATL, under contract for us, tested two vehicles, a 1999 LEV Ford Windstar mini-van and a 1999 LEV Ford Taurus. Both vehicles were procured from a rental agency in California and had approximately 50K miles. Thus, they were equipped with catalysts which had been aged with 50,000 miles of in-use driving, albeit at higher annual mileage rates than typical in-use vehicles. Both vehicles had low emissions, especially the Taurus which had emissions below Tier 2 levels.

ATL used the exact same test procedure as us for our in-house testing. The vehicles were initially tested over the FTP cycle using low sulfur fuel (30 ppm) to establish a baseline. Tests were run until emission results stabilized, typically three to four FTPs (approximately 60 to 80 miles). This was followed by FTP testing on a high sulfur fuel (350 ppm). Again, tests were run until emission levels were stable. Upon completion of high sulfur testing, the fuel was switched back to the low sulfur fuel and the vehicles ran a combination of LA4 cycle immediately

followed by a FTP. These tests were also run until emissions stabilized, not exceeding eight LA4 + FTP cycles. Because we were anticipating new powertrain control modules (PCM) from Ford that were to be equipped with SFTP-compliant calibrations, we did not run either vehicle over the US06 cycle. The following Table summarizes the results.

Table B-14. Sulfur Irreversibility: ATL Test Program

		NMHC		***NOx***	
		Purge Cycle		*Purge cycle*	
Model	Vehicle Type	LA4	US06	LA4	US06
Taurus	LDV	30.0	n/a	34.0	n/a
Windstar	LDT2	26.0	n/a	29.0	n/a

As can be seen, both of these vehicles were partially reversible. The level of irreversibility for both vehicles falls almost exactly in the middle of the data spread for all of the pre-SFTP vehicles.

f. Irreversibility for Long-Term Sulfur Exposure

In section A., we discussed the effect long-term exposure to sulfur has on sulfur sensitivity. We found that, based on a sample of six pre-SFTP LEV vehicles, long-term exposure to high sulfur fuel resulted in an additional sensitivity in emissions to sulfur of 149 percent for NMHC and 48 percent for NOx, above the original emission sensitivity levels when comparing emissions from a fuel sulfur level of 30 ppm to a fuel sulfur level of 330 ppm. For example, if baseline emissions were 0.10 g/mi NOx and high sulfur emissions were 0.15 g/mi NOx after short term exposure, then high sulfur emissions would be about 0.175 g/mi NOx after long term exposure. However, the data from these six vehicles indicates that when these vehicles were operated again on 30 ppm sulfur fuel with an LA4 purge cycle, the extra emissions sensitivity resulting from long-term exposure was completely recovered. In other words, all of the vehicles showed the same or lower emissions on low sulfur fuel after long-term exposure to high sulfur fuel as they did after short term exposure to high sulfur fuel. This would suggest that after long-term exposure to sulfur, emissions are capable of recovering to short-term levels with only moderate FTP-type driving. We are projecting this phenomenon to occur for both pre-SFTP and SFTP-compliant vehicles, though this data is available only for pre-SFTP vehicles. Thus, there is some uncertainty in applying it to SFTP-compliant Tier 2 vehicles, as well. However, the same is true for the data showing a larger sulfur sensitivity after long-term exposure to high sulfur fuel.

2. SFTP-compliant LEV and Tier 2 vehicles

The following three sections describe sulfur irreversibility test programs that utilize SFTP-compliant, low emitting LEVs and prototype Tier 2 vehicles. All of these programs occurred after publication of the NPRM. We are also quantifying irreversibility for NMHC and NOx emissions together instead of independently, because per our discussion above and our own experience developing the emission control strategy for the Expedition discussed below, sensitivity and irreversibility of either pollutant appears to be very dependent on the particular strategy chosen to reduce these emissions (particularly engine calibration and catalyst loading of precious metals and oxygen storage).

a. DaimlerChrysler Sulfur Irreversibility Program

DaimlerChrysler tested a prototype "Tier 2-like" 3.3L Dodge Caravan that met SFTP emission standards and was equipped with a 100K aged catalyst. DaimlerChrysler tested the vehicle over a test procedure very similar to the short-term portion of our sulfur irreversibility test program for the Cavalier and Accord. The only differences were that they tested a high sulfur fuel level of 450 ppm instead of 350 ppm, and they performed reversibility testing with the REP05 cycle in lieu of the US06 cycle for sulfur purging prior to FTP tests after operation on high sulfur fuel. The following Table lists results for the Caravan.

Table B-15. Sulfur Irreversibility: DaimlerChrysler Test Program (%)

	NMHC		***NOx***		***NMHC + NOx***	
	Purge Cycle		*Purge Cycle*		*Purge Cycle*	
Vehicle	LA4	REP05	LA4	REP05	LA4	REP05
Caravan	18.0	39.0	29.0	5.0	27.0	11.0

The Caravan was partially reversible for NMHC, NOx, and NMHC + NOx. The vehicle was more reversible after REP05 operation than LA4 operation for NOx, but not NMHC emissions. NMHC + NOx emissions indicate significant irreversibility for LA4 operation and moderate irreversibility even after REP05 operation.

b. EPA Sulfur Reversibility Program

In addition to the two pre-SFTP LEVs vehicles that we tested, we also tested a 1999 Ford Expedition SUV from our Tier 2 technology demonstration program. The vehicle was equipped with a 50K aged catalyst system. We modified the Expedition such that it met Tier 2 intermediate useful life emissions standards (bin 4 - 0.075 g/mi NMOG, 0.05 g/mi NOx) as well as federal and California SFTP standards with reasonable margins of safety. The modifications made consisted of calibration changes and an advanced catalyst system (see Chapter IV.A of the RIA for a

detailed description of our Tier 2 test work with the Expedition). The vehicle was initially tested over the FTP cycle using low sulfur fuel (30 ppm) to establish a baseline. We tested until the emission results stabilized, typically three to four FTPs. This was followed by FTP testing on a high sulfur fuel (350 ppm). Again, tests were run until emission levels were stable. Upon completion of high sulfur testing, the fuel was switched back to the low sulfur fuel and the vehicles ran a combination of LA4 cycle immediately followed by a FTP. These tests were also run until emissions stabilized, not exceeding eight LA4 + FTP cycles. The entire test procedure was repeated with the REP05 cycle in place of the LA4 cycle as a purge cycle. The following Table lists the results for the Expedition.

Table B-16. Sulfur Irreversibility: EPA Test Program (%)

	NMHC		***NOx***		***NMHC + NOx***	
	Purge Cycle		*Purge Cycle*		*Purge Cycle*	
Vehicle	LA4	REP05	LA4	REP05	LA4	REP05
Expedition	78.0	91.0	21.0	0.0	65.0	70.0

The Expedition was partially reversible for NOx over LA4 conditions and fully reversible over the REP05. However, the most interesting observation was that it was highly irreversible for NMHC over all driving conditions, but especially for aggressive. The results for NMHC , although more severe for the Expedition, were similar to the Caravan in that both vehicles were more irreversible over the REP05 than the LA4 cycle. Looking at NMHC + NOx results, indicate that the Expedition was highly irreversible for all driving conditions.

c. ATL Sulfur Reversibility Program

ATL, under contract for us, tested two vehicles, a 1999 LEV Ford Windstar mini-van and a 1999 LEV Ford F-150 pick-up truck. Both vehicles were procured from a rental agency in California and had approximately 50K miles. Thus, they were equipped with catalysts which had been aged with 50,000 miles of in-use driving, albeit at higher annual mileage rates than typical in-use vehicles. Both vehicles were then equipped with new powertrain control modules (PCM) with calibrations modified to meet SFTP emission standards, courtesy of Ford. Both vehicles had low emissions, but not at Tier 2 emission levels. A third vehicle (Taurus) was procured by ATL, but a SFTP-compliant PCM was not available, so it was not tested with the other two vehicles.

ATL used the exact same test procedure as us for our in-house testing. The vehicles were initially tested over the FTP cycle using low sulfur fuel (30 ppm) to establish a baseline. Tests were run until emission results stabilized, typically three to four FTPs. This was followed by

FTP testing on a high sulfur fuel (350 ppm). Again, tests were run until emission levels were stable. Upon completion of high sulfur testing, the fuel was switched back to the low sulfur fuel and the vehicles ran a combination of LA4 cycle immediately followed by a FTP. These tests were also run until emissions stabilized, not exceeding eight LA4 + FTP cycles. The entire test procedure was repeated with the REP05 cycle in place of the LA4 cycle as a purge cycle. The following Table summarizes the results.

Table B-17. Sulfur Irreversibility: ATL Test Program (%)

	NMHC		***NOx***		***NMHC + NOx***	
	Purge Cycle		*Purge Cycle*		*Purge Cycle*	
Vehicle	LA4	REP05	LA4	REP05	LA4	REP05
Windstar	0.0	0.0	35.0	0.0	31.0	0.0
F-150	60.0	25.0	13.0	7.0	18.0	9.0

For the LA4 cycle, both vehicles experienced considerable irreversibility for NMHC, NOx, and NMHC + NOx, except for NMHC emissions with the Windstar. With the REP05 cycle, the Windstar was fully reversible for all pollutants, while the F-150 was still partially reversible.

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 much 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.

EPA established a number of criteria for evaluating the available data in order to project likely levels of in-use sulfur irreversibility. 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.

Development of the subsequent criteria are more complex, because the issues of SFTP compliance, vehicles emissions performance 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. Four of the vehicles were equipped with "prototype" SFTP-compliant calibrations, meaning they met both the Tier 1 and LEV US06 standards. Of these four vehicles, only one (EPA Ford Expedition) met the SC03 standards as well as the US06 standards.

As discussed earlier, there will be considerable trade-offs in NMOG and NOx control in order to meet strict Tier 2 emission standards. There can be considerable uncertainty associated with balancing these trade-offs at very low emissions levels if the vehicle is periodically operated on high sulfur fuels, making the ability to remove sulfur from the catalyst highly uncertain. For example, a given catalyst today may be fully reversible for one pollutant and only partially reversible for another. However, because of the trade-off in NMOG and NOx performance, the modifications necessary to get that vehicle to meet both emission standards may result in the opposite effect for reversibility; i.e., full reversibility for NMOG and partial reversibility for NOx. Therefore, a very important criterion in conjunction with SFTP compliance is LEV emission performance for pre-SFTP vehicles and "Tier 2-like" emission performance for SFTP-compliant Tier 2 vehicles.

Likewise, for the bulk of the data which is for pre-SFTP LEVs, only the LA4 and US06 driving cycles were used in the test programs. 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 from the REP05 cycle. 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-use during aggressive driving.

The four SFTP-compliant vehicles used the REP05 cycle in lieu of the US06 cycle. The REP05 cycle was developed by EPA to be is representative of aggressive driving that occurs outside the LA4 or FTP cycle. All but one of the aggressive driving segments found in the US06 cycle were taken from the REP05. While each segment of the US06 cycle was taken from actual in-use driving, the timing and combination of these segments is not representative of in-use driving in the way REP05 is representative. As with the US06 cycle, however, the length of time that the catalyst is exposed to both high temperatures and rich conditions could be much higher than would occur in the real world, resulting in the removal of more sulfur than would be removed in-use even during aggressive driving. Thus, while it is likely that typical vehicles will

experience the reversibility which was measured after driving over the REP05 cycle, we cannot be certain that this is the case.

As mentioned in Section B, meeting the SFTP standards will require 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. 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:

Pre-SFTP Vehicles

1. Only use data from vehicles with aged catalyst systems,
2. Emphasize data from vehicles with LEV emission levels, and
3. Use data where the sulfur was purged using either the LA4 or US06 cycle.

SFTP-Compliant LEV and Tier 2 vehicles

1. Only use data from vehicles with aged catalyst systems,
2. Emphasize data from vehicles with emission levels appropriate for the LEV and Tier 2 standards,
3. Use data from vehicles that were modified to meet SFTP standards, and
4. Use data where the sulfur was purged using either the LA4 or REP05 cycle.

E. Projected Levels of Sulfur Irreversibility In-Use

1. Pre-SFTP Vehicles

Applying the first criterion developed in Section D. results in the retention of the CRC and EPA data (Tables B-2 and B-9), 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 irreversibility of sulfur effects for pre-SFTP vehicles do not rely on the API data except that in Table B-6.

Table B-18. Pre-SFTP Sulfur Irreversibility: Summary of Relevant Test Programs (%)

	NMHC		***NOx***	
	Purge Cycle		*Purge Cycle*	
Models	LA4	US06	LA4	US06
CRC (6 vehicles)	0.0	0.0	16.0	4.0
EPA (2 vehicles)	75.0	n/a	38.0	n/a
ATL (2 vehicles)	28.0	n/a	30.0	n/a
API (2-3 vehicles)	0.0	14.0	0.0	12.0
Fleet Estimate	14.0	0.0	20.0	5.0

For pre-SFTP vehicles (Tier 0, Tier 1 and NLEV), as described above, we decided to utilize reversibility measurements using both the LA4 and US06 driving cycles. We decided to project reversibility for these vehicles by taking the mid-point of the LA4 and US06 values for NMHC and NOx, respectively. Therefore, for these vehicles, using the average of these test results, we project that NMHC emissions are almost fully reversible at four percent irreversibility, while NOx emissions are 12 percent irreversible.

2. SFTP-Compliant LEV and Tier 2 vehicles

The DaimlerChrysler, EPA, and ATL data all met the first criterion of aged catalyst systems. The DaimlerChrysler vehicle was equipped with a 100K aged catalyst, while the vehicles from the other two programs had 50K aged catalyst systems. As for emission performance, all four vehicles were LEVs, meeting the LEV standards with considerable margins of safety. The Expedition and Caravan were both modified in an attempt to meet Tier 2 standards. Only the Expedition actually met both Tier 2 NOx and NMOG emission standards with a typical margin of safety. The Caravan was close to Tier 2 levels, but exceeded the NOx standard. The F-150 was also close to Tier 2 levels, while the Windstar exceeded Tier 2 levels by a significant margin. It should be noted, however, that all four vehicles are LDTs which were certified to substantially higher emission standards than the Tier 2 standards in their baseline configurations. Also, because these vehicles are LDTs, their catalyst temperatures are typically higher than LDVs, which is good for removing sulfur from the catalyst.

All four vehicles from the three programs met the federal and California SFTP emission standards for the aggressive driving portion (US06) with considerable margin. The Expedition also met the SFTP emission standards for the air-conditioning portion of the test (SC03) as well.

As discussed above, trade-offs between NMOG and NOx control in order to meet Tier 2 standards combined with periodic operation on high sulfur fuel will result in uncertainty in the ability to remove sulfur from the catalyst. Therefore, for SFTP-compliant Tier 2 vehicles, we feel that the most appropriate way to analyze irreversibility is to evaluate NMHC and NOx together (i.e., NMHC + NOx), rather than separately. The following Table shows the results for the four vehicles from the DaimlerChrysler, EPA, and ATL test programs.

Table B-19. SFTP-Compliant Sulfur Irreversibility: Summary of Relevant Test Programs (%)

	NMHC + NOx	
	FTP Purge	*REP05 Purge*
Daimler-Chrysler Caravan	27.0	11.0
Ford Expedition	64.8	69.6
Ford Windstar	31.4	0.0
Ford F-150	18.3	9.1
Average	29.4	10.9
Average w/ lower weights for Caravan and Windstar	29.4	16.6

As can be seen, NMHC + NOx irreversibility is generally much lower after high speed, aggressive driving than after more average city driving. As previously discussed, the REP05 cycle represents the top 28 percent of driving with the highest speeds and hardest accelerations. Thus, most people will drive like the REP05 cycle at least part of the time; however, it is not clear whether occasional driving like the REP05 cycle will provide all of the reversibility enhancement that was provided by the entire REP05 cycle performed in sequence.

There is also still significant variability between the irreversibility of individual vehicles, with the Expedition showing the highest irreversibility by far. This is significant for determining a SFTP-compliant Tier 2 irreversibility estimate, because the Expedition is the only vehicle which complies with both the NMHC and NOx Tier 2 standards with a reasonable amount of headroom. The Windstar (@ 0.12 g/mi NOx) and the Caravan (@ 0.09 g/mi) exceed the Tier 2 NOx standard by significant margins, while the F-150 truck had NOx emissions just slightly above the 0.07 g/mi standard.

Therefore, to determine an irreversibility estimate for SFTP-compliant Tier 2 vehicles, we had to account for the differences in various vehicle's compliance with the Tier 2 standards. We

accomplished this by reducing the weight given to the Windstar and Caravan. We recalculated the average irreversibility by reducing the weight assigned to the Windstar and Caravan to one-fourth and one-half of a vehicle, respectively. As shown in the table above, this has no impact on the average irreversibility after FTP driving, but reduces that after REP05 driving modestly. The REP05 cycle represents about 28 percent of all in-use driving. Due to roadway limitations, no one can drive like the REP05 cycle 100% of the time (i.e., residential areas, congested streets, etc.). Therefore, it is reasonable to project that the majority of vehicles are driven in this way at least part of the time. However, it is likely that some vehicles are never or very rarely driven this aggressively. Therefore, we project that roughly 75 percent of vehicles are driven regularly like the REP05 cycle and that 25 percent are not. Thus, we decided to weigh the irreversibility after FTP driving by 25 percent and that after REP05 driving by 75 percent. This results in an average NMHC+NOx irreversibility of 20 percent.

We also wanted to focus on the irreversibility of the Expedition, since it was the only vehicle meeting the Tier 2 standards with adequate headroom. The Expedition had irreversibility levels of 65-70 percent over the two driving cycles. Since the lower irreversibility was seen over the FTP, that figure (65 percent) seems reasonable for an estimate based solely on the Expedition. Therefore, for Tier 2 vehicles, we project that irreversibility of NMHC+NOx emissions will fall somewhere between the low level of 20 percent, based on all four vehicles, and 65 percent based on the Expedition. For emission modeling and cost effective analyses, we decided to use a midpoint estimate of 42.5 percent for Tier 2 vehicles. As for SFTP-compliant LEV vehicles, we decided to use a straight average of the four vehicles weighing the irreversibility after FTP driving by 25 percent and that after REP05 driving by 75 percent, similar to what we did for Tier 2 vehicles. This resulted in an average NMHC+NOx irreversibility of 15 percent. As mentioned above, we project that Tier 0 and Tier 1 vehicles are fully reversible.

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 Report Number M6.FUL.001

Appendix C: Refinery Energy and Global Warming Impacts and Emissions

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 in 1997. We simplified our methodology here relative to that used for the cost analysis. We estimate the energy impact of desulfurizing gasoline under two scenarios. The first assumes that refiners will use the improved desulfurization technologies discussed in Chapter IV.B. This represents the near term scenario, when refiners are projected to use a mixture of proven, improved, and adsorption technologies. The second scenario assumes that refiners will use the advanced adsorption technologies also discussed in that chapter. This represents the long term scenario, when refiners are projected to use only the adsorption technologies. We use 1997 as the base year for this analysis because that is the base year of the cost calculation, which is a basis for this analysis, and because of the uncertainty in projecting U.S. global warming gas emissions in future years.

To determine the percentage increase in refinery energy consumed by desulfurizing gasoline, we first established the baseline energy consumption by PADD 3 refineries using 1994 Energy Information Administration data, which is the most recent energy consumption data available. We project the baseline energy consumption of PADD 3 refineries from 1994 to 1997 using an estimated increase in energy consumption of 6 percent, which is based on 2.05 percent increase in increased refinery throughput per year. This PADD 3 energy consumption calculation is summarized below in Table V-46. The energy consumed by PADD 3 refineries in 1997 is estimated to be about 1,500 trillion BTUs.

Table C-1. 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

The total amount of energy consumed to desulfurize gasoline down to 30 ppm target is calculated by adding up the fuel gas, steam and electricity, in terms of British thermal units (BTUs) consumed, for the desulfurization unit, hydrogen production and octane makeup . First we estimated the energy consumed running both the CDTECH and Octgain 220 processing units. Consistent with how the cost of desulfurization was estimated for these improved technologies, each desulfurization technology was presumed to handle half of PADD 3's desulfurization needs. Then the energy consumed for recovering octane and producing hydrogen demand is calculated.

For both CDTECH and Octgain, we presumed that reformer capacity[1] was available to make up the octane lost from desulfurization. We accounted for the amount of hydrogen that the reformer would produce and by subtracting the reformer production from the hydrotreater demand, we estimated the amount of hydrogen which had to be provided by an existing hydrogen plant. 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. A summary of the estimated CDTECH and Octgain energy and hydrogen demands in PADD 3 is summarized in Tables V-47 and V-48, respectively.

[1] According to the 1996 API/NPRA survey of gasoline quality and refinery operations, spare reformer capacity is available in the U.S. If a particular refiner has no spare reformer capacity, then the energy consumed and global warming emissions emitted can then be assumed to be emitted by an expanded reformer, or other octane generating units which likely consume less energy than the reformer due to their less severe operating conditions.

Table C-2. Estimated Annual Energy and Hydrogen Demand of CDTECH Desulfurization Units for Half of PADD 3

CDTECH Utility Demands	*Process Demand*	*Yearly Throughput*	*BTU Conversion Factor*	*Energy and Hydrogen Consumed*
Electricity	0.44 KwH/Bbl	273 MMBbls	3.41 MBtu/KwH	410 MMMBtu
Fuel Gas	41250 Btu/Bbl	273 MMBbls	-	11,250 MMMBtu
Hydrogen	102 Scf/Bbl	273 MMBbls	-	27,800 MMScf
Reformer		Hydrogen	Produced	12,320 MMScf
Electricity	2.6 KwH/Bbl	12 MMBbls feed	3.41 MBtu/KwH	105 MMMBtu
Fuel Gas	0.06 FOE/Bbl	12 MMBbls feed	6 MMBtu/Bbl	4350 MMMBtu
Steam	94 Lb/Bbl	12 MMBbls feed	0.809 MBtu/Lb	1100 MMMBtu
Hydrogen Plant		Hydrogen	Produced	14,180 MMScf
Fuel Gas	0.11 FOE/Bbl	8.5 MMBbls H2	6 MMBtu/Bbl	5680MMMBtu
Electricity	1.69 KwH/Bbl	8.5 MMBbls H2	6 MMBtu/Bbl	50 MMMBtu
Total				22,950 MMMBtu

Table C-3. Estimated Annual Energy and Hydrogen Demand of OCTGAIN Desulfurization Units for Half of PADD 3

OCTGAIN 220 Utility Demands	*Process Demand*	*Yearly Throughput*	*BTU Conversion Factor*	*Energy and Hydrogen Consumed*
Electricity	1.55 KwH/Bbl	213 MMBbls	3.41 MBtu/KwH	1440 MMBtu
Fuel Gas	44500 Btu/Bbl	213 MMBbls	-	9470 MMMBtu
Steam	0 Lb/Bbl	213 MMBbls	0.809 MBtu/Lb	0 MMMBtu
Hydrogen	130 Scf/Bbl	213 MMBbls	-	27,700 MMScf
Splitter			-	
Electricity	0.17 KwH/Bbl	273 MMBbls	3.41 MBtu/KwH	80 MMMBtu
Fuel Gas	0 FOE/Bbl	273 MMBbls	6 MM Btu/Bbl	0 MMMBtu
Steam	45 Lb/Bbl	273 MMBbls	0.809 MBtu/Lb	5960 MMMBtu
Reformer		Hydrogen	Produced	1,140 MMScf
Electricity	2.6 KwH/Bbl	1.2 MMBbls	3.41 MBtu/KwH	11 MMMBtu
Fuel Gas	0.06 FOE/Bbl	1.2 MMBbls	6 MM Btu/Bbl	445 MMMBtu
Steam	94 Lb/Bbl	1.2 MMBbls	0.809 MBtu/Lb	94 MMMBtu
Hydrogen Plant		Hydrogen	Produced	26,600 MMScf
Fuel Gas	0.11 FOE/Bbl	13.5 MMBblsH2	6 MMBtu/Bbl	9040 MMMBtu
Electricity	1.69 KwH/Bbl	13.5 MMBblsH2	6 MMBtu/Bbl	75 MMMBtu
Total				26,600 MMMBtu

We used the same methodology to estimate the energy consumed for the adsorption technologies by Black and Veatch and Phillips, with each presumed to desulfurize half the gasoline pool. Those estimates are summarized in Tables V-49 and V-50.

Table C-4. Estimated Annual Energy and Hydrogen Demand of Black and Veatch Desulfurization Units for Half of PADD 3

Black and Veatch Utility Demands	*Process Demand*	*Yearly Throughput*	*BTU Conversion Factor*	*Energy and Hydrogen Consumed*
Electricity	1.92 KwH/Bbl	272 MMBbls	3.41 MBtu/KwH	1790 MMBtu
Fuel Gas	24100 Btu/Bbl	272 MMBbls	-	6580 MMMBtu
Steam	0 Lb/Bbl	272 MMBbls	0.809 MBtu/Lb	0 MMMBtu
Hydrogen	14 Scf/Bbl	272 MMBbls	-	3900 MMScf
Hydrogen Plant		Hydrogen	Produced	3900 MMScf
Fuel Gas	0.11 FOE/Bbl	13.5 MMBblsH2	6 MMBtu/Bbl	1330 MMMBtu
Electricity	1.69 KwH/Bbl	13.5 MMBblsH2	6 MMBtu/Bbl	11 MMMBtu
Diesel Hydrotreater				1170 MMMBtu
Total				10,900 MMMBtu

Table C-5. Estimated Annual Energy and Hydrogen Demand of Phillips Desulfurization Units for Half of PADD 3

Phillips Utility Demands	*Process Demand*	*Yearly Throughput*	*BTU Conversion Factor*	*Energy and Hydrogen Consumed*
Electricity	0 KwH/Bbl	272 MMBbls	3.41 MBtu/KwH	1790 MMBtu
Fuel Gas	49400 Btu/Bbl	272 MMBbls	-	6580 MMMBtu
Steam	0 Lb/Bbl	272 MMBbls	0.809 MBtu/Lb	0 MMMBtu
Hydrogen	70 Scf/Bbl	272 MMBbls	-	19,100 MMScf
Reformer		Hydrogen	Produced	8590 MMScf
Electricity	2.6 KwH/Bbl	9.3 MMBbls	3.41 MBtu/KwH	83 MMMBtu
Fuel Gas	0.06 FOE/Bbl	9.3 MMBbls	6 MM Btu/Bbl	3350 MMMBtu
Steam	94 Lb/Bbl	9.3 MMBbls	0.809 MBtu/Lb	847 MMMBtu
Hydrogen Plant		Hydrogen	Produced	15,750 MMScf
Fuel Gas	0.11 FOE/Bbl	13.5 MMBblsH2	6 MMBtu/Bbl	3580 MMMBtu
Electricity	1.69 KwH/Bbl	13.5 MMBblsH2	6 MMBtu/Bbl	30 MMMBtu
Total				21,400 MMMBtu

As these tables show, the average increase in energy consumption for the improved gasoline desulfurization technologies to meet a 30 ppm gasoline sulfur program, including the energy needed to provide hydrogen and make up octane loss, is estimated to be about 50 trillion BTUs based on 1997 volumes. This increase in energy use is about 3.2 percent of the baseline PADD 3 refining industry energy consumption.

For the U.S. outside of California, the refining industry is estimated to consume 3000 trillion BTUs per year.[2] Thus the increase in energy demand for the U.S. refining industry, based on PADD 3 and using the 3.2 percent factor calculated above, is estimated to be about 96 trillion

[2]This estimate is based on the presumption that PADD 3 consumes 50 percent of the energy in the U.S. outside of California.

BTUs per year.

In future years (i.e., after 2019), assuming that all FCC gasoline desulfurization is switched over to the adsorption desulfurization technologies, PADD 3 refiners are expected to consume 32 trillion BTU's over the baseline, which represents a 2.1 percent increase in PADD 3 refinery energy demand. Projecting this PADD 3 energy demand to the entire U.S., and based on the adsorption technologies, we estimate that the U.S. refining industry would consume an additional 63 trillion BTUs of energy to desulfurize gasoline based on a 1997 baseline.

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 refinery energy and, thus, is presumed to be the source of all refinery emissions of carbon dioxide. The carbon dioxide emission factor is estimated to be 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).[1] For simplicity, this analysis assumes that all BTUs consumed in a refinery are produced by these fuel sources. On this basis, CO2 emissions from all U.S. refineries would increase by 6.7 million tons per year in the 1997 base year based on the improved desulfurization technologies, and CO2 emissions would increase by 4.2 million tons in the 1997 base year based on the adsorption technologies.

The increase in CO2 emissions for installing improved desulfurization technologies is a one-time step increase in CO2 emissions which represents 0.12 percent of the U.S. CO2 emissions inventory, which is 5.4 billion tons of CO2 per year in based on 1997 emissons.[2] This increase also represents about 9 percent of the total projected increase in U.S. CO2 emissions in a single year, which is about 70 million tons per year in 1997. Based on our presumption that the adsorption technologies will replace the mix of proven and improved desulfurization technologies (expected to occur after 2019), worldwide CO2 emissions are projected to be 0.08 percent higher than the baseline due to the U.S. desulfurization program, which is 60 percent (or 40 percent less) of the total projected one-time increase in U.S. CO2 emissions based on the mix of desulfurization technologies which we presume to be used at the outset of the program. The increase in energy consumed and carbon dioxide emissions is summarized in Table V-51.

Table C- 6. Increase in Energy Consumed and Carbon Dioxide Emissions Due to Desulfurizing Gasoline (1997 energy use and emissions)

	Improved Desulfurization Technologies	Adsorption Desulfurization Technologies
Increase in Energy Consumed (trillion Btu) Percent Increase in U.S. Refining Industry Energy Consumed	96 3.2	63 2.1
Increase in CO2 Emissions (million tons) One-Time Percent Increase in Yearly U.S. CO2 Emissions	6.7 0.12	4.2 0.08

The desulfurization of gasoline will increase emissions of conventional pollutants from refineries. At a minimum, desulfurizing gasoline will require the addition of a naphtha hydrotreater. However, refiners will need a source of hydrogen and make up the loss of octane. A likely way for refiners to make up that lost octane is to increase the feed to an existing reformer. In addition to the octane boost, the reformer also provides a source of hydrogen. If the amount of hydrogen provided by the reformer is insufficient, the refiner is assumed to either produce more hydrogen from an existing hydrogen plant, or install another hydrogen plant to provide the balance of hydrogen.

Each of these units require heaters to provide heat for reactions. Heaters emit oxide of nitrogen (NOx) emissions, volatile organic carbon (VOC) emissions, carbon monoxide (CO), particulates and sulfur oxide (SOx). VOC emissions are also emitted from leaks from pipes, valves, pumps etc. of refinery units which process petroleum.

To estimate the increase in emissions from desulfurizing gasoline, we contacted Mobil Oil to obtain emissions information from Mobil on their Octgain unit in operation at their Joliet, Illinois refinery. Mobil provided information to us for a 25,000 barrel per day Octgain unit.[3] The information provided was expressed in aggregate emissions per year, emissions per pound of fuel gas consumed, and emissions per hour. We used the hourly emissions rate with the hourly heater energy consumption as a divisor. This ratio expressed the emissions rate in terms of the energy consumed in the heater, which allowed us to base our emissions analysis on the PADD 3 energy analysis summarized above.

Using the PADD 3 analysis above, we are presuming that the emissions per energy consumed ratio, which we calculate in the Table C-7 below, is the same for all desulfurization technologies. This assumption is reasonable since heaters should be essentially the same for any

refinery processing unit. Except for VOC emissions, we also assume that the emissions from the other units that provide octane and hydrogen can be estimated by the emission factors in Table C-7. Since hydrogen plants normally only react natural gas, and since the octane produced from the reformer is likely from a unit already present in the refinery, we do not expect any additional VOC emissions from these units. Consistent with that premise, we only account for the VOC emissions from the hydrotreating unit. The VOC emission values reflect our presumption that refiners have adopted, or will have adopted, leak detection and maintenance programs for significant VOC emission control, which is consistent with the environmental programs in place, or expected to be in place, in most refineries. We expressed the NOx emissions as a range; the larger number reflects Mobil's estimate of NOx emissions from a heater with conventional burners, and the lower number is our estimate of a heater with ultra-low burners (which incorporates a 75 percent reductions in emissions). The information provided by Mobil Oil and our recalculated emissions values are summarized in the following table.

Table C-7. Pollutant Emissions from an Octgain unit

Pollutant	*Emissions (lbs per hour)*	*Emissions (lbs per MMMbtu)*
NOx*	6.19 - 1.55	140 - 35
VOC**	1.08	25
CO	1.55	35
Particulates	0.13	3.0
SOx	0.56	13

* Emissions based on two different types of burners, the upper range value is for a conventional burner provided by Mobil Oil, lower range value is our estimate for a for an ultra-low NOx burner which emits 75 percent less NOx per unit energy consumed.
** Emissions based on a unit monitored with a leak detection and maintenance program.

Next we revisit the increased energy demand due to desulfurizing gasoline for PADD 3 from Tables C-2 through C-5 above which are based on the four desulfurization technologies which formed the basis for our energy analysis. Based on the estimated increased PADD 3 energy demand, we then estimate the increased energy demand and resulting emissions increases for an average-sized refinery, which would be producing about 70,000 barrels per day gasoline or refining about 133,000 barrels per day crude oil, and for the U.S. refining industry. Like the PADD 3 energy analysis, we aggregate the two improved desulfurization technologies for one estimate, and aggregate the two adsorption technologies for the second estimate.

The actual emission increases from any given refinery could be more or less than our

estimates, due to several refinery-specific factors, such as the specific type of gasoline desulfurization technology chosen, the actual amount of gasoline produced per barrel of crude oil, the refinery's baseline gasoline sulfur level, and the actual level of emissions control. Therefore, EPA's estimates should in no way be viewed as the actual level of emission increases from a given refinery, but rather, as a relative estimate of refinery emissions increases, for general comparison with the benefits of the Tier 2/gasoline sulfur program. The true emission increases can only be estimated by specific refineries as they prepare permit applications for gasoline desulfurization projects. Refiners have also indicated that they may be making modernizations, plant expansions, or debottlenecking changes along with gasoline desulfurization changes. All of these changes, while not attributable to the Tier 2/sulfur program, could nevertheless result in emission increases higher than EPA's estimates.

The emission estimates for an average-sized refinery and for the U.S. refining industry are summarized in Table C-8 below.

Table C-8. Projected Increased Energy Use and Increased Pollutant Emissions of an Average-Sized Refinery and the U.S. Refining Industry due to Meeting the 30 ppm Gasoline Sulfur Standard (2004)

Technology Name	*Increased Energy Demand for PADD 3 (MMMBtu/yr)*	*Projected Increase in Energy Use and Emissions for an Average-Sized Refinery (Tons/year)*	
Energy Demand (MMBtu/year)	53,200	1830	110,400
Improved Desulfurization Technologies CDTech & Octgain 220		NOx 130 - 32 VOC 11 CO 32 Particulate 3 SOx 12	NOx 7730 - 1930 VOC 670 CO 1930 Particulate 165 SOx 695
Energy Demand (MMBtu/year)	32,300	1110	72,500
Adsorption Desulfurization Technologies Black and Veatch & Phillips		NOx 80 - 20 VOC 7 CO 20 Particulate 2 SOx 7	NOx 5100 - 1270 VOC 440 CO 1270 Particulate 110 SOx 460

This analysis shows that the projected increase in refinery emissions due to desulfurizing gasoline is trivial compared to the significant emission reductions expected from the tighter motor Tier 2 vehicle standards. For both NOx and VOC and considering emissions in 2010, the increased emissions from refineries is less than one quarter of one percent of the decrease in NOx emissions reductions due to motor vehicle standards. In future years, as Tier 2 vehicles phase into the fleet, emission reductions from motor vehicles are expected to outpace emission increases in the refinery, and as adsorption technologies replace proven and improved desulfurization technologies in future years, the difference is expected to be even greater.

Appendix C References

1. Wang, M.Q., GREET 1.4 - Transportation Fuel-Cycle Model, Center for Transportation Research, Argonne National Laboratory.

2. Emissions of Greenhouse Gases in the United States 1998, Energy Information Administration, October 1998.

3. Chuba, Mike, OCTGAIN Environmental Impact Evaluation, January 19, 1999.

Appendix D: EPA's Legal Authority for Gasoline Sulfur Control

We are adopting 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 our current our requirements that affect gasoline sulfur content, and explain our bases for controlling 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.[1]

All gasoline is subject to Section 211(f) of the Act, which prohibits fuel or fuel additive 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[2]), which limits the sulfur content of unleaded gasoline to 0.1 weight percent (1000 ppm) sulfur.

B. How the 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 promulgating controls on 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

[1]Because sulfur is directly or indirectly controlled by EPA requirements, and will be controlled directly under today’s action, states are preempted from initiating sulfur control programs unless they are identical to the federal requirements. See the discussion in Section IV.C. of the preamble on this subject.

[2]Standard Specification for Automotive Spark-Ignition Engine Fuel

more detail in Chapter III above, 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 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 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.

EPA has also satisfied the statutory requirement to consider "other technologically or economically feasible means of achieving emission standards under section [202 of the Act]." This provision has been interpreted as requiring consideration of establishing emissions standards under § 202 prior to establishing controls or prohibitions on fuels or fuel additives under § 211(c)(1)(A). See *Ethyl Corp. v. EPA*, 541 F.2d. 1, 31-32 (D.C. Cir. 1976). In *Ethyl*, the court stated that § 211(c)(2)(A) calls for good faith consideration of the evidence and options, not for mandatory deference to regulation under § 202 compared to fuel controls. *Id*. at 32, n.66.

In today's action, EPA for the first time is establishing standards for fuels and vehicles together. Thus, it is first important to consider that the sulfur standards are not being adopted as an alternative to vehicle emissions standards, but in addition to such standards, and as a necessary prerequisite to ensuring that vehicles can meet the vehicle standards. In addition, the Tier 2 standards being adopted today will begin phasing-in in 2004, but will not be fully phased in for the fleet of new motor vehicles until 2009, and even at that time, many non-Tier 2 vehicles will still be on the road. Thus, another point to consider is that the emissions standards under § 202 will achieve smaller emissions benefits in the early years of the program and will not achieve their full emissions benefits for a number of years, while the sulfur standards will achieve significant, immediate emissions benefits through reducing emissions from the existing fleet of motor vehicles (primarily Tier 1 vehicles and LEVs), and will continue to achieve increasing benefits as the fleet turns over to Tier 2 vehicles, especially in light of the expected increase in vehicle miles travelled.

EPA has also considered emissions standards under § 202 that are more stringent than Tier 2 as an alternative to regulating gasoline sulfur. However, for the reasons described in Chapter IV, we conclude that the Tier 2 standards represent the level of emission control that is economically and technologically feasible from new motor vehicles in the time frame over which the standards are implemented. Moreover, we considered Tier 2 standards without control of

gasoline sulfur as an alternative to regulating gasoline sulfur. However, we have concluded that the Tier 2 standards would not be feasible without control of gasoline sulfur. For these reasons, we find that the alternatives of either more stringent vehicle standards, or Tier 2 standards without sulfur control, are not technologically or economically feasible options to regulating gasoline sulfur.

Our consideration of other technologically and economically feasible means of achieving emissions standards under § 202 of the Act supports the conclusion that the sulfur standards adopted today represent an appropriate exercise of the Agency's discretion under § 211(c)(1)(A), even when the Tier 2 standards are considered.

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 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 adopted today). Thus, Tier 0 and Tier 1 vehicles have higher emissions when they are exposed to sulfur levels substantially higher than the sulfur standard adopted today. 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 gasoline sulfur control.

The sulfur impact on the catalysts used in later model vehicles is clearly significant. High sulfur levels have been shown to significantly reduce the conversion efficiency of 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 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 100 percent increase in NMHC and 197 percent increase in NOx emissions when operated on 330 ppm sulfur fuel compared to 30 ppm sulfur fuel (see Appendix B for more details). This level of emissions increase is significant enough that it would undermine the technical and economic feasibility of the Tier 2 standards.

This level of impact on emission control system efficiency would mean actual in-use emissions reductions from the 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.

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, on average over their long-term operation, have to use fuel with sulfur levels no greater than 30 ppm to avoid significant impairment of their emissions control systems. Furthermore, short-term operation on gasoline with sulfur levels higher than 80 ppm will have a significant adverse effect on the desired emission performance and will significantly impair 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.

Therefore, 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.

In summary, 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 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 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 Tier 2 standards. While the impact on emissions control systems of Tier 2 vehicles and LEVs is a sufficient basis to control gasoline sulfur under Section 211(c)(1)(B), a similar analysis for Tier 0 and Tier 1 vehicles also supports 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.
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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 fuel control with such devices or systems which are or will be in general use that do not require the fuel control. As described above, we conclude that the emissions control systems expected to be used to meet the 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, and Chapters IV, V, and VII above, including an analysis of the environmental benefits of the fuel control, an analysis of the costs and the technological feasibility of controlling sulfur to the levels required by today's action, and a cost-benefit analysis of the 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 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 general use in gasoline-powered vehicles that can meet the 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, as well as in Appendix B above, 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, we anticipate that all the gasoline vehicle technologies expected to be used to meet the Tier 2 standards will require the use of low sulfur gasoline. If we do not control gasoline sulfur to the levels required by today's rule, we would not be able to set Tier 2 standards as stringent as those we are adopting. Moreover, vehicles already on the road would continue to emit at higher levels than they would if operated on low sulfur fuel. These benefits from the existing fleet, which are particularly significant in the early years of the program, cannot be achieved through new vehicle emissions standards. Consequently, we conclude that the benefits that would be achieved through implementation of the vehicle and sulfur control programs in today's rule cannot be achieved through the use of emission control technology that is not sulfur-sensitive.

This also means that if we were to adopt vehicle emissions control standards without controlling gasoline sulfur content, the standards would be significantly less stringent than those based on what would be technologically feasible with current sulfur levels, rather than what is feasible with lower sulfur. In such a situation, the cost of the vehicle emissions control technology would likely be similar to the costs of meeting the 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 with low sulfur gasoline, 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. Thus, the same benefits achieved by today's program could not be achieved through vehicle emissions standards alone, because of the sensitivity of the emissions control technology to sulfur.

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 prohibiting sulfur in gasoline, but rather controlling the levels of sulfur in gasoline, this finding is not required prior to regulation. However, EPA does not believe that the sulfur standards adopted today 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 current sulfur levels.

We believe that gasoline formulated to meet the low sulfur standards will have a

significant net benefit to public health due to reduced emissions of harmful compounds. 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 from the engine itself, we believe that the improved catalyst performance enabled by the low sulfur fuel will more than offset any slight increase in harmful emissions from the engine that might result, such that the net emissions effect of the sulfur control is a substantial reduction in emissions, compared to emissions from gasoline without the sulfur control.

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 sulfur 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 action 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.

Appendix D References

1. *EPA Staff Paper on Gasoline Sulfur Issues* (EPA420-R-98-004), May 1998.