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Tier 2
Report to Congress

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Tier 2 Study

July 31, 1998

FINAL

I. EXECUTIVE SUMMARY

Purpose of the Tier 2 Study

This Tier 2 Study examines whether it is appropriate to require more stringent emission standards for new passenger cars and light duty trucks, which make up the majority of motor vehicles on the road today. As directed by Congress, the Environmental Protection Agency (EPA) in this examination assesses the air quality need, technical feasibility, and cost effectiveness of such technologies. This study is the first step in determining if more stringent vehicle standards are needed to meet the National Ambient Air Quality Standards.

The Clean Air Act (CAA) directs the EPA to identify and set national ambient air quality standards (NAAQS) for pollutants that cause adverse effects to public health and the environment. EPA has set standards for six common air pollutants, known as "criteria pollutants." They are ground-level ozone (an important component of smog), carbon monoxide, lead, nitrogen dioxide, sulfur dioxide, and particulate matter (measured as PM_{10} and $PM_{2.5}$). For each of these six pollutants, EPA set health-based or "primary" standards to protect public health and welfare-based or "secondary" standards to protect the environment (crops, vegetation, wildlife, buildings and national monuments, visibility, etc).

The CAA sets specific exhaust emission standards, beginning with the 1994 model year, for light-duty vehicles (LDV), or passenger cars, and light-duty trucks (LDT), including sport utility vehicles, minivans, and pick-up trucks. These are "Tier 1" emission standards. The Act requires the study of whether or not further reductions in emissions from these vehicles should be required by setting more stringent "Tier 2" emission standards. This assessment must address the need for further reductions in motor vehicle emissions to attain and maintain the NAAQS, including, at a minimum, three factors:

- the air quality need for more stringent standards,
- the availability of technology to implement more stringent standards, and
- the cost effectiveness of more stringent motor vehicle standards, as well as alternative means to attain and maintain the NAAQS.

This "Tier 2 Study" addresses these factors, as well as others relevant to the consideration of whether to establish more stringent light-duty car and truck emission standards. For example, the study incorporates in its analysis the National Low Emission Vehicle (National LEV or NLEV) program, a voluntary agreement among automakers and Northeastern states to produce cleaner cars nationally. The National LEV program ensures that, beginning in model year 1999 and fully phased in by model year 2001, vehicles will meet emission standards that are cleaner than Tier 1 standards by harmonizing with the more stringent exhaust emission standards required by California.

The requirements for the Tier 2 Study and the manner by which the study was developed are described in *Chapter II. Introduction.* As required by Congress, this study was released to the public for comment on April 23, 1998. After the close of the public comment period, EPA summarized the comments received, modified the draft study as necessary, and created this final report for submission to Congress. The public comments and EPA's response, when appropriate, are summarized in *Appendices E and F*. Overall, the comments resulted in minor changes to the study and did not change any of the findings of the study.

This study does not include proposed new emission standards. Instead, it focuses on addressing the three factors identified in the statute and raises and discusses broadly other related issues. If it is determined that more stringent emission standards are necessary and viable, the Agency will, through a rulemaking process, promulgate such standards by the end of 1999. The issues discussed in this study would be more fully developed and analyzed as part of this rulemaking.

Status of Air Quality in the United States

Air quality in the United States continues to improve. Nationally, the 1996 air quality levels are the best on record for all six criteria pollutants. In fact, the 1990s show a steady trend of improvement.

The improvements in air quality and economic prosperity that have occurred since EPA initiated air pollution control programs in the early 1970s illustrate that economic growth and environmental protection can be compatible. Since 1970, national total emissions of the six criteria pollutants declined 32 percent, while U.S. population increased 29 percent and gross domestic product increased 104 percent. Motor vehicle emissions have decreased 58% for volatile organic compounds, 40% for carbon monoxide, and 3% for nitrogen oxides while vehicle miles traveled have increased 121 percent.

Despite these continued improvements in air quality, however, approximately 46 million people live in counties where air quality levels exceeded the level of the national air quality standards for at least one of the six criteria pollutants that were in effect in 1996.

Even taking into consideration the trend toward improving air quality, many areas will not be in attainment with the NAAQS in 2007, in spite of implementation of the National Low Emission Vehicle (National LEV) program, programs to reduce regional transport of ozone emissions, and other air pollution controls. Furthermore, many areas that are in attainment will need ongoing programs to maintain their attainment, especially in light of continued economic growth.

Motor Vehicles' Contribution to Air Pollution

While current cars emit about 97% fewer pollutants than 1970 models, emissions from motor vehicles still contribute a large portion of our air pollution. Nationwide, mobile sources are estimated to contribute more than half of the nitrogen oxides (NOx) inventory; 42% of the volatile organic compounds (VOC) inventory; one-quarter of the particulate matter-10 (PM-10) inventory; and 80% of the carbon monoxide (CO) emissions.

In 1996, LDVs and LDTs contributed more than 25% of national VOC emissions. LDV and LDTs contributed more than 53% of national CO and contributions to national NOx were almost 22%.

American motorists traveled 2.5 trillion miles in 1997, with a nearly constant growth of 2% a year. In addition, sport utility vehicles, minivans and small pick-up trucks comprise almost half of the passenger vehicles sold in the United States today, dramatically changing the overall composition of motor vehicles on the road, as well as the emissions inventory.

Overview of the Tier 2 Study

Emissions from motor vehicles include volatile organic compounds, carbon monoxide, nitrogen oxides, and particulate matter. VOC and NOx emissions combine to produce ozone, or smog, in the atmosphere. Gaseous VOC and NOx emissions also help form PM in the atmosphere. Elevated levels of ambient ozone, CO, and PM have been associated with increases in both human morbidity and mortality. In addition, VOC emissions from motor vehicles include known and probable human carcinogens. NOx emissions contribute to impaired visibility and crop damage, as well as the acidification of lakes and estuaries.

Chapter III. Assessment of Air Quality Need describes and assesses the air quality need for more stringent control of LDV and LDT emissions. The available evidence, discussed in this chapter, supports the need for emission reductions beyond that provided by the Tier 1 standards, the National LEV program and other control programs.

LDV and LDT emissions primarily affect the attainment of NAAQS for three pollutants: ozone, particulate matter, and carbon monoxide. Motor vehicles' emission of these pollutants or their precursors and the effects on NAAQS attainment is discussed. The atmospheric pathways through which LDV and LDT emissions affect these NAAQS are identified, as well as health and welfare impacts that are not directly addressed by the NAAQS.

This assessment finds that, in the time frame contemplated for Tier 2 standards, there will be an air quality need for emission reductions to aid in meeting and maintaining the NAAQS for both ozone and PM. Air quality projections of both ozone and PM-10 in the years 2007 to 2010 show continued nonattainment in a number of local areas, even after the implementation of existing emission controls. The contribution of LDVs and LDTs to VOC and NOx emissions that form ozone is projected to be substantial. Further VOC and/or NOx emission reductions beyond those provided by the Tier 1 light-duty motor vehicle standards, National LEV, and other programs are still needed in order for all areas of the nation to attain the NAAQS for ozone. These reductions would also provide needed assistance to additional areas in maintaining their projected compliance with the ozone NAAQS.

Further reductions in emissions of PM and PM precursors beyond those provided by the Clean Air Act are still needed in order for all areas of the nation to attain the NAAQS for PM_{10}. These reductions would also provide needed assistance to additional areas in maintaining their projected compliance with the PM_{10} NAAQS.

While emissions of PM from LDVs are relatively small, the trend toward heavier vehicles and the use of diesel fuel makes this an issue that must be analyzed. PM emissions from gasoline-fueled vehicles are quite low, while PM emissions from diesel vehicles meeting the Tier 1 PM standards are at least an order of magnitude greater. Widespread use of the diesel engine in LDVs and LDTs without more stringent Tier 2 standards for particulate emissions could significantly increase ambient levels of PM_{10}, worsening compliance further.

In contrast with ozone and PM, EPA does not project significant numbers of CO nonattainment areas in the future. Furthermore, any future exceedances will occur during wintertime conditions. The air quality need for further CO emission reductions from motor vehicles is being evaluated separately, in the context of the requirement to evaluate cold CO emission reductions.

Chapter IV. Assessment of Technical Feasibility examines the technological feasibility of controlling light-duty vehicle and light-duty truck emissions beyond the level of control provided for by Tier 1 emission standards. The technological feasibility of more stringent LDV and LDT emission standards is apparent. There is abundant evidence that technology exists to reduce LDV and LDT emissions below Tier 1 levels.

The review of vehicle emission control technology begins with a discussion of the emission performance of current Tier 1, National LEV, and California LEV technology vehicles. The chapter then reviews the status and potential of a number of emission control technologies which could be used to get emission control beyond Tier 1, and even beyond National LEV, standards. Various technologies that could be used to reduce vehicle emissions below levels currently incorporated in the National LEV and California LEV programs are described, ranging from improvements to base engine designs to advancements in exhaust after-treatment systems. The effect that gasoline sulfur may have on potential Tier 2 technologies is examined, as it has become apparent that this is a critical factor to be considered.

The technologies discussed in this chapter are either currently in production on one or more vehicle models or are in the final stages of development. Given the rapid pace of technological advances made in the motor vehicle manufacturing industry in recent years, one can assume even greater opportunities available in 2004 and beyond. Automotive manufacturing companies are already producing LDVs that meet National LEV standards, achieving much lower emission levels than currently required. Some manufacturers have committed to market LDTs that meet National LEV standards as soon as the 1999 model year.

An examination of the cost effectiveness of more stringent light-duty emissions standards is found in *Chapter V. Assessment of Cost and Cost Effectiveness*, including a review of the cost effectiveness of both mobile and stationary source controls for the primary pollutants of concern. Information on costs and cost effectiveness for potential future emission control technologies is presented in this chapter. This includes the cost effectiveness of LEV technologies, as well as technologies that achieve emission reductions beyond LEV standards. The chapter estimates cost effectiveness of certain emission reductions without making a determination of the specific numerical values of potential regulatory standards.

Estimates of the cost of future technologies are highly uncertain and often inflated. Frequently, engineers from the auto industry, as well as government regulators and outside experts, predict future costs that eventually prove to be too high when the technology is actually manufactured and installed on mass-produced vehicles. As stated previously, Tier 2 standards cannot be effective until the 2004 model year at the earliest. Therefore, although the cost estimates included in this study are EPA's best assessment of future technology, they may be conservatively high.

EPA evaluates specific motor vehicle emission control technologies, including tighter air-fuel controls and improved catalyst designs. EPA estimates that these technologies should be able to reduce NMHC (non-methane hydrocarbons) by as much as 77% and NOx emissions by 80%, relative to Tier 1 vehicles on a per mile basis, at a cost well below $5000 per ton on an annual basis. Comparing these reductions relative to National LEV yields a 7% reduction in NMHC and 30% in NOx, at a cost also well below $5000 per ton. These emission reductions would also be more than sufficient to meet the default Tier 2 standards listed in Table 3 of section 202(i) of the CAA.

EPA evaluates the cost effectiveness of other current or potential control methods for controlling emissions. The techniques for reducing LDV and LDT emissions appear to be comparable to or more cost effective than many alternative methods of emission reduction. In developing the National LEV regulations, EPA found that the National LEV standards provided cost effective emission reductions from the Tier 1 standards relative to other emission control programs (roughly $2000 per ton of NMHC and NOx controlled).

In addition to estimates of cost, this chapter also attempts to quantify the emission reduction capabilities of these future technologies. In this way, the cost effectiveness, in units of dollars per ton of emissions reduced, can be calculated and compared.

Next Steps

Following submission of this Report to Congress, EPA will by rule, determine whether: 1) there is an air quality need for further emission reductions; 2) the technology for meeting more stringent emissions standards will be available; and 3) obtaining further reductions in emissions from light-duty vehicles and certain light-duty trucks will be needed and cost effective. If these conditions exist, EPA will promulgate emission standards for such vehicles by December 1999, providing significant and frequent opportunities for the involvement of interested parties throughout the rulemaking process.

In its rulemaking, EPA will examine additional issues, as discussed in *Chapter VI: Regulatory Issues* of this Tier 2 study. They will include the relative stringency of LDV and LDT standards, the appropriateness of having separate standards for gasoline and diesel vehicles versus having the same standards for such vehicles, and effects of sulfur in gasoline on catalyst efficiency.

All LDVs have historically been required to meet the same numerical emission standards. For example, large luxury cars and small sub-compacts both meet the same emission standards, because both types of vehicles are used as personal transportation. In contrast, higher numerical emission standards have historically been established for LDTs. As LDTs become a larger portion of the passenger fleet, they have a disproportionate impact on in-use emissions. Options for setting LDT emission standards given a particular set of LDV standards include: requiring LDTs to meet the same numerical emission standards as LDVs; setting the LDT standards to require use of the same emission control technology as the LDV standards; or setting different standards based on vehicle use.

Another consideration is whether the same emission standards should be applied to similar vehicles regardless of what fuel is utilized. Here, the primary fuel options for conventional vehicles are gasoline and diesel fuel. The pollutants of most interest with regard to applying the same standards to gasoline and diesel vehicles are NOx and PM exhaust emissions. Both diesel and gasoline vehicles appear to be capable of meeting the range of possible Tier 2 NMHC and CO emission standards, so the issue of equivalent standards does not arise with respect to these pollutants.

Sulfur in gasoline affects emissions of HC, CO and NOx by inhibiting the performance of the catalyst. Recent information from test programs performed by the Coordinating Research Council (CRC) and the auto industry suggests that not only do LEV and Tier 1 vehicles exhibit decreased emissions performance due to fuel sulfur, but the more advanced the technology, the more sensitive (on a percentage basis) the catalysts are to sulfur. The studies indicate that increasing sulfur content could more than double NOx emissions and have a less severe, though noticeable, effect on HC emissions. EPA addressed this issue in a recently released *Staff Paper on Gasoline Sulfur Issues* (May 1998). EPA plans to consider issues related to sulfur levels in gasoline, including geographic applicability and costs of controls, as part of the Tier 2 rulemaking.

II. INTRODUCTION

In drafting the Clean Air Act, as amended in 1990, Congress envisioned that it may be necessary to require additional emission reductions from new passenger vehicles in the beginning of the 21st Century to provide needed protection of public health. Section 202 (i) of the CAA outlines a process for assessing whether more stringent exhaust emission reductions from light-duty vehicles and light-duty trucks should be required. Congress required the Environmental Protection Agency to report the results of this assessment to Congress. Congress identified specific standards[1] that EPA must consider in making this assessment, but stated that the study should also consider other possible standards. These standards, referred to as the "Tier 2 standards" in this study, would be more stringent than the standards required for LDVs and LDTs in the CAA beginning in model year 1994[2], but could not be implemented prior to the 2004 model year.

Specifically, Congress mandated that this study examine[3]:

1) the need for further reductions in emissions in order to attain or maintain the National Ambient Air Quality Standards, taking into consideration the waiver provisions of section 209(b),

2) the availability of technology (including the costs thereof) in the case of light-duty vehicles and light-duty trucks with a loaded vehicle weight of 3750 lbs or less, for meeting more stringent emission standards than those provided in subsections (g) and (h) for model years commencing not earlier than after January 1, 2003, and not later than model year 2006, including the lead time and safety and energy impacts of meeting more stringent emission standards; and

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[1] Clean Air Act; Section 202 (i); Table 3: Pending Emission Standards for Gasoline and Diesel Fueled Light-duty Vehicles and Light-duty Trucks 3,750 lbs LVW or Less.

Pollutant	Emission Level in grams per mile (g/mi)
NMHC	0.125 g/mi
NOx	0.2 g/mi
CO	1.7 g/mi

[2] Section 202 (g) and (h).

[3] Section 202 (i), Congress specified that, "The Administrator, with the participation of the Office of Technology Assessment, shall..." However, the 104th Congress voted to cease funding the Office of Technology Assessment after September 30, 1995, prior to the Agency developing plans for the Tier 2 study.

3) the need for, and cost effectiveness of, obtaining further reductions in emissions from such light-duty vehicles and light-duty trucks, taking into consideration alternative means of attaining or maintaining the national primary ambient air quality standards pursuant to state implementation plans and other requirement of this Act, including their feasibility and cost effectiveness.

As the first draft of this study was being completed, an historic agreement between automakers and the states, coordinated by EPA, established a voluntary National Low Emission Vehicle program. This program requires that vehicles, sold in model year 1999 in the Northeast and sold nationwide in model year 2001, meet more stringent emission standards than current federal Tier 1 standards. The National LEV program also harmonizes, to the greatest practical extent, federal requirements with the more stringent exhaust emission standards established by the state of California.[4] This program was prompted by the established air quality need in the northeastern United States to assist states in meeting the National Ambient Air Quality Standards. The National LEV program provides an additional feasibility and cost effectiveness baseline for more stringent exhaust emission standards in the future compared to that identified by Congress for the Tier 2 standards.

In conducting this study, EPA ensured that issues relevant to the study were explored using a public process. The Agency published a Staff White Paper (See 62 FR 18346; April 15, 1997) and conducted a public workshop on April 23, 1997. In addition, the Agency participated in numerous meetings with states, environmental organizations and industry representatives.

As required by Congress, this study was released to the public for comment on April 23, 1998. After providing 45 days for public comment, EPA summarized the comments received (see Appendices E and F), modified the draft study as necessary, and created this final report for submission to Congress.

Based on the conclusions of this study, EPA now plans to determine, by rule, whether: 1) there is a need for further emission reductions; 2) the technology for meeting more stringent emissions standards will be available; and, 3) further reductions in emissions from light-duty vehicles and certain light-duty trucks will be needed and cost effective, taking into consideration other alternatives. If EPA determines that these conditions exist, then EPA shall promulgate emission standards for such vehicles.

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[4] California has the authority under section 209(b) of the CAA to establish state specific vehicle and engine emissions and testing programs.

III. ASSESSING THE AIR QUALITY NEED

The goal of this chapter is to assess the air quality need for additional control of motor vehicle emissions that hinder areas of the country from attaining and/or maintaining National Ambient Air Quality Standards, in particular those for ozone, particulate matter and carbon monoxide.[5] To understand the impact of these pollutants, and ozone precursors, this chapter outlines their threat to public health and welfare and the manner in which they are formed and transported in air. In assessing air quality need, EPA examined projections of future areas of NAAQS nonattainment, as well as projections of areas needing to closely monitor maintenance plans in the future. This chapter then assesses the contribution of light-duty vehicles (LDVs) and light-duty trucks (LDTs) to the overall inventory for each pollutant and briefly explains other benefits of LDV and LDT emission controls. Finally, this chapter reviews future projections of air quality given all known and projected control strategies in the time frame contemplated for potential Tier 2 controls. Evidence that additional motor vehicle controls should be considered would include the fact that motor vehicles substantially contribute to total emission inventories in nonattainment areas and in areas which affect nonattainment through transport, as well as areas that may have difficulty maintaining their attainment status.

The available data indicate that in the time frame contemplated for Tier 2 standards there will be an air quality need for emission reductions to aid in meeting the NAAQS for both ozone and PM. EPA is continuing to evaluate the air quality need for further CO emission reductions in the context of the requirement to evaluate cold CO emission reductions as discussed later in this chapter. The available evidence also indicates that motor vehicle emissions will remain a significant contributor to air pollution in a significant number of areas of the country.

A. Health and Welfare Effects of Ozone

Ground-level ozone is the prime ingredient of smog, the pollution that blankets many areas during the summer.[6] 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. Repeated exposures to ozone can exacerbate symptoms and the frequency of episodes for people with respiratory diseases such as asthma. Other health effects attributed to short term exposures include significant decreases in lung function and increased respiratory symptoms such as chest pain and cough. These effects are generally associated with moderate or heavy exercise or exertion. Those most at risk include children who are active outdoors during the summer, outdoor workers, and people with pre-existing respiratory diseases like asthma. In

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[5] The Tier 2 standards would have no direct impact on the NAAQS for sulfur dioxide. However, gasoline sulfur controls to enable tighter Tier 2 standards, as discussed in Chapter VI, would reduce ambient levels of sulfur dioxide.

[6] Ozone also occurs naturally in the stratosphere and provides a protective layer high above the earth.

addition, long-term exposures to ozone may cause irreversible changes in the lungs which can lead to chronic aging of the lungs or chronic respiratory disease.

Ambient ozone also affects crop yield, 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 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.

Ozone is not emitted directly into the atmosphere, but is formed by a reaction of VOC and NOx in the presence of heat and sunlight. Ground-level 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 are also emitted by natural sources such as vegetation. NOx is emitted from motor vehicles, power plants and other source of combustion. Changing weather patterns contribute to yearly differences in ozone concentrations and differences from city to city. Ozone can also be transported into an area from pollution sources found hundreds of miles upwind.

VOC emissions are not only important for their contribution to ambient ozone. Some fraction of the VOCs emitted from motor vehicle 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.

NOx emissions produce a wide variety of health and welfare effects. 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 other nationally important estuaries along the East and Gulf Coasts. Eutrophication can produce multiple adverse effects on water quality and the aquatic environment, including increased nuisance and toxic algal blooms, excessive phytoplankton growth, low or no dissolved oxygen in bottom waters, and reduced sunlight causing losses in submerged aquatic vegetation critical for healthy estuarine ecosystems. Nitrogen dioxide and airborne nitrate also contribute to pollutant haze, which impairs visibility and can reduce residential property values and revenues from tourism.

B. Role of VOC and NOx Emissions in Producing Atmospheric Ozone

The production of ozone from VOC and NOx emissions[7] involves a complex set of chemical reactions, and different mixtures of VOCs and NOx can result in different ozone levels. For example, large amounts of VOC and small amounts of NOx make ozone rapidly, but ozone production is quickly limited by removal of the NOx. VOC reductions under these circumstances show little effect on ozone while NOx reductions reduce ozone. (This condition is referred to as NOx limited.)

Large amounts of NOx and small amounts of VOC result in the formation of inorganic nitrates, but little ozone. In these cases, reduction of VOC emissions reduces ozone, but the reduction of NOx emissions can actually increase ozone. (This condition is referred to as VOC limited.) The highest levels of ozone are produced when both VOC and NOx emissions are present in significant quantities.

The formation of ozone is further complicated by biogenic (natural) emissions, meteorology and transport of ozone and ozone precursors. The contribution of VOC emissions from biogenic sources to local ambient ozone concentrations can be significant and often produces conditions which are NOx limited. Many of the above chemical reactions are sensitive to temperature. When ambient temperatures remain high for several days and the air is relatively stagnant, ozone and its precursors can actually build up and produce more ozone than typically would occur on a single high temperature day. When air is moving, ozone and its precursors can be transported downwind and contribute to elevated ozone levels outside of the area where the NOx is emitted.

This study focuses on the response of ambient ozone to the reduction in either VOC or NOx emissions, or both. In general, specific local areas are often described as being VOC or NOx limited. Rural areas are almost always NOx limited, due to the relatively large amounts of biogenic (from plants and trees) VOC emissions there. Urbanized areas can be either VOC or NOx-limited, or a mixture of the two (moderate sensitivity to either pollutant, versus strong sensitivity to one and little sensitivity to the other). In projecting future attainment of the revised ozone NAAQS, EPA found that significant reductions in both VOC and NOx emissions would be necessary.

C. Current Compliance with the Ozone NAAQS

As of October, 1997, EPA classified 59 ozone nonattainment areas with respect to the 1-hour ozone standard, encompassing all or part of 249 counties. The population of these 59 areas, based on the 1990 Census, is approximately 102 million, or 40 percent of the total U.S. population. These areas are located in the 37 easternmost states, Arizona, New Mexico, and California.

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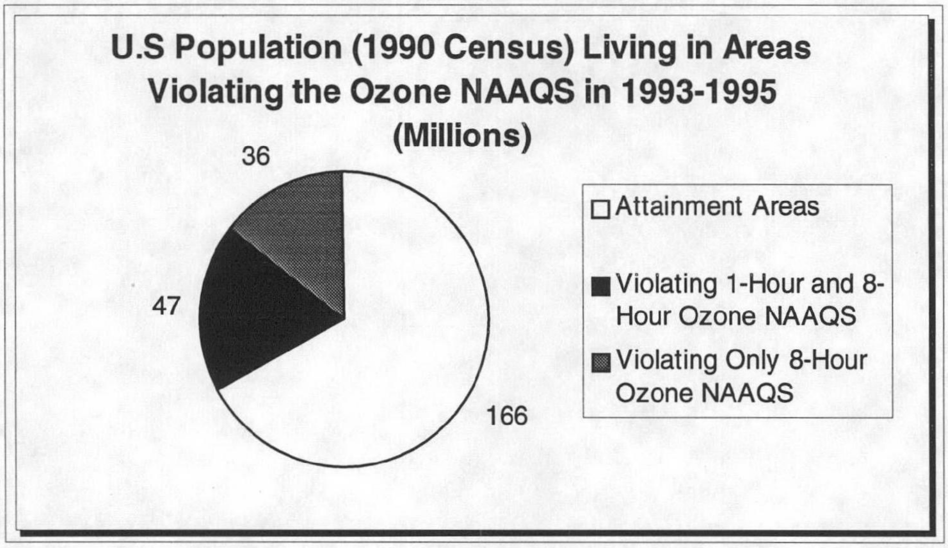
[7] CO also participates in the production of ozone, much like a slowly reacting VOC.

In July 1997, EPA established a new 8-hour ozone NAAQS to better protect against longer exposure periods at lower concentrations than the current 1-hour standard. The 1-hour NAAQS is still applicable in certain areas during the transition to the eight-hour standard (62 FR 38856, July 17, 1997). EPA reviewed ambient ozone monitoring data for the period 1993 through 1995 to determine which counties violated either the 1-hour or 8-hour NAAQS for ozone during this time period.[8,9] Eighty-four counties violated the 1-hour NAAQS during this 3-year period, while 248 counties violated the 8-hour NAAQS. The 84 counties had a 1990 population of 47 million, while the 248 counties had a 1990 population of 83 million. EPA is reviewing more recent air quality data for 1996 and 1997. A preliminary assessment of 1994 through 1996 ozone monitoring data reveals only marginal changes in the number of counties experiencing a nonattainment problem with the 8-hour NAAQS, and essentially no change in the population levels impacted by nonattainment.



D. Future Ambient Ozone Levels

The analysis of future ozone attainment provides a basis for assessment of the need for additional emission reductions to achieve attainment and assure maintenance of the NAAQS. EPA recently performed two projections of future ozone attainment status in the years 2007 to 2010. The first was part of EPA's 1997 ozone NAAQS rulemaking.

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[8] This use of the term "nonattainment" in reference to a specific area is not meant as an official designation or future determination as to the attainment status of the area.

[9] U.S. Environmental Protection Agency, Finding of Significant Contribution and Rulemaking for Certain States in the Ozone Transport Assessment Group Region for Purposes of Reducing Regional Transport of Ozone; Proposed Rule, 62 FR 60318 (November 7, 1997) ("OTAG SIP Call NPRM").

The second was conducted for the EPA's recent notice of proposed rulemaking regarding requirements for State Implementation Plans for 37 easternmost states. Through a two-year effort known as the Ozone Transport Assessment Group (OTAG), EPA worked in partnership with state and local government agencies in the 37 easternmost states, industry and academia to address ozone transport. The work resulted in a proposed rule to reduce the regional transport of ozone (OTAG SIP Call NPRM). The ozone projections supporting the OTAG SIP Call NPRM used more advanced regional ozone modeling tools than those made in support of the revised ozone NAAQS. However, the ozone NAAQS analysis covered the entire nation, while the OTAG SIP Call NPRM only addressed ozone levels in the eastern U.S. Therefore, both are discussed below. In developing a projection of future ozone nonattainment for the purpose of this study, EPA combined the projections from the OTAG SIP Call NPRM for the 37-state OTAG region with the projections from the Regulatory Impact Analysis (RIA) for the revised ozone NAAQS for the remaining 11 states in the continental United States.

As part of the RIA for the revised ozone NAAQS, EPA projected future ambient ozone levels in 2010 using a Regional Oxidant Model (ROM) extrapolation methodology. One of the scenarios evaluated was a 2010 baseline, which included emission controls which have already been implemented or mandated by the Clean Air Act, regional NOx emission control in the eastern U.S. estimated to be associated with the then upcoming OTAG SIP Call NPRM, plus the National Low Emission Vehicle program. This set of emission control strategies generally represents all of the emissions reductions which may be expected from measures currently adopted or planned by the states.

EPA used ROM air quality modeling, historical ozone air quality monitoring data and emission inventory estimates to project baseline 2010 ozone levels for counties in the 48 contiguous states. For the purpose of this study, the standard and consolidated metropolitan statistical areas (MSAs and CMSAs) containing these counties were identified. Nine areas with a 1990 population of approximately 49 million people were projected to be in nonattainment of the 1-hour ozone standard, 32 million people outside of California. Nineteen areas (with approximately 79 million people as of 1990) were projected to be in nonattainment with the 8-hour ozone NAAQS, 51 million people outside of California. The 51 million people living in the projected nonattainment areas outside of California represent more than a fifth of the U.S. population in 1990.[10]

The Tier 2 standards would primarily affect ozone outside of California due to the applicability of California's traditionally more stringent motor vehicle standards to vehicles sold in California. However, the Tier 2 standards would also indirectly, but significantly improve ozone levels within California. This indirect benefit is due to the migration of non-California vehicles into California when people move into that state. It is also due to the temporary business and leisure travel of non-Californians into California. The California Air Resources

[10] Populations in 1990 are presented in this study because of their ready availability and accuracy. Populations in future NAAQS nonattainment and maintenance areas will generally be much higher.

Board (ARB) recognized this benefit in the context of the NLEV program. The California ARB used the benefits of the NLEV program to compensate for emission increases associated with a delay in the implementation schedule for zero-emission vehicles.

Once an area attains a NAAQS, the CAA requires that it establish a plan for maintaining this attainment. Otherwise, future economic and population growth can increase emissions to the point where the area again violates the NAAQS. To estimate the number of areas that need to be concerned about ozone NAAQS compliance in the future, EPA (for the Tier 2 study) also identified metropolitan areas containing counties that were projected to be below the 8-hour ozone NAAQS, but with a relatively small margin of safety (i.e., 15%). VOC and NOx emission reductions associated with the Tier 2 standards would assist these areas in maintaining their compliance.

In the ozone NAAQS RIA, EPA also projected that available local VOC and NOx controls (at a cost of up to $10,000 per ton of VOC or NOx in 1990 dollars) could bring only two of these 19 areas into attainment with the new 8-hour NAAQS. Seventeen (17) of the 19 areas remained out of attainment after all available local controls. Overall, the available local controls in the 19 areas only achieved 38% and 23% of the necessary VOC and NOx emission reductions required. Clearly, these areas would need additional emission reductions in order to achieve the new ozone NAAQS. As mentioned above, both the OTAG SIP Call and National LEV programs were included in the baseline projections. Therefore, only motor vehicle controls beyond those provided by Tier 1 and National LEV would qualify as additional control.

In the OTAG SIP Call NPRM, EPA proposed that 22 states and the District of Columbia be required to submit revised SIPs demonstrating reductions in NOx emissions in order to reduce the transport of ozone into ozone nonattainment areas. EPA relied upon the ambient ozone modeling conducted during the OTAG process in developing the proposed emission reductions. OTAG evaluated a wide variety of VOC and NOx emission controls for stationary, area and mobile sources over a two year period. EPA reviewed OTAG ozone modeling which included utility NOx emission reductions most closely resembling those being proposed, and controls for other sources (stationary, areas and mobile) required by the CAA or which had already been implemented. This modeling, like that conducted during the ozone NAAQS revisions process, also assumed the implementation of a National LEV program. Complete details of the modeling process can be found in the OTAG SIP Call NPRM and associated documents. A list of the specific emission control strategies assumed in this modeling is presented in *Appendix A. Future Ozone Nonattainment Projections.*

For the purpose of the Tier 2 study, EPA reviewed the results of the OTAG SIP Call NPRM analyses and found that 8 areas with a population of approximately 41 million people were projected to be in nonattainment of the 1-hour ozone standard. Fifteen areas (with approximately 63 million people) were projected to be in nonattainment with the 8-hour ozone NAAQS.

Combining the OTAG SIP Call NPRM projections for the OTAG region with those of the ozone NAAQS RIA for the remainder of the country, EPA developed the following projections of ozone nonattainment and maintenance areas in 2007 (OTAG region) and 2010 (remaining 11 states). The metropolitan areas projected to be in nonattainment are presented in *Appendix A.*

Table 3.1 2007/2010 Ozone Nonattainment with CAA Controls, OTAG SIP Call, & NLEV

	OTAG Region (2007)	Non-CA, Non-OTAG (2010)	California (2010)
Violating 1-Hour NAAQS			
Number of Areas	8	0	4
1990 Population (millions)	41	0	18
Violating 8-Hour NAAQS			
Number of Areas	15	1	6
1990 Population (millions)	63	2	28
Maintenance of the 8-Hour NAAQS (within 15% of NAAQS)			
Number of Areas	85	11	7
1990 Population (millions)	118	11	9

For the purposes of this study, EPA also identified the Standard Metropolitan Statistical Areas (SMSA) and CMSAs containing counties which were projected to be below the 8-hour ozone NAAQS, but within 15% of the NAAQS. EPA found 103 areas (96 non-California areas) to have projected ozone levels within 15% of the NAAQS, with a 1990 population of 136 million (129 million outside of California). As already stated, additional emission reductions would certainly assist such areas to maintain their attainment status and may actually be required, given meteorological variability and uncertainties in emission and ozone modeling.

These projections of future ozone nonattainment provide evidence for the need for additional VOC and NOx emission reductions beyond those considered in these studies. The CAA provides states flexibility in selecting local emission control strategies to achieve the NAAQS. EPA has augmented these local controls with cost effective national programs, some mandated by the CAA and others using EPA's discretionary authority under the CAA. The above analyses indicate that both local and national measures appear to be necessary for the nation to achieve the ozone NAAQS. Tier 2 standards for LDVs and LDTs appear to be a reasonable national control option for consideration. Because the above ozone projections of future nonattainment already assumed and incorporated the permanent implementation of the National LEV program, the focus for motor vehicle control programs should be on VOC and NOx emission controls beyond the National LEV standards.

E. Contribution of LDV/LDT Emissions to Total VOC and NOx Inventories

Since motor vehicles and their fuels were first regulated 25 to 30 years ago, their relative contribution to ozone nonattainment problems has diminished, in spite of explosive growth in the amount of travel. The relative cost of adopting further motor vehicle controls compared to other reduction strategies depends in part on their future contribution to VOC and NOx emissions in ozone nonattainment areas and areas contributing to ozone nonattainment through pollutant transport. Auto industry comments received by EPA after publication of a preliminary white paper on Tier 2 standards issues indicated that an updated assessment should be made of the importance of LDVs and LDTs to the ozone nonattainment problem. Specifically, commenters suggested that new information about the durability of emission control systems would alter the projections of nonattainment made in the studies mentioned previously, perhaps to the extent that no additional measures would be needed. In developing the study, EPA analyzed new mobile source modeling data associated with a number of factors.

Emissions from motor vehicles are usually estimated by combining estimates of emissions per mile (commonly called emission factors) with local estimates of vehicle miles traveled. EPA developed a series of models to project in-use emission factors from on-road motor vehicles. EPA is currently revising the MOBILE5 model. MOBILE6 will be issued in 1999.

While the analytical efforts involved in developing MOBILE6 are still underway, EPA performed preliminary assessments of four key factors which could affect the need for Tier 2 standards.[11] These factors are:

1) In-use emission deterioration rates for Tier 1 vehicles, LEVs, and late model Tier 0 vehicles;

2) The effect of "off-cycle" driving patterns and conditions on LDV and LDT emissions, as well as the effect of off-cycle emission standards on these emissions;[12]

3) The effect of fuel sulfur on emissions from low emitting vehicles, such as CA LEVs and NLEVs; and

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[11] MOBILE6 is being developed through an extensive and open process which is continuing in parallel with the Tier 2 standards process. The changes to MOBILE5b described herein should not be construed as pre-judging the outcome of the MOBILE6 development process, but simply represent EPA's current best estimate of some of the factors which are most relevant to the evaluation of the Tier 2 LDV/LDT standards.

[12] "Off-cycle" emissions are those which occur during driving conditions not included in EPA's historical certification driving cycle, the LA-4 cycle. The specific off-cycle driving conditions addressed here are aggressive driving (high speeds and high accelerations) and driving with the air conditioner on.

4) The characterization of the LDT fleet (i.e., relative LDV and LDT sales, and LDT registrations and annual mileage versus age)

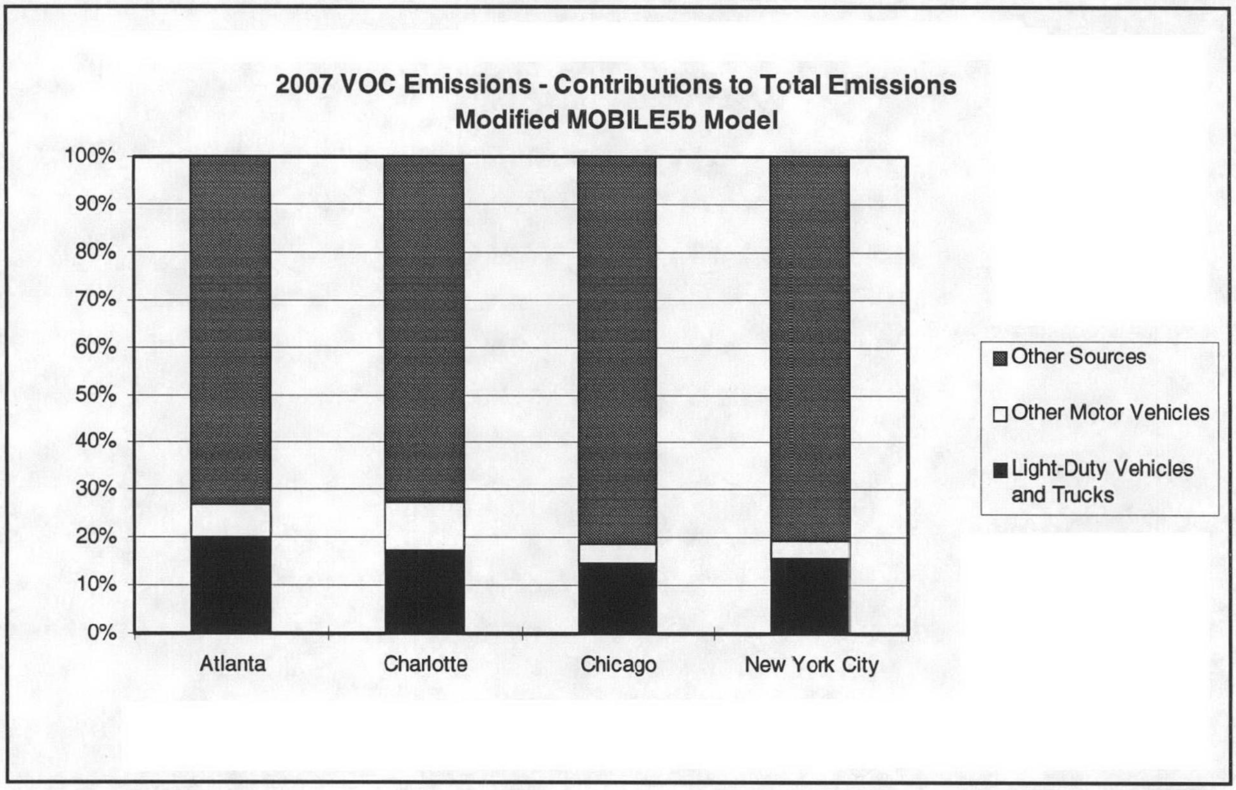
Regarding the first factor, recent testing of in-use vehicles produced since the late 1980s shows much lower deterioration rates than were projected in 1993. As most of the in-use emissions from LDVs and LDTs projected by MOBILE5 were due to deterioration in emission control after a vehicle was first sold, reducing this deterioration decreases projected in-use emissions dramatically.

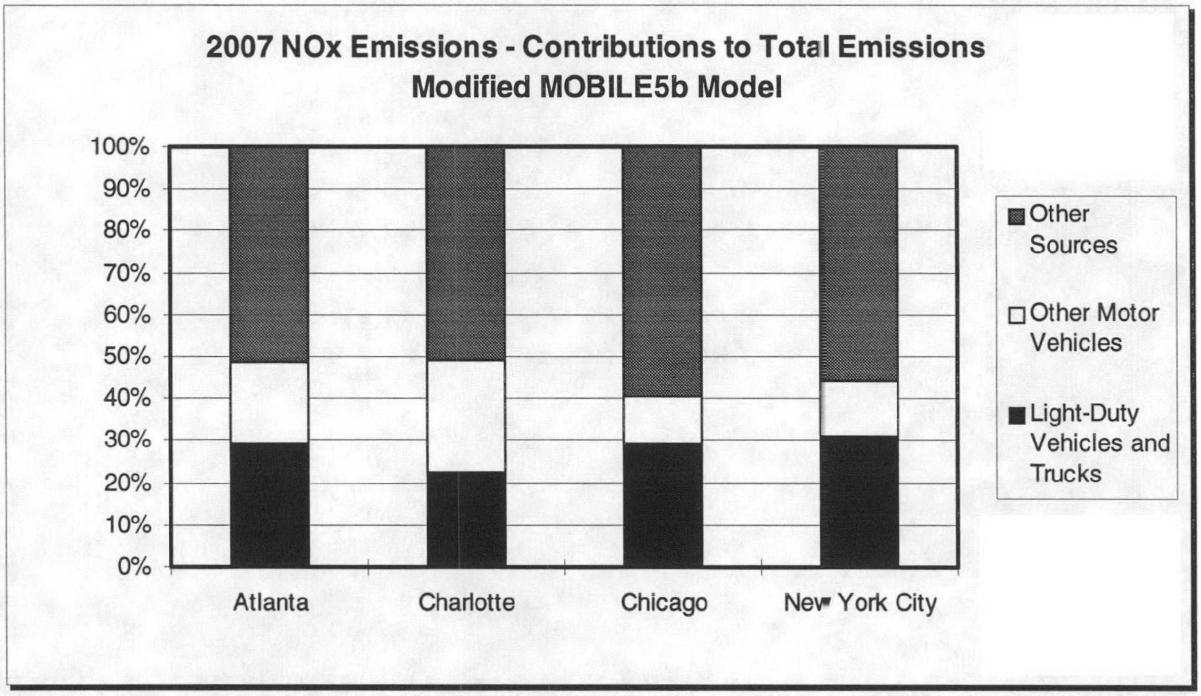
In contrast, updated estimates of the other three factors all tend to increase in-use emission projections. Emissions during driving conditions not represented in EPA's certification driving cycle tend to be higher than those included in the test, since prior to implementation of the Supplemental FTP there is little incentive for manufacturers to reduce these "off-cycle" emissions. Higher levels of fuel sulfur have been shown to increase emissions by reducing catalyst efficiency. In-use emissions increase whenever vehicles operate on fuel containing more sulfur than certification fuel. Moreover, vehicles with very low emissions, such as LEVs, now appear to be much more sensitive to sulfur than Tier 1 vehicles. Finally, LDTs tend to emit more than LDVs as their emission standards have traditionally been numerically higher. The recent dramatic trend toward the purchase of LDTs (e.g., sport utility vehicles) over LDVs was not predicted in MOBILE5b. Increasing the fraction of in-use driving represented by LDTs increases fleet-wide emission projections.

Overall, the four changes to MOBILE5b increase projected in-use emissions from LDVs and LDTs (relative to MOBILE5b) in areas with enhanced Inspection and Maintenance (I/M) programs. CO and NOx emissions also increase in areas without I/M. However, NMHC emission projections decrease in areas without I/M. A more detailed discussion of this analysis and the modifications made to MOBILE5b can be found in *Appendix A.*

EPA used the modified MOBILE5b model described above to estimate the contribution of LDV and LDT emissions in four urban ozone nonattainment areas. The four areas were: New York City, Chicago, Atlanta, and Charlotte. The first three areas represent the three greatest ozone air quality challenges in the eastern U.S. according to the OTAG ozone modeling. Charlotte represents a smaller, but growing area with a growing ozone problem.

The LDV/LDT and total motor vehicle contributions to total VOC and NOx emissions in the four ozone areas are shown in the figures below. Light-duty vehicles and trucks contribute 14-20% of total VOC emissions and 22-32% of total NOx emissions based on the modified MOBILE5b model. All of these percentage contributions are higher than would have been predicted using MOBILE5b.


2007 VOC Emissions - Contributions to Total Emissions
Modified MOBILE5b Model
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Atlanta
Charlotte
Chicago
New York City
Other Sources
Other Motor Vehicles
Light-Duty Vehicles and Trucks



Given that the modified MOBILE5b model projects higher emissions than MOBILE5b, the number of ozone nonattainment areas projected to exist in 2007 should be at least as high as was described above. Thus, the new MOBILE6 model is unlikely to eliminate the need for further VOC and NOx emission reductions in order for all areas to attain the ozone NAAQS. The contribution of LDVs and LDTs to emission inventories in ozone nonattainment areas is also sufficiently large to be considered a reasonable target for further emission control.

F. Health and Welfare Effects of Particulate Matter

Particulate matter 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 and manmade sources, such as windblown dust, motor vehicles, construction sites, factories, and fires. Particles are also formed in the atmosphere by condensation or the transformation of emitted gases such as sulfur dioxide, nitrogen oxides, and volatile organic compounds.

Scientific studies suggest a likely causal role of ambient particulate matter in contributing to a series of health effects. The key health effects categories associated with particulate matter include premature mortality, aggravation of respiratory and cardiovascular disease (as indicated by increased hospital admissions and emergency room visits, school absences, work loss days, and restricted activity days), changes in lung function and increased respiratory symptoms, changes to lung tissues and structure, and altered respiratory defense mechanisms. PM also causes damage to materials and soiling. It is a major cause of substantial visibility impairment in many parts of the U.S.

Motor vehicle particle emissions and the particles formed by the transformation of motor vehicle gaseous emissions tend to be in the fine particle range. Fine particles (those less than 2.5 micrometers in diameter) are of health concern because they easily reach the deepest recesses of the lungs. Scientific studies have linked fine particles (alone or in combination with other air pollutants), with a series of significant health problems, including premature death; respiratory related hospital admissions and emergency room visits; aggravated asthma; acute respiratory symptoms, including aggravated coughing and difficult or painful breathing; chronic bronchitis; and decreased lung function that can be experienced as shortness of breath.

G. Current and Future Nonattainment Status

The first NAAQS for particulate matter regulated total suspended particulate in the atmosphere. In 1987, EPA replaced that standard with one for inhalable PM (PM_{10} - particles less than ten microns in size), because the smaller particles, due to their ability to reach the lower regions of the respiratory tract, are more likely responsible for the adverse health effects. The major source of PM_{10} is fugitive emissions from agricultural tilling, construction, fires, and unpaved roads. Some revisions to the PM_{10} standards were made in 1997. EPA has also recently added new fine particle standards ($PM_{2.5}$). Most of the particulate due to motor vehicles falls in the fine particle category. These standards have both an annual and a daily component. The annual component is set to protect against long-term exposures, while the daily component protects against more extreme short-term events.

EPA recently projected ambient PM_{10} levels and the number of U.S. counties expected to be in violation of the revised PM_{10} NAAQS in 2010.[13] Forty-five CMSAs, SMSAs and counties[14] were projected to be in nonattainment of the original PM_{10} standards in 2010; Eleven CMSAs, SMSAs and counties were projected to be in nonattainment of the revised PM_{10} standards. Using the same methodology, 102 CMSAs, SMSAs and counties were projected to violate the new $PM_{2.5}$ NAAQS. More information about this analysis may be found in *Appendix A*.

It should be noted that an error was made in the figure in the Draft Tier 2 Study which indicated the number of areas that would be in nonattainment of the PM standards ("Counties

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[13] Regulatory Impact Analyses for the Particulate Matter and Ozone National Ambient Air Quality Standards and Proposed Regional Haze Rule, Innovative Strategies and Economics Group, Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, Research Triangle Park, N.C., July 16, 1997.

[14] Current definitions of PM_{10} nonattainment counties were used. These definitions sometimes include the entire CMSA or SMSA and sometimes include only a county.

Projected to violate NAAQS for PM in 2010," page 23). That figure showed 147 areas violating the new NAAQS for $PM_{2.5}$. This error resulted from a double-counting of 45 of the counties which are also projected to be in violation of the PM_{10} standard. The correct number is 102 counties, as shown in Table 3.2.

Table 3.2 Projected 2010 PM10/PM2.5 Nonattainment

	22-State OTAG Region *	Non-CA, Non-OTAG	California
Violating Original PM10 NAAQS			
Number of Areas	8	25	12
1990 Population (millions)	8	3	7
Violating Revised PM10 NAAQS			
Number of Areas	2	3	6
1990 Population (millions)	4	1	5
Violating New PM2.5 NAAQS			
Number of Areas	59	33	10
1990 Population (millions)	34	8	13

* Plus ME, VT, NH, and future ozone nonattainment areas in TX and AZ

Based on the 1990 census, about 10 million people lived in the 11 counties projected to be in nonattainment of the revised PM_{10} NAAQS, with about half living in the 22-state OTAG region (plus areas with future ozone problems) and about half living in California. Ambient PM reductions from more stringent motor vehicle standards would primarily affect areas outside of California, because California has its own motor vehicle emission control program. California areas would also benefit, however, through the temporary travel and permanent migration of out-state vehicles into California. Of the nonattainment counties outside of California, two are within urban areas (Dallas, Philadelphia). These urban areas contain the vast majority of the non-California, nonattainment population.

In 1990, about 55 million people lived in the 102 counties projected to be in nonattainment with the new $PM_{2.5}$ NAAQS, with about 60% living in the 22-state OTAG region (plus areas with future ozone problems) and about 25% living in California.

Overall, a significant number of areas are projected to exceed the PM_{10} NAAQS in 2010 with existing emission controls, indicating that further particulate emission reductions appear to be needed. Tier 2 particulate standards would reduce ambient levels of $PM_{2.5}$, as well as PM_{10} (or at least prevent increases), since the majority of particulate emissions from both gasoline and diesel powered vehicles are smaller than 2.5 micrometers in diameter. As mentioned above, the number of counties projected to violate the new $PM_{2.5}$ NAAQS is much larger than that for the revised PM_{10} standards. Thus, Tier 2 particulate standards intended to assist attainment of the PM_{10} NAAQS could also benefit areas with elevated $PM_{2.5}$ levels.

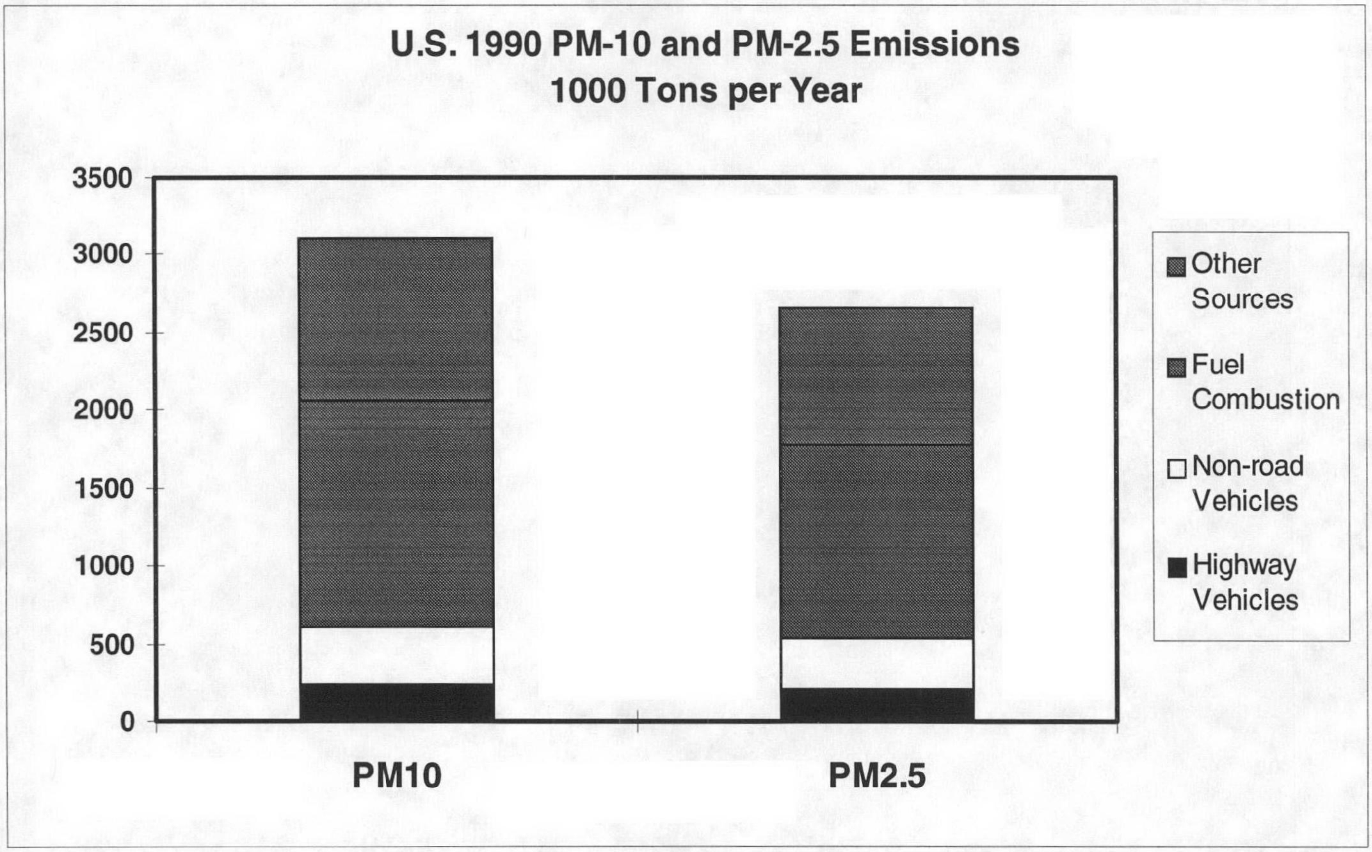
H. Particulate Emissions from Light-Duty Vehicles and Trucks

1. Direct Tailpipe Emissions

Congress set Tier 1 PM emission standards for LDVs and LDTs in the 1990 amendments to the CAA. These standards are 0.10-0.12 g/mi at 100,000 miles. Tier 1 and LEV gasoline LDVs and LDTs emit well below these Tier 1 PM standards (less than 0.010 g/mi). Diesel vehicles meet the standards, but with very little compliance margin.

EPA projects that PM emissions from Tier 1 and LEV LDVs and LDTs average 0.01 g/mi at 20 mph and 0.02-0.03 g/mi at 35 mph (from PART5 model). In contrast, diesel vehicles are projected to emit 0.10-0.11 g/mi PM. Thus, diesel PM emissions are 3.5-10 times higher than those from gasoline vehicles. The greater PM emission level of light-duty diesels currently has a limited impact on ambient PM levels, due to the small number of light-duty diesels being sold. However, diesel engines are becoming a more popular option for larger LDTs and lighter HDVs, particularly pick-ups and sport utility vehicles. PM emissions from the light-duty fleet could increase dramatically if diesel sales increased without a change in the Tier 1 diesel PM standard.

The following chart shows the relative contribution of vehicles versus other fine particle emission sources (excluding fugitive dust emissions).



Secondary Formation of PM from Gaseous Emissions

In addition to their direct tailpipe PM emissions, gaseous emissions from LDVs and LDTs can also affect ambient PM levels. In particular, gaseous emissions of SOx, NOx and VOC form aerosols in the atmosphere through chemical transformation. These aerosols exist as PM in the atmosphere.

The great majority of sulfur that enters the gasoline engine via the fuel is emitted in the form of sulfur dioxide. A small fraction (1-2%) of the sulfur is emitted directly as sulfuric acid. Sulfur dioxide reacts in the atmosphere to produce sulfur trioxide, which quickly combines with water to form sulfuric acid. Sulfuric acid exists as a particulate matter in the atmosphere, due to its low vapor pressure. Sulfuric acid can subsequently react with ammonia to form ammonium bi-sulfate and ammonium sulfate, both of which also exist as PM in the atmosphere.

Most NOx emitted converts to gaseous nitric acid in the atmosphere. Nitric acid can react with ammonia to form ammonium nitrate, which becomes PM in the atmosphere. However, ammonia reacts preferentially with sulfuric acid over nitric acid. As there is generally an excess of sulfuric acid in the atmosphere relative to ammonia, the presence of sulfuric acid suppresses the formation of ammonium nitrate and therefore the contribution of NOx emissions to fine ambient PM. Implementation of control programs required by the CAA is leading to significant reductions in sulfur dioxide emissions, which will reduce ambient levels of sulfuric acid. Therefore, the conversion of NOx to nitrate PM could increase.

Organic aerosol can be formed in the atmosphere from gaseous VOC emissions. The reactions that form secondary organic aerosol are generally more complex than those forming sulfates and nitrates, primarily because of the great variety of specific organic molecules comprising VOCs.[15] Cyclic-olefins and aromatics produce the most secondary organic aerosol per mass of VOC. Coniferous trees are the primary source of cyclic-olefins (pinene and terpinene), while gasoline-fueled vehicles are a primary source of ambient aromatics.

I. Health and Welfare Effects of Carbon Monoxide

Carbon monoxide (CO) is a tasteless, odorless, and colorless gas produced though the incomplete combustion of carbon-based fuels. CO 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 levels. Exposure to elevated CO levels is associated with impairment of visual perception, work capacity, manual dexterity, learning ability and performance of complex tasks.

1. Current and Future Nonattainment Status

Since 1979, the number of areas in the nation violating the NAAQS for CO[16] has decreased by a factor of almost ten, from 48 areas in 1979 to five areas in 1995 and 1996. For the 1997 calendar year through the end of November 1997, only one area of the country had experienced an exceedance of the standard.

In addition to the substantial decrease in the number of areas where the NAAQS is exceeded, the severity of the exceedances has also decreased significantly. 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% over the 9 ppm standard.

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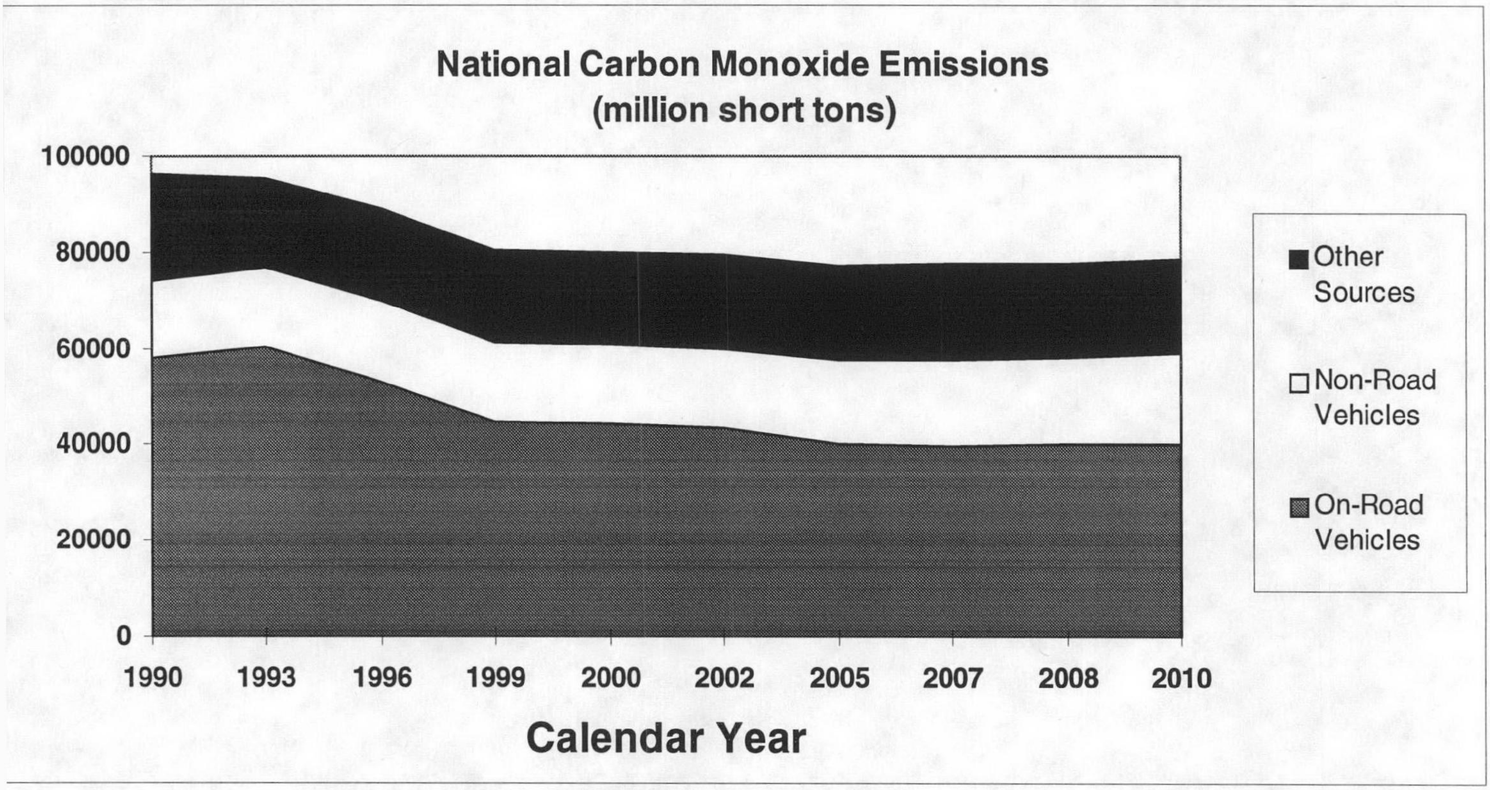
[15] A more detailed discussion of secondary organic aerosol can be found in Appendix 1.

[16] The NAAQS for CO as defined in *40 CFR Part 50.8* is: "9 parts per million for an 8-hour average concentration not to be exceeded more than once per year."

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, similar to the Congressional requirement for this Tier 2 study, 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.

2. Contribution of LDVs/LDTs to Carbon Monoxide Emissions

At the national level, motor vehicle exhaust is estimated to contribute more than three-fourths of all CO emissions; In cities, 95 percent of all CO emissions are produced by automobiles. Other sources of CO include industrial processes within large factories, power plants, and natural sources such as wild fires.



Exceedences of the CO NAAQS over the past three years tended to occur during winter months of the year. This may indicate that further reductions in emission standards should be directed towards emissions during cold weather ("cold CO standards," which apply at temperatures of 15 to 25 degrees Fahrenheit), rather than warm weather (Tier 1 CO standards, which apply at temperatures of 68-86 degrees Fahrenheit). However, as many of the CO nonattainment areas are in the southern part of the U.S., more stringent "warm weather CO" standards should not be ruled out at this time.

J. Air Toxic Emissions from Motor Vehicles

The Clean Air Act lists 188 hazardous air pollutants (HAPs) or air toxics requiring EPA evaluation and regulation (see CAA Section 112). The measurable health effects of exposure to air toxics include not only cancer, but also non-cancer effects, such as immunological, neurological, reproductive, developmental, and respiratory effects. Usually cancer incidence is chosen to measure the problem since non-carcinogenic end points are much more difficult to relate to specific toxic emissions.

EPA is developing an Integrated Urban Air Toxics Strategy, to be finalized by the end of 1998. The strategy will list certain area source categories of HAP emissions for later regulation under section 112(d) and will reduce the incidence of cancer attributable to exposure to HAPs emitted by stationary sources by not less than 75 percent. Another goal, per section 202(l) of the Clean Air Act, is to develop cost-effective standards for motor vehicles and their fuels for at least benzene and formaldehyde.

Mobile sources contribute significantly to only a small subset of the 188 HAPs. In 1993, EPA published the Motor Vehicle-Related Air Toxics Study (MVRATS). This study comprehensively summarized what was known about motor vehicle-related air toxics, focusing on carcinogenic risk. Only qualitative discussion of non-cancer effects was included due to the lack of sufficient health data to quantify these effects. The primary carcinogens examined were benzene, formaldehyde, 1,3-butadiene, acetaldehyde and diesel particulate matter. Roughly 8-9% of total VOC emissions from gasoline vehicles consist of benzene, formaldehyde, 1,3-butadiene, or acetaldehyde. In general, emissions of air toxics from gasoline vehicle exhaust are expected to decrease proportionately with reductions in VOC emissions. The primary diesel-related air toxic addressed quantitatively by MVRATS is diesel particulate. The consideration of Tier 2 particulate emission standards is addressed in more detail in Chapter VI.

CHAPTER IV. ASSESSMENT OF TECHNICAL FEASIBILITY

The purpose of this chapter is to examine the technical feasibility of controlling light-duty vehicle emissions beyond the level of control provided for by Tier 1 emission standards. This chapter reviews and describes a variety of technologies capable of reducing emissions from Tier 1 levels. This chapter also estimates the emission reductions of selected technologies. Automotive emission control technology has made remarkable advances in the past several years and many of the technologies discussed in this chapter are technically feasible.

Some of the technologies discussed in this chapter, such as improvements to base engine designs (to reduce engine-out emissions) and advancements in exhaust aftertreatment systems (improved catalyst designs), are either in production on at least one or more vehicle models or are in the final stages of development and will likely be introduced in model year (MY)1999 or MY2000 vehicles. Other technologies, such as fuel cells, are in earlier stages of development and are potentially feasible by MY2004.

The next question to be addressed by this study is how cost effective these technologies are. The cost-effectiveness discussion can be found in *Chapter V. Assessment of Cost and Cost Effectiveness*. For illustrative purposes, this chapter will provide a brief discussion of potential Tier 2 technologies. A more extensive discussion of the various technologies can be found in *Appendix B. Vehicle Technology.*

In section 202(i), Table 3, of the CAA, Congress provided specific numerical values for Tier 2 standards for EPA to consider in this study. Congress also instructed EPA to consider standards that were different (either more or less stringent) than those specified in the CAA, as long as such standards were more stringent than the Tier 1 standards. The emission reductions associated with the selected emission control technologies discussed in this study will be compared with those required to meet the standards shown in Table 3 of the CAA.

The review of vehicle emission control technology begins with a discussion of the emission performance of technology found on current Tier 1, National LEV, and California Low Emission Vehicle (LEV) technology vehicles. The first section also reviews the status and potential of a number of emission control technologies which could be used to get emission control beyond Tier 1 standards. The second section describes various technologies that could be used to reduce vehicle emissions below levels currently incorporated in the National LEV and California LEV programs. The third section provides a brief overview of the effect fuel sulfur may have on potential Tier 2 technologies.

A. Currently Feasible Vehicle Emission Control Technology

There have been considerable advances in emission control technology on conventional vehicles over the past several years. Many of these advances occurred as a result of the standards incorporated in the California LEV program which are more stringent than Tier 1 levels, i.e., Transitional Low Emission Vehicle (TLEV), LEV, and Ultra Low Emission Vehicle (ULEV). These standards are included in the NLEV program, which will generally require the introduction of vehicles meeting the LEV standards nationwide in MY2001. In fact, there are already many vehicles in production, including some federal models, that meet TLEV and LEV standards, and in some cases, ULEV standards.

Table 4.1 Tier 1, Default Tier 2, and LEV Emission Standards and Certification Levels for Light Duty Vehicles (LDV)*

		50,000 Mile (g/mi)			100,000 Mile (g/mi)		
		NMHC	CO	NOx	NMHC	CO	NOx
Standard	Tier 1	0.25	3.4	0.4	0.31	4.2	0.60
	Tier 2**	--	--	--	0.125	1.7	0.20
	LEV	0.075	3.4	0.2	0.09	4.2	0.30
Cert Levels	Tier 1	0.03-0.25	0.47-3.3	0.03-0.40	0.04-0.24	0.6-3.4	0.04-0.60
	LEV	0.04-0.06	0.2-1.3	0.06-0.13	0.023-0.078	0.2-1.7	0.07-0.26

* Particulate standards: Tier 1 = 0.08 g/mi (50,000 miles), 0.10 g/mi (100,000 miles)
LEV = 0.08 g/mi (100,000 miles)

** Default Tier 2 standards in Table 3 of the CAA

Certification data in Table 4.1 derives from manufacturer certifications for 1998 LEV-certified vehicles. As the data show, manufacturers are certifying LEVs with NMHC emissions and NOx emissions at less than one-third the level of the 100,000 mile standards. Certification to one-half or more of the standard is more typical. EPA recognizes that this additional margin gives manufacturers the ability to ensure their LEVs comply with the standards even with in-use variability and uncertainty of vehicle performance of the newer LEV vehicles, but it also demonstrates that the technology is feasible to produce vehicles with emissions well below Tier 1 levels. It is quite clear, given current federal and California certification information, that the technology exists for essentially all conventional vehicles to achieve lower emissions than are required by Tier 1 standards.[17]

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[17] This study focuses on feasible technology that can achieve HC and NOx reductions. Even though technology relating specifically to CO reductions is not discussed in detail, EPA notes that many of the technologies used to reduce HC emissions also yield CO reductions as well.

EPA also analyzed various individual technologies for their ability to provide further emissions reductions. Improvement in emission controls requires reducing emissions levels coming out of the engine ("engine-out" emissions) or increasing the efficiency of exhaust aftertreatment systems. Typically, manufacturers use both approaches when trying to lower emission levels. Emission reduction improvements for conventional vehicle technology (i.e., vehicles equipped with gasoline-fueled engines) come from four main technological areas. These are improvements in base engine design, more precise air-fuel ratio control, better fuel delivery and atomization, and continued advances in exhaust aftertreatment. The table below summarizes technologies that can be used to reduce emissions from Tier 1 vehicles. It is important to point out that the use of all of the following technologies is not required to further reduce emissions. The choices and combinations of technologies will depend on several factors, such as cost, current engine-out emission levels, effectiveness of existing emission control systems and individual manufacturer preferences. As noted above, with the exception of a few technologies, many of these technologies are used on at least a few Tier 1, TLEV, LEV and ULEV vehicles already in production.

Table 4.2 Feasible Technologies for Emission Reductions (Reductions from Tier 1 Levels)

Technology	HC	NOx
Modifications to combustion chamber	3-10%	3-10%
Multiple valves with variable valve timing	30%	3-10%
Increased EGR (including electronic control)	0%	≥10%
Improved A/F control (i.e., improved HEGO, improved power-train control module microprocessor, faster fuel injectors, transient adaptive fuel control algorithms, dual HEGO, and improved calibration)	10%	20%
UEGO	5%	23-35%
Air/fuel control in individual cylinders	22%	3%
Increased EGR (including electronic EGR)	0%	≥10%
Air-assisted fuel injectors	3-10%	0%
Catalyst improvements (thermal stability, washcoat, cell densities)	10%	10%
Increased catalyst loading and volume	10%	20%
Advanced catalyst designs (tri-metal, multi-layered)	20-37%	30-57%
Close-coupled catalysts	50-70%	0-10%
Electrically-heated catalysts	≥10%	5-10%
HC adsorbers	≥10%	0%

NOTE: In general, these percentages cannot be simply summed to achieve a total emission reduction when more than one emission control technology is being applied.

Most of these technologies are either conventional technologies or extensions of conventional technologies that have been in existence for some time now and have been proven commercially, and are currently used on at least a few Tier 1, TLEV, LEV, or ULEV vehicles. EPA is not aware of any potential safety concerns or energy impacts associated with their use. Again, because these technologies are established technologies, EPA does not feel that any of these technologies require unique lead time considerations. The primary lead time issue is development of specific sets of control technology and engine calibrations for individual engine families and vehicle models. This aspect of lead time will be considered during the Tier 2 rulemaking process.

The following discussion, focusing on technology needed for HC and NOx reductions, is based on "Low-Emission Vehicle and Zero-Emission Vehicle Program Review", a staff report published in November, 1996 by the California Air Resources Board (CARB) as part of its biannual review of the California LEV program, information from the Manufacturers of Emission Controls Association (MECA) and numerous vehicle manufacturers. EPA also contracted Energy and Environmental Analysis, Inc. (EEA) to conduct a study evaluating the potential availability of emission control technology to meet more stringent emission standards for light-duty vehicles and light-duty trucks. The report is titled "Benefits and Cost of Potential Tier 2 Emission Reduction Technologies." A detailed discussion of these technologies is provided in *Appendix B. Vehicle Technology.*

1. Base Engine Improvements

There are several design techniques that can be used to reduce engine-out emissions, especially for HC and NOx. The main causes of excessive engine-out emissions are unburned fuel for HC and high combustion temperatures for NOx. Methods for reducing engine-out HC emissions include the reducing 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 listed under 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 with increased exhaust gas recirculation (EGR) and multiple valves (intake and exhaust) with variable-valve timing.

2. Improvements in Air-Fuel Ratio Control

Modern three-way catalysts require the air-fuel ratio (A/F) to be as close to stoichiometric operation (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 (less than 1% deviation in A/F or roughly $\pm$ 0.15). Thus, it is imperative to maintain the A/F ratio within this tight window of stoichiometric operation if emissions are to be further reduced. In fact, the tighter the A/F ratio can be maintained, the higher the overall three-way catalyst conversion efficiency that can generally be achieved, resulting in further reductions to emissions. Therefore, technologies that enhance tighter A/F control can realize significant reductions in HC, CO, and NOx emissions.

Contemporary vehicles have been able to maintain stoichiometric operation, or very close to it, by using closed-loop feedback fuel control systems. At the heart of these systems is a single heated exhaust gas oxygen (HEGO) sensor. The HEGO sensor continuously switches between rich and lean readings. By attempting to maintain an equal number of rich readings with lean readings over a given period, the fuel control system is able to maintain stoichiometric operation. While this fuel control system is capable of maintaining the A/F ratio with the required accuracy under steady-state operating conditions, the system accuracy is challenged during transient operation where rapidly changing throttle conditions occur.

In addition to improved HEGO sensor designs, an additional post-catalyst HEGO sensor can be used for additional fuel control refinements, resulting in a more robust and precise fuel control system and reductions in HC and NOx. Another technology that can improve A/F control is the use of an universal exhaust gas oxygen (UEGO) sensor, also known as a "linear oxygen sensor," in lieu of a conventional HEGO sensor. UEGO sensors are capable of recognizing both the direction and magnitude of A/F transients since the voltage output is "proportional" with changing A/F ratio (each voltage value corresponds to a certain A/F), facilitating faster response of the fuel feedback control system and tighter control of the A/F ratio.

Rich and lean A/F spikes that occur during transient operation can result in high emissions. Therefore, any technologies that can help the fuel control system better anticipate these A/F spikes can result in lower emissions. There are several technologies that can help achieve this, such as controlling the A/F in each individual cylinder, rather than for the entire engine, and the incorporation of transient adaptive fuel control algorithms that compensate for component tolerances, component wear, varying environmental conditions, varying fuel composition conditions, etc., that occur during transient operation. Finally, the use of electronic throttle control in lieu of conventional mechanical systems, faster response fuel injectors, and a quicker power-train control module microprocessor can help further tighten A/F control.

3. 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 pollutants. Sequential multi-point fuel injection and air-assisted fuel injectors are examples of technologies available for improving fuel atomization.

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 into several cylinders. Since only one of the cylinders is actually ready for fuel at the moment of injection, the other cylinder(s) gets fuel at inappropriate times. 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 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 most, if not all, vehicles soon.

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 show 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.

4. Improvements to Exhaust Aftertreatment Systems

Tremendous advancements in exhaust aftertreatment systems have emerged in the last few years. The advancements in exhaust aftertreatment systems are probably the single most important area of emission control development. Such advancements allow manufacturers to more effectively reduce exhaust emissions, both during warmed-up operation as well as right after a cold start, when the majority of emissions occur. Catalyst manufacturers are progressively moving to palladium as the main precious metal in automotive catalyst applications. Improvements to catalyst thermal stability and washcoat technologies allow manufacturers to place catalysts closer to the engine, thereby increasing the catalyst's light-off time and thus increasing its emission reduction capability. The design of higher cell densities and the use of two-layer washcoat applications increases catalyst efficiency. There has also been much development in HC and NOx absorber technology, which act to trap pollutants during cold starts and release them after the catalyst is operating effectively. The use of secondary air injection systems and insulated or dual wall exhaust pipes also contribute to the improvements in exhaust aftertreatment and reduction in HC emissions. A detailed discussion of these technologies is provided in *Appendix B. Vehicle Technology.*

5. Improvements in Engine Calibration Techniques

One of the most important emission control strategies is not hardware-related. Rather, it is the software and, more specifically, 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. As the PCM becomes more powerful with greater memory capability and speed, algorithms can become more sophisticated. Advancements in computer processors, engine control sensors and actuators and computer software, in conjunction with experience in developing calibrations, allows manufacturers to improve and refine their calibration skills, 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 additional hardware, such as electrically heated catalysts (EHC) or adsorbers.

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

6. Technology for Reduction of Particulate Emissions

Particulate emissions from gasoline-fueled vehicles consist of both carbon- and sulfur-containing compounds. The carbonaceous particulate is produced from both the gasoline fuel and engine lubricating oil. Available data indicate that particulate emissions are highest during cold starts and lower during hot starts and warmed up operation. Technology aimed at reducing gaseous NMHC emissions, such as improved air-fuel ratio control, tends to reduce carbonaceous particulate emissions, as well. Carbonaceous particulate emission control from gasoline vehicles will likely accompany required NMHC emission control. The predominant form of sulfur-containing particulate from motor vehicles is sulfuric acid (commonly referred to as sulfate). This sulfate is produced in both the engine and the exhaust system by the oxidation of sulfur dioxide. However, the current approach of operating engines as close to stoichiometric as possible coupled with advanced three-way catalysts appears to keep sulfate emissions at very low levels. Therefore, the primary technique available for reducing sulfate emissions is to reduce gasoline sulfur levels.

Diesel particulate emissions also consist of both carbonaceous and sulfate particulate. Unlike gasoline emissions, carbonaceous particulate and NMHC emissions from a diesel engine are not as directly related. Engine-related techniques for reducing particulate emissions include higher fuel injection pressures, electronic engine control of injection timing, rate and duration and turbo charging/aftercooling. Exhaust aftertreatment techniques include the use of an oxidation catalyst or a trap. The oxidation catalyst primarily reduces the heavy organic portion of the carbonaceous particulate, which usually represents 30-50% of total carbonaceous particulate emissions. Traps can reduce both organic and solid carbon particulate and are capable of controlling 70-90% of carbonaceous particulate emissions.

Diesel-powered LDVs and LDTs produced in the late 1980s were capable of meeting particulate emission standards in the range of 0.1-0.2 g/mi without the use of exhaust aftertreatment. One manufacturer also produced some vehicles equipped with traps. A few light-duty diesel models are being certified to the current Tier 1 standards of 0.1-0.12 g/mi without the need for aftertreatment.

Sulfate emissions from a diesel engine form primarily in the engine and generally represent 2% of the total sulfur in the fuel. The primary method to reduce sulfate emissions is to reduce the sulfur content of diesel fuel. Under some conditions, the use of an oxidation catalyst or a catalyst-containing trap can increase tailpipe out sulfate emissions.

B. Advanced Technologies

In addition to the technologies described above to reduce emissions from conventional vehicles, technologies providing even greater reductions are being analyzed and developed. These technologies are in various stages of development and some of them could be introduced on ULEVs and zero emission vehicles (ZEV) to meet state and federal programs. Manufacturers are also developing non-conventional vehicle technologies, in part as a response to the desire for vehicles with lower emissions than those vehicles currently available or expected in the next few model years. Many of these technologies could be utilized in the next generation of vehicles sold nationwide.

California's emission control program has served as the impetus for development of advanced emissions control technology, and technologies used to meet current stringent standards in California could also be feasible for introduction nationwide.[18] The California LEV emission control program requires manufacturers to produce ULEV vehicles in order to meet the

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[18] California proposed more stringent emission control standards in December, 1997. The California LEV 2 program would reduce by 75% the current NOx standard for LEVs and ULEVs and introduce a new category of standards, the super ULEV (SULEV: NMOG = 0.01 g/mi, CO = 1.0 g/mi, and NOx = 0.02 g/mi). The SULEV standards are 120,000 mile standards. California is expected to make a final decision regarding the LEV 2 program in November, 1998. EPA and California are trying to harmonize their programs when possible (e.g., National LEV). EPA is closely monitoring California's actions regarding its LEV 2 proposal and will determine which parts of the program, if any, are appropriate to address in the federal rulemaking.

fleet average NMOG requirements.[19] In many instances, manufacturers will use a combination of the technologies described above to design and produce vehicles which comply with ULEV standards. As California noted in its November, 1996 staff report, manufacturers may also need to introduce EHCs on some vehicles where emissions control is more difficult, such as vehicles with limited underhood space or larger displacement engines. Electrically-heated catalysts use an auxiliary heating device to bring the catalyst up to its operating temperature more quickly than typical heating by engine exhaust. One manufacturer announced it has developed a gasoline-powered vehicle that utilizes advanced engine designs and catalysts to reduce emissions levels to significantly below ULEV standards. Some manufacturers also chose to produce ULEVs using engines that burn compressed natural gas. These engines give manufacturers additional flexibility in designing and producing vehicles that meet the tighter ULEV standards. In general, these engines are similar to gasoline-powered engines, but have modified fuel delivery and storage systems. Compressed natural gas (CNG) powered vehicles also have lower evaporative emissions than gasoline-powered vehicles.

California also requires manufacturers to develop ZEV technology, with widespread introduction targeted for MY2003. Much of the development effort to date has focused on electric vehicles, and many manufacturers have already made ZEVs available to consumers and fleet purchasers. These vehicles use many newer technologies, such as advanced charging and regenerating systems and vehicle structural design. Battery technology, which has been the major technical limitation to date, has been and will be the focus of much developmental work. Improved nickel-metal hydride, sodium nickel-chloride, lithium polymer, and lithium ion batteries are some of the battery types being developed for use in electric vehicles produced in the near future.

Manufacturers are also actively developing other non-conventional vehicle propulsion systems which could emit pollutants at lower rates, possibly even significantly lower, than current Tier 1 vehicles. While none of these systems are currently available in the United States, they could be technologically feasible early in the next century. One system utilizes a hybrid propulsion system, which combines a gasoline or diesel-powered engine with an electric motor and is optimized to operate at maximum efficiency over changing driving conditions. These designs can result in very high fuel efficiency and also very low emission levels (a manufacturer estimates up to one tenth the current levels of HC, CO, and NOx).[20]

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[19] The National LEV program does not require ULEVs to be produced for a manufacturer to meet the fleet average NMOG requirements. However, manufacturers are likely to produce and sell vehicles meeting ULEV standards under the National LEV program, especially if a manufacturer needs to offset Tier 1 or TLEVs in its fleet after MY2000 or if a manufacturer produces 50-state ULEV engine families and wants to generate fleet average NMOG credits.

[20] One manufacturer has introduced in Japan a hybrid vehicle which incorporates a gasoline engine and an electric motor. Emissions are reduced in part by operating the engine under a constant load and thus minimizing air-fuel ratio changes.

This type of propulsion is also being developed as part of a joint venture between the federal government and the domestic auto manufacturers. The Partnership for a New Generation Vehicle (PNGV) has a design goal of producing production prototypes by 2004 that would achieve up to 80 miles per gallon with very low emissions. Design work is focusing on hybrid electric drives, powered by direct-injection drives or fuel cells, advanced batteries, advanced combustion engines using renewable fuels and petroleum fuels, and increased use of lightweight materials in vehicle construction. Technologies developed from this process, in addition to being integrated into a PNGV vehicle, could be used to reduce emissions from vehicles meeting more stringent standards.

Fuel cells are a promising propulsion system that is being developed for possible introduction to consumers early in the next century. A fuel cell is an electrochemical device that generates electricity from a chemical reaction between hydrogen and oxygen. The necessary hydrogen can either be carried as a compressed gas or extracted from a fuel carried on the vehicle, such as gasoline or methanol. The electricity produced from a fuel cell drives a traction motor that in turn drives the wheels. Fuel cell use gives a vehicle long range, good performance, rapid refueling and low or even zero emission levels.

C. Sulfur's Effect on Tier 2 Technology

The sulfur found in gasoline does not affect engine-out emissions of HC, CO, and NOx, but it increases exhaust emissions of these pollutants by inhibiting the performance of the three-way catalyst (TWC). The degree of sulfur inhibition to the catalyst has been shown to be variable and depends upon both catalyst formulation and operating conditions. (Sulfur inhibition is very sensitive to A/F ratio.) Sulfur strongly competes with pollutants for "space" on the active catalyst surface. This limits the efficiency of catalyst systems to convert pollutants. Current evidence, however, indicates that sulfur is not a permanent catalyst poison like lead (Pb). This means that increases in emissions caused by high sulfur fuels may be at least partially reversed once the high sulfur fuel is no longer used. Studies are underway to determine how quickly, completely, and easily the sulfur will come off the catalyst when the vehicle is refueled with a low sulfur fuel.

Recent information from the sulfur test programs performed by the Coordinating Research Council (CRC) and the auto industry, suggests that not only do LEV and Tier 1 vehicles exhibit decreased emissions performance due to fuel sulfur, but the more advanced the technology, the more sensitive (on a percentage basis) the catalysts are to sulfur. The studies indicate that increasing sulfur content could more than double NOx emissions and have a less severe, though noticeable, effect on HC emissions. In addition, vehicle manufacturers claim that elevated fuel sulfur levels can interfere with the functioning of vehicle onboard diagnostic systems by triggering the illumination of the vehicle's malfunction light. Any development of Tier 2 standards will review the effect of sulfur on possible Tier 2 technologies, and possible ways to reduce such effect. For example, some catalyst formulations show less sulfur sensitivity than others; EPA will pursue this issue further in an effort to better understand why some catalysts respond differently to sulfur. EPA is aware that the American Petroleum Institute (API), as well as some catalyst manufacturers, are further analyzing this issue. The Agency will assess appropriate sulfur control programs for commercial fuel and appropriate certification fuel specifications that are more representative of sulfur levels in commerce, as discussed in Chapter VI.

CHAPTER V. ASSESSMENT OF COST AND COST EFFECTIVENESS

The Clean Air Act requires EPA to examine "the need for, and cost effectiveness of, obtaining further reductions in emissions from light-duty vehicles and light-duty trucks, taking into consideration alternative means of attaining or maintaining the national primary ambient air quality standards ..." (emphasis added). As discussed in the previous chapter, technology is available today to reduce emissions from light duty vehicles well below Tier 1 levels. The National LEV program assures that passenger cars and light trucks will be produced beginning in the 1999 model year to LEV levels. The purpose of this chapter is to present information on costs and cost effectiveness for potential emission control technologies beyond Tier 1 technologies. This includes the cost effectiveness of LEV technologies, as well as technologies that achieve emission reductions beyond LEV standards. The chapter estimates cost effectiveness of certain emission reductions without making a determination of the specific numerical values of potential regulatory standards.

One lesson to be learned from the past 30 years of controlling motor vehicle pollution is that the costs of future technologies are usually less than originally estimated. The auto industry, as well as government regulators and outside experts, tend to over-predict future costs. The actual costs are usually lower than predicted when the technology is manufactured and installed on mass-produced vehicles. As stated previously, Tier 2 standards cannot be effective until the 2004 model year at the earliest. That is over five model years from the present. Therefore, although the following cost estimates are EPA's best assessment of the technology discussed in *Chapter IV. Assessment of Technical Feasibility*, they may prove to be over-predictions when viewed several years into the future.

In addition to estimations of cost, this chapter also attempts to quantify the emission reduction capabilities of these technologies. In this way, the cost effectiveness, in units of dollars per ton of emissions reduced, can be calculated and compared.

The sources for the emissions reductions and costs of the various emission control technologies were the EEA report, the CARB report, MECA, API, confidential information from vehicle manufacturers and EPA technical assessments. Of these sources, only EEA, CARB and several vehicle manufacturers supplied information on costs. Consequently, these are the sources that are primarily used for establishing cost effectiveness.

A. Cost Effectiveness of Low Emission Vehicle Technologies

It is not necessary to incorporate all of the technologies discussed in the previous chapter in order to produce vehicles capable of emitting below Tier 1 levels. The choices and combinations of technologies will depend on several factors, such as current engine-out emission levels, effectiveness of current emission control technologies, and individual manufacturer preferences.

As discussed in *Chapter IV. Assessment of Technical Feasibility*, two of the most promising emission control strategies for reducing emissions below Tier 1 levels are more precise air/fuel (A/F) control and improved catalyst designs. One or the other or a combination of these technologies are, in fact, what manufacturers have indicated they will utilize to achieve LEV standards under the California or national LEV programs.

A vehicle designed to meet LEV standards will achieve the following emission reductions relative to Tier 1 vehicles:

Table 5.1 Percent Reduction in Emissions of a LEV Vehicle Compared to Tier 1

Pollutant	Percent Emissions Reduction
NMHC	70%
NOx	50%

In the Regulatory Impact Analysis (RIA) prepared in support of the National LEV rulemaking, EPA estimated the emission reduction benefits of National LEV vehicles in 49 states (other than California). The costs in the RIA were based on California Air Resources Board (CARB) estimates of California LEV (CALEV) program vehicle costs, revised in 1996. As summarized in the table below, the total net present value HC emission reductions were estimated to be 28.0 kilograms (kg), while the NOx emission reductions were estimated to be 25.3 kg. The net present value cost was estimated to be $115 per vehicle.

Table 5.2 Emissions Reduction, Cost and Cost Effectiveness of a LEV Vehicle

Pollutant	Emissions Reduction (kg/vehicle)	Cost/vehicle ($)	Cost Effectiveness ($/ton)
NMHC	28.0	57.5*	2054.
NOx	25.3	57.5*	2273.
NMHC+NOx	53.3	115.++	2158.

* Cost per vehicle assigned 50% each to NMHC and NOx.

++ After full phase in 2001 LEV cost is estimated to be $95 per vehicle.

As can be seen, the overall cost effectiveness of National LEV vehicles, based on a 1996 estimate, is $2158 per ton. Note that the above analysis uses gasoline-powered passenger cars certified on California low sulfur gasoline and operated on higher-sulfur Federal gasoline, based on information available at the time the program was developed and considers year round emission reductions. EPA expects similar cost effectiveness results had the calculations been performed for light trucks. In addition, EPA expects that these cost-effectiveness results are similar to those for the standards listed in Table 3 of section 202(i). The standards listed in that table (and consequent emission reductions) are similar to LEV standards. The Table 3 NOx standard is somewhat more stringent, the Table 3 NMHC standard is somewhat less stringent. In addition, the technologies expected to be used to meet the Table 3 levels (and consequent costs) are similar to the technologies expected to meet the LEV standards.

The automakers recently voluntarily agreed to produce LEV vehicles under the National LEV regulatory framework. Some auto companies have also announced they would produce certain light-duty trucks to meet LEV standards sooner than they would be required under the National LEV program. In addition, some companies stated they will voluntarily reduce emissions from light-duty trucks not included in the National LEV program. EPA's analysis of the cost effectiveness of future light-duty vehicle emission standards focuses on standards more stringent than LEV levels.

B. Cost Effectiveness of Technologies Beyond LEVs

The previous chapter presents information on the technical feasibility of achieving emission levels beyond the LEV standards. A number of these technologies, such as ultra-precise air-fuel ratio control, increases in catalyst loading or cell density, closer catalyst proximity to the exhaust manifold, and variable valve timing, are available today. Others are expected to be available to vehicle manufacturers before 2004. Although there does not exist a large amount of specific data on the costs of such technologies, this section of the study will summarize the available information. All of the following percentage emission reductions and costs are incremental to Tier 1 technologies.

Estimates of emission reductions resulting from increases in catalyst loading and volume were consistent among the various sources. EEA estimates a benefit of 10% for HC and 20% for NOx. MECA and several vehicle manufacturers concurred with these estimates. For improvements to catalyst formulations and substrate designs, the estimates were again a consensus of 10% for HC and NOx. The benefit of using a close-coupled catalyst were estimated by various vehicle manufacturers to range up to 70% for HC, and 10% for NOx. Information from the American Petroleum Institute suggests that for catalysts utilizing tri-metal and multi-layer designs, emission reductions ranging up to 37% can be achieved for HC and up to 57% for NOx.

Estimates of emission reductions associated with ultra-precise A/F control vary. Information from MECA and two vehicle manufacturers suggest that NOx emission benefits can range up to 70%, while EEA estimated emission reductions of greater than 10% (no upper limit was provided) for HC and NOx. For the purposes of this study, EPA estimates that the combination of faster response fuel injectors, a faster PCM microprocessor, improved HEGO sensor design (i.e., planar design) and the use of dual HEGO sensors and adaptive transient fuel control would result in emission reductions at least up to 10% for NMHC and 20% for NOx. The upper range of the estimates from MECA and the two manufacturers are actually higher than this estimate, because they believed that an important part of achieving tighter A/F control is the continued development of more sophisticated calibration strategies used in conjunction with the above mentioned technology.

Combining the emissions reduction potential of catalyst improvements and more precise A/F control cited above, EPA estimates that NMHC tailpipe emissions of light-duty vehicles and trucks produced in the 2004 model year time frame would be 77% less than Tier 1 vehicles. This would equate to a NMHC emission standard of approximately 0.06 g/mi for LDV/LDT1 (LDT below 3,450 pounds curb weight). As discussed below, EPA does not believe this is an upper limit of the capability of future technology to reduce NMHC emissions.

In the case of NOx emissions, the above catalyst improvements and more precise A/F control were combined with EPA's technical assessment of the potential for improvements in EGR systems, such as electronically controlled EGR. This analysis shows that NOx emissions from light-duty vehicles and trucks produced in the 2004 model year would be 80% less than Tier 1 vehicles. This would equate to a NOx standard of approximately 0.08 g/mi for LDV/LDT1.

Although the purpose of this study is not to propose Tier 2 emission standards, these emission reductions can also be compared to those needed to achieve the default Tier 2 standards, listed above in Table 4.1. Applying the 77% and 80% NMHC and NOx reductions, respectively, to the 100,000-mile Tier 1 standards (also listed in Table 4.1) yields 100,000-mile emission levels of approximately 0.07 g/mi NMHC and 0.12 g/mi NOx. These levels are below the default Tier 2 standards, suggesting that the default Tier 2 standards are technically feasible.

Emissions tests used to estimate the potential for catalyst-related technologies were primarily performed at low sulfur levels (e.g., 30-100 ppm). Because the effectiveness of some of the above catalyst-related technologies may be adversely affected by fuel sulfur content, the above emission reductions potentials could be less if vehicles are operated on higher sulfur fuels.

Using these emission reduction factors, EPA estimated in-use emissions performance on a per vehicle basis to represent a 77% and 80% reduction in NMHC and NOx emissions, respectively. EPA performed a preliminary cost analysis of these technologies using the sources cited above as well as EPA's own assessment. The results showed that the cost of additional technology to achieve the emission reductions above for NMHC and NOx combined is $136 for LDV/LDT1, and $161 for LDT2/LDT3/LDT4. (See *Appendix C. Emission Reductions, Cost and Cost Effectiveness* for details of this analysis.)

With this information it was possible to calculate the cost effectiveness of the selected technologies that achieve emission reductions beyond LEV levels. This was done using the above cost factors and emission reduction effectiveness for LDVs and LDTs separately. The results are shown below:

Table 5.3 Emissions Reductions, Costs and Cost Effectiveness of Technologies Beyond LEV and Incremental to Tier 1

Vehicle Class/ Pollutant	Nominal Emission Level (g/mi)	Emissions Reduction (g/mi)	Cost per Vehicle ($)	Annual Cost Effectiveness ($/ton)
LDV/LDT1				
NMHC	0.06	0.181	57.33 *	3151.
NOx	0.08	0.422	78.75*	1858.
NMHC+NOx		0.603	136.	2245.
LDT2,3,4				
NMHC	0.07**	0.199	69.93*	3212.
NOx	0.14**	0.456	91.35*	1842.
NMHC+NOx		0.653	161.	2256.

* Cost per vehicle assigned 50% each to NMHC and NOx, after assigning EGR cost ($17) to NOx control.
** Standards shown represent LDT2/LDT3. Nominal standards for LDT4 could be 0.09 g/mi for NMHC and 0.22 for NOx.

EPA has also calculated the cost effectiveness of the package of technologies which would achieve reductions beyond LEV levels as an incremental comparison to the National LEV program. An "in-effect" finding for this voluntary program was published earlier this year, and National LEV vehicles will be available nationwide beginning in the 2001 model year. While EPA believes that the proper cost effectiveness analysis compares control measures against a Tier 1 baseline, an analysis using a National LEV baseline is illustrative for the purposes of this study. Using the same methodology as was presented above, the above package of technologies reduce NMHC plus NOx emissions beyond those levels achieved by the NLEV standards at a cost of $2400 per ton. This is only marginally higher than the cost effectiveness of these technologies relative to the Tier 1 standards.

These estimates of the cost effectiveness of Tier 2 technologies do not include any cost for reducing the sulfur level of commercial gasoline. Since the emission tests used to estimate the potential for catalyst improvements were primarily performed at low sulfur levels (e.g., <100 ppm and nominally 40 ppm), these cost per ton estimates are most directly applicable when low sulfur fuel is assumed to be used in both the Tier 1 and Tier 2 cases. The technologies described above also reduce emissions when higher sulfur fuels are used. However, the potential for catalyst-related technologies, including improved air-fuel ratio control, can be adversely affected by fuel sulfur content. This is mitigated by the fact that the baseline Tier 1 emission levels would be higher with high sulfur fuel and the overall emission reduction is a combination of the percentage emission reduction times the baseline emission level. Still, similar cost per ton estimates assuming the use of high sulfur gasoline may be slightly higher. In the case where the cost effectiveness of Tier 2 technologies is compared to the NLEV standards, the cost per ton estimates should be approximately the same at either low or high sulfur fuels, since the effect of high sulfur levels is affecting both NLEV and Tier 2 technology.

It is important to note that the presentation of these estimates does not imply that EPA believes these levels of emission reductions are upper limits of future technology. As discussed in the previous chapter, there are a number of emission control technologies that either have been demonstrated to date or are expected to be available for use on production vehicles by 2004 that can achieve emission reductions beyond those discussed above. For purposes of this study, EPA selected certain technologies for which estimates of emissions performance and costs were available. EPA expects that other, more effective, technology will be available prior to 2004. Nonetheless, it appears the cost effectiveness of technology that exists today to reduce emissions of light-duty vehicles and trucks beyond LEV levels is within the range of other available control strategies.

C. Comparison to Other Control Strategies

This section discusses the cost effectiveness of other emission control strategies that may provide alternative means of attaining or maintaining the NAAQS. EPA estimates the cost and cost effectiveness of specific control measures as part of individual rulemaking. The estimates are made available for public review and comment before final regulations are promulgated. Numerous control measures have been put in place since the 1990 Clean Air Act amendments.

A review of national vehicle control measures mentioned in this report showed a range of cost effectiveness estimates. Regarding motor vehicle controls, EPA estimates of the cost effectiveness of recently promulgated programs are:

- Tier 1 standards for LDVs and LDTs: $6000 per ton of HC and $1380-1800 per ton of NOx
- Supplemental FTP (SFTP) standards for aggressive driving: $457-$552 per ton of HC and $150-$172 per ton of NOx
- SFTP standards for emissions with the air conditioning on: $2,050-$2,574 per ton of NOx
- On-board diagnostics (OBD) requirements: $1,974 per ton of HC, $1,974 per ton of NOx, and $124 per ton of CO

Recent controls required on stationary point sources have been in the same general range.

The question relevant to this study is, how do the cost effectiveness estimates for technologies beyond Tier 1 compare with alternative control measures that have not yet been put in place? The Regulatory Impact Analyses prepared for the recently revised NAAQS contains the most comprehensive set of cost effectiveness estimates for potential emission control measures. The RIA included measures for ozone precursors and particulate matter control ranging from strategies that produce a cost savings up to and more than $10,000 per ton of pollutant reduced.

The NAAQS analysis indicates that even after known and available control measures are implemented, there will remain a substantial number of areas that are in need of additional pollutant reductions in order to attain the new air quality standards. For these emission reductions, which will need to come from a combination of mobile and stationary sources, the NAAQS RIA incorporates a cost effectiveness threshold of $10,000 per ton of pollutant reduced. The analysis documents many current technologies with control costs less than $10,000 per ton and expects future and emerging technologies to produce similar cost effective control strategies. The average control cost for measures included in the NAAQS ozone analysis is approximately $2,600 per ton for NOx and $3,700 per ton for HC reductions.

The following are examples of potential control strategies and the cost per ton estimates from the NAAQS RIA (incremental cost in 1990$):

- Industrial boilers conversion to natural gas: approximately $2,000 per ton of NOx removed.
- Marine commercial engines: approximately $6,503 per ton of NOx removed.
- New heavy-duty vehicles powered by natural gas: approximately $2,400 per ton of NOx avoided.

Based on this review of the NAAQS RIA, which is the best and most recent analyses of cost effectiveness for a wide range of control measures, it appears that light-duty vehicle emission standards that are more stringent than Tier 1 would be cost effective relative to the control measures included in the NAAQS RIA. Further, it appears that technology is known today that could reduce emission levels of HC and NOx from light-duty vehicles beyond LEV levels in a cost effective manner. As shown above, it appears to EPA that technology is known that has the potential to reduce HC emissions to levels at least 77% below Tier 1 levels at a cost effectiveness of about $3300 per ton. Likewise, it appears that technology is known that has the potential to reduce NOx emissions to levels at least 80% below Tier 1 levels at about $1800 per ton, with a combined HC + NOx cost effectiveness of about $2,300 per ton. These cost effectiveness estimates are well within the range of cost effectiveness of other, alternative control measures that could be applied to both stationary and mobile sources in the future in order to attain or maintain the NAAQS. In the above analysis the cost effectiveness on a per ton basis examines both national control programs and local, regional or seasonal measures.

As mentioned previously, the above estimates of potential emission reductions from Tier 1 levels (77% HC and 80% NOx) are not meant to imply limits of any future emission standards. They were selected for analyses in this report to illustrate point estimates of emission reductions that appear technically feasible and cost effective. EPA expects there are additional control technologies that are or will soon be available that have potential to result in reductions that go beyond the estimates analyzed here.

The discussion above addresses costs and cost effectiveness of HC and NOx reductions. It does not include information on carbon monoxide or particulate matter reductions. As mentioned earlier in this report, EPA is working on a study of the need for more stringent light-duty vehicle CO standards that would apply at cold temperatures. That study is the appropriate forum to address issues related to future CO emission requirements. It should be noted, however, that most of the technology discussed in this report as reducing HC will also cause significant reductions in CO emissions. The cost estimates presented above for HC-reducing technology were calculated by assigning the costs to HC or HC + NOx control. If a portion of the costs had been assigned to account for the expected CO reductions, the HC and NOx cost effectiveness would appear more favorable.

No cost or cost effectiveness calculations were performed for additional future PM controls, although *Chapter IV. Assessment of Technical Feasibility* discussed PM control technology. The contribution of light-duty vehicles to the overall PM emissions inventory is small. It may grow in the future, however. A number of auto and engine manufacturers recently announced their intentions to consider the use of small diesel engines for the light-duty segment, particularly light trucks and sport utility vehicles. For this reason it is appropriate for EPA to consider the levels of future PM emission standards for light-duty vehicles as part of the rulemaking that will be initiated following this study. If EPA decides to propose more stringent PM standards for future vehicles, a full cost and cost effectiveness analysis will be performed as part of proposed rulemaking.

VI. REGULATORY ISSUES

In determining whether Tier 2 standards for LDVs and LDTs are appropriate, there are a number of important issues that EPA will need to resolve that relate to the broader issues of air quality, technical feasibility, and cost effectiveness. Seven issues are presented in this chapter:

A) Relative stringency of the Tier 2 LDV and LDT standards
B) Uniform versus separate standards for gasoline and diesel vehicles
C) Evaporative HC emission standards
D) Corporate average emission standards
E) Extended useful life and other ways to improve in-use emission performance
F) Test fuel specifications
G) Fuel sulfur and distillation properties

A. Relative Stringency of LDV and LDT Standards

All LDVs are required to meet the same numerical emission standards according to Clean Air Act requirements. For example, large luxury cars and small sub-compacts, both used as for personal transportation, meet the same emission standards. In contrast, EPA and CARB have historically set higher numerical emission standards for LDTs than LDVs. While this was done in part due to the larger size and mass of many LDTs, it was also due to their ability to haul cargo. Higher loads produce higher exhaust temperatures, which require that catalysts be placed further back from the engine, delaying light-off. Higher loads can also limit use of EGR for NOx control. Today, mini-vans, small pick-ups, and sport-utility vehicles dominate LDT sales. Full size pick-ups and vans (those vehicles most likely to be used in commercial applications) represent less than 30% of total LDT sales. Also, over the past few years, improvements in the temperature limits of automotive catalysts appear to have reduced the need to set less stringent LDT emission standards as may have been true in the past.

In addition to the trend of designing LDTs explicitly for passenger transportation, total LDT sales increased dramatically and now approach total car sales. Because of their numerically higher emission standards, LDTs have a disproportionate impact on in-use emissions. Using the modified MOBILE5b model described in *Chapter III. Assessment of Air Quality Need*, national LDT emissions of HC and NOx will exceed LDV emissions by 83% and 66% respectively, in the year 2007.

There are many options available for setting LDT emission standards given a particular set of LDV standards. Three possible options are:

1) Require LDTs to meet the same numerical emission standards as LDVs, which would mean setting standards regardless of vehicle use;

2) Set the LDT performance standards based on use of the same emission control technology most likely to be used to meet the LDV standards; or
3) Set different standards based on vehicle use.

Option 1 provides the greatest environmental benefit and could be justified based on the belief that the great majority of LDT use is the same as that of LDVs. Under the current California LEV standards, requiring LDTs to meet the same emission standards as LDVs would provide the same emission benefits as reducing the LDV and LDT standards by 50%. (The details of this analysis are presented in Appendix D.) This option would also most closely lead to a determination of emission standards based on the expected use of the vehicle. It could, however, result in higher emission control costs for some LDTs. This option might be appropriate for those LDTs that were not used primarily for personal transportation.

The second option seeks to impose roughly equivalent emission control technology for both LDTs and LDVs. LDVs and LDTs would still have marginally different emission standards to account for the different vehicle weights and payloads, but the types of emission control technologies found on each vehicle type would not differ as much as current LDVs and LDTs.

The third option may provide manufacturers with an incentive to produce LDTs in lieu of LDVs if there is a significant difference in standards, though this choice is limited to an extent by consumer demand. For example, more stringent LDV vehicle standards could be applied proportionately to LDTs.

Another issue involved in setting LDT emission standards is the classification of LDTs into weight categories, each potentially with its own set of emission standards. The current LDT classifications are based on both curb weight and gross vehicle weight rating (GVWR) (see Table 6.1). The higher the curb weight or GVWR, the numerically higher the applicable emission standards. While recognizing the increasingly more difficult task of meeting a given set of emission standards with a heavier vehicle, this system also provides an incentive for manufacturers to add weight to their vehicles in order to bump them up into a heavier classification. There can also be a fuel consumption penalty associated with this action.

Table 6.1 Federal Light Truck Classifications

Classification	Gross Vehicle Weight Rating (GVWR), pounds*	Curb Weight, pounds*	Adjusted Loaded Vehicle Weight, pounds*
LDT1	0-6000	0-3450	
LDT2	0-6000	>3450	
LDT3	6001-8500		<5750
LDT4	6001-8500		>5750

* Curb weight is the weight of the vehicle sitting empty. GVWR is the measure of how much cargo a vehicle can carry. Literally, GVWR is the maximum allowed weight of the vehicle when it is fully loaded. Adjusted loaded vehicle weight is the numerical average of the curb weight and the GVWR.

CARB recently proposed a second phase of LEV emission standards for LDVs and LDTs. As part of this proposal, CARB proposed to require LDVs and LDTs to meet essentially the same emission standards and to redefine LDTs to include any truck at or below 7000 pounds curb weight. If this approach were to be used by EPA for nationwide standards, it would move a significant number of current HDVs into the LDT class. EPA's rulemaking will examine whether the current divisions of LDTs based on curb weight and GVWR should be changed to use more appropriate criteria.

B. Uniform Application of Emission Standards

Uniform standards refers to the application of the same emission standards to similar vehicles regardless of what fuel is utilized. Here, the primary fuel options for conventional engines are gasoline and diesel fuel. The pollutants of most interest in this section are NOx and PM exhaust emissions. Both diesel and gasoline vehicles appear to be capable of meeting the range of possible Tier 2 HC and CO emission standards, so the issue of equivalent standards does not arise with respect to these pollutants. Therefore, NOx emission standards are discussed first below, followed by PM emission standards.

1. NOx Standards

Section 202(g) of the CAA provides that light-duty diesels are required to meet less stringent Tier 1 LDV/LDT NOx standards through model year 2003 than light-duty gasoline vehicles. For example, diesel LDVs and LDT1s are only required to meet a 1.0 g/mi NOx standard at 50,000 miles instead of the 0.4 g/mi NOx standard applicable to gasoline-fueled vehicles. This does not apply in California or to National LEV vehicles certified to TLEV, LEV, and ULEV standards. Should EPA decide not to promulgate Tier 2 standards, this difference in standards would expire and both gasoline and diesel vehicles would be required to meet the same Tier 1 emission standards. The CAA does not mention any continuation of this relaxation in the context of the Tier 2 standards;. Further, the default Tier 2 emission standards[21] apply to both gasoline and diesel vehicles. While it is clear that Congress intended to ease the NOx standards

[21] The default Tier 2 emission standards would apply where EPA finds that there is a need for the Tier 2 standards and that such emission controls are feasible and cost effective, but does not promulgate any alternative Tier 2 standard (see section 202(i)(3)(B) of the CAA). These default standards for LDVs are 0.125 g/mi NMHC, 1.7 g/mi CO and 0.20 g/mi NOx, at 100,000 miles.

of diesel Tier 1 vehicles through 2003, it also appears that Congress intended this to be a temporary measure.

Diesel engines are currently used in a small portion of the LDV and LDT fleets. Therefore, they have little impact on fleet-wide emissions or fuel consumption. Diesels could, however, comprise a greater fraction of sales in years to come. For example, the diesel engine has been identified by the Partnership for a New Generation of Vehicles as the most promising near term technology for high fuel efficiency vehicles. The U.S. government recently committed significant research funds to promote the development of high-efficiency, low-emissions diesels for future vehicles sold in the U.S. The target for the NOx emissions of the PNGV vehicle is 0.20 g/mi, or the current California LEV standard, for LDVs and LDT1s. However, EPA has projected in this study (see Chapter V) that emission levels for NOx below 0.20 g/mi are feasible for gasoline engines. In order to meet such NOx levels, significant development work to diesel engine and aftertreatment performance would be required.

The selection of the diesel as the near-term PNGV technology is due to its high fuel efficiency, as compared to gasoline vehicles. When used in the same vehicle, the diesel engine is more efficient than today's gasoline engine. There is a trend in the automotive marketplace, however, toward larger, heavier vehicles that also sit higher off the road and are equipped with 4-wheel or all-wheel drive. These features decrease fuel economy. Thus, the diesel engine could be used to increase the average size and weight of the vehicle fleet while still complying with the Corporate Average Fuel Economy (CAFÉ) standards. In this case, fleet average fuel economy would not increase. Another advantage of the diesel engine is that its fuel produces essentially no evaporative emissions.

2. Tier 2 Particulate Standards

The CAA set Tier 1 particulate standards of 0.10-0.12 g/mi for LDVs and LDTs at 100,000 miles. These standards were based on the capabilities of diesel engine technology. Gasoline vehicles can meet much more stringent PM standards (e.g., less than 0.01 g/mi). The CAA does not include default Tier 2 PM standards, as it does for NMHC, CO and NOx standards. It directs EPA to consider standards more stringent than the Tier 1 standards to meet all NAAQS, which include the particulate NAAQS. It is appropriate to consider Tier 2 PM standards along with those for the three gaseous pollutants.

Diesel LDVs and LDTs emit more PM emissions than gasoline-fueled vehicles, and the small number of light-duty diesels currently sold makes their overall air quality impact small. Diesels could become more prevalent in the future, however, and the public health impact of their particulate emissions could be quite substantial. The primary technical issue is whether to set Tier 2 particulate standards based on the capability of the gasoline engine and require diesels to meet this standard in order to be sold or to set a more relaxed standard based on current and projected diesel technology.

EPA has not performed a detailed analysis of the capability of diesel engines to meet stringent PM standards. California recently proposed a 0.01 g/mi PM standard for all LDVs and LDTs, which would begin phasing in with the 2004 model year. The goals of the Partnership for a New Generation of Vehicles include a 0.01 g/mi PM target.

In developing the proposed Tier 2 standards, EPA will perform assessments of the environmental impacts of diesel PM emissions to facilitate resolution of this issue. One assessment will estimate the ambient levels of PM_{10} and $PM_{2.5}$ which would likely occur in urban areas should substantial numbers of light-duty diesels be sold. This assessment will be performed for possible Tier 2 PM standards ranging between 0.01 and 0.10 g/mi. EPA will also assess the personal exposure to diesel PM emissions and project the resultant cancer impact of this exposure.

In addition, EPA will assess the capability of future diesel engine designs to meet these standards and whether the environmental impacts are severe enough to require PM standards below the current capability of diesel engines. The diesel engine is not the only technology that provides higher fuel efficiency than the current gasoline engine. Direct injection gasoline (GDI) engines are being developed by a large number of automakers. These engines appear to provide much of the fuel efficiency improvement available from a diesel engine. EPA will include these engines in this assessment.

One last issue regarding Tier 2 PM emission standards is whether to establish such standards only for operation over the traditional FTP driving cycle, or to also establish standards for emissions during aggressive driving and air conditioner operation. EPA did not establish any Tier 1 SFTP standards for PM emissions. EPA has not performed any assessments of the costs or benefits of such standards, but will consider them in developing the proposed Tier 2 standards.

C. Evaporative HC Emission Standards

Evaporative HC emissions from Tier 1 and LEV vehicles exceed exhaust NMHC emissions in-use. (Evaporative HC emissions as used herein include running losses, hot soak emissions, diurnal emissions and resting losses.) It may be appropriate to consider tightening the current evaporative HC emission standards in the process of considering tighter Tier 2 exhaust emission standards.

CARB recently proposed a "zero evaporative emission" requirement which would essentially require that evaporative HC emissions be below measurable levels. One manufacturer recently announced the ability to produce a vehicle with "zero evaporative emissions" in-use. CARB pointed to this vehicle, as well as to several other emission control technologies, as a basis for the recently proposed zero-evap standards. These technologies included a second charcoal canister to trap HC emissions not absorbed by the standard canister, bladder fuel tank systems, pressurized fuel tanks, pressurized vapor reservoir systems, insulated fuel tanks and improved seals for the onboard vapor recovery systems (refueling emission controls). CARB also pointed out that a number of current vehicles have certification levels of evaporative emissions that equal less than one-fifth of the current emission standards.

EPA has not assessed the feasibility of tighter evaporative HC standards, nor their cost and air quality benefit. These assessments will be performed prior to the proposal of the Tier 2 emission standards and will be used to determine whether more stringent evaporative HC standards should be proposed along with more stringent exhaust emission standards. Should EPA decide to include evaporative HC standards in its Tier 2 standards proposal, EPA will also evaluate several new regulatory options for their control to provide the manufacturers greater compliance flexibility.

D. Corporate Average Tier 2 Standards

The current Tier 1 emission standards apply to each LDV or LDT separately. There is no flexibility to have some vehicles meet a more stringent and some vehicles meet a less stringent standard and allow manufacturers to comply with standards based on a fleet average. EPA has, however, established corporate average emissions standards in other contexts (e.g., heavy-duty engine standards). The voluntary National LEV program uses a fleet average standard to help determine manufacturer compliance with the requirements. Also, compliance with CARB's LEV and proposed LEV-II standards is accomplished on a corporate average basis. CARB and the National LEV program limit this flexibility somewhat, however, by specifying a limited number of NMOG emission standards to which individual vehicle models may be certified. NOx emission standards are directly tied to the specific NMOG emission standard selected for each vehicle model (i.e., TLEV, LEV, ULEV).

The flexibility of a corporate average standard can encourage the design and production of vehicles with advanced emission controls, as manufacturers can receive credit for the additional emission reductions provided by vehicles certified to more stringent emission levels. Such controls could include such vehicular concepts as gasoline-electric or diesel-electric hybrid vehicles, electric vehicles and fuel-cell powered vehicles, as well as more optimal combinations of emission control technologies. It can also facilitate the application of more stringent standards, because the flexibility of averaging across a product line would allow manufacturers to meet an overall corporate standard even when their highest emitting vehicles are less able to meet a stringent standard (e.g., uniform standards for gasoline and diesel powered vehicles).

An additional advantage of averaging and trading systems generally is that they achieve the target emission reductions at the lowest cost without EPA having to consider the incremental cost-effectiveness of controls on a vehicle model basis. Without some form of averaging and trading, it is possible that none of the three options for dealing with LDTs discussed above would minimize the cost of the emission reductions that could be achieved.

E. Extended Useful Life and Other Options to Improve In-Use Performance

Section 202(i) of the CAA, in directing EPA to perform this Tier 2 study, also directed EPA to consider extending the useful lives of the LDV and LDT emission standards. EPA believes that the purpose of this direction was to emphasize Congress' focus on the reduction of emissions in-use and not simply by vehicle prototypes or by vehicles at low-mileage. Congress extended the useful life of the LDV standards from 50,000 miles to 100,000 miles in the 1990 amendments to the CAA, but clearly believed that more might be needed to ensure appropriate in-use emissions performance.

This focus on in-use emissions is consistent with EPA's focus on ensuring that its emission standards produce emission reductions in the real world. Examples of this include the onboard diagnostic (OBD) system requirements, the cold temperature CO standards and the supplemental Federal Test Procedure (FTP) standards addressing off-cycle vehicle operation. Extending the useful life of the emission standards is one possible approach to improving in-use emissions performance. Such an extension would be consistent with marketplace trends toward longer actual vehicle lives, as was mentioned in *Chapter III. Assessment of Air Quality Need.* California has also proposed to extend the useful life of its Phase 2 LEV emission standards for LDVs and LDTs to 120,000 miles from their current 100,000 miles. (EPA's useful life requirements for its LDT standards is already 120,000-130,000 miles.)

EPA has not performed assessments of either the cost or in-use emission benefits of this option. The in-use emission benefits will clearly depend on the baseline level of in-use emission deterioration, which is being updated in MOBILE6. EPA plans to perform these economic and environmental assessments to determine if this (or any related) options should be included in the proposed Tier 2 standards.

F. Test Fuel Specifications

In order for EPA emission standards to produce emission reductions in the real world, the test procedures used to determine compliance with these standards must be representative of real world conditions. If test procedures are not representative, increases in emissions in use may not be discovered in testing and thus mask substantially higher in-use emissions. That was EPA's rationale behind the recent development of emission standards and test procedures for:

1) Aggressive driving patterns and air conditioning use;
2) Evaporative, running loss and resting loss emissions at high ambient temperatures and during extended, multi-day soaks; and
3) CO emissions at low ambient temperatures.

Regarding test fuels, while the current specifications for the certification gasoline are sufficiently broad to include a wide range of gasoline, including average or typical gasolines, in practice the composition of the fuel used for emission testing (commonly referred to as Indolene) has not been representative of commercial gasoline. In particular, both the olefin and sulfur contents of Indolene tend to be quite low relative to average commercial gasolines. For example, Indolene tends to have a sulfur content of 100 ppm or less, while commercial gasoline averages more than 300 ppm sulfur, with some commercial fuels containing 1000 ppm sulfur.

As mentioned above in *Chapter III. Assessment of Air Quality Need* and *Chapter IV. Assessment of Technical Feasibility*, sulfur reduces catalyst efficiency significantly, particularly for LEVs. Differences between sulfur levels in test and in-use fuels could have a significant impact on the in-use emissions performance of motor vehicles. EPA believes that it is very important that the fuel used for emission testing of Tier 2 vehicles be as representative as possible of commercial gasoline. EPA will review its test procedures to consider more representative fuel in testing. An issue with respect to sulfur would be whether the emission test fuel sulfur level should be matched to that of the average commercial gasoline, the worst commercial gasoline, or the average or worst gasoline sold in a smaller geographic area, such as the worst ozone nonattainment areas.

G. Gasoline Sulfur

As discussed briefly in *Chapter IV. Assessment of Technical Feasibility,* the presence of sulfur in gasoline has an impact on the performance of catalysts and thus on tailpipe emissions. As catalyst technology has progressed, the sensitivity of catalyst efficiency to sulfur has appeared to increase. Because the impact of gasoline sulfur on emissions is significant, EPA has started to analyze the issues associated with a gasoline sulfur control program. This section discusses the issues that must be considered when evaluating the cost and cost-effectiveness of reducing gasoline sulfur. A more complete evaluation of these issues, including analyses of the data available to date, is presented in a recently released Staff Paper on gasoline sulfur.[22] This Staff Paper is part of EPA's commitment to undertake a parallel process, involving all interested stakeholders, to determine appropriate measures to address the impact of sulfur on vehicle performance.

[22] "EPA Staff Paper on Gasoline Sulfur Issues," EPA-420-R-98-005, May 1998.

Sulfur occurs naturally in crude oil and ends up in gasoline as a result of the refining process. Currently, the sulfur content of both conventional and reformulated gasolines (RFG) sold nationally average over 300 ppm. Maximum levels may get as high as 1000 ppm in conventional gasoline and 500 ppm in reformulated gasoline (RFG). California gasoline averages around 30 ppm, and is capped at a maximum 80 ppm. The oil industry estimates that beginning in the year 2000, Federal Phase II RFG will average around 150 ppm sulfur, due to the NOx reduction requirements for summertime RFG.

The amount of sulfur in the gasoline from any refinery depends on a number of factors, including the amount of sulfur in the crude oil used and the extent and type of processing within the refinery. Typically, sulfur in gasoline is reduced by hydrotreating certain hydrocarbon streams. Hydrotreating requires hydrogen, which must be produced in the refinery or purchased at substantial cost. The cost to the refining industry of reducing gasoline sulfur levels is impacted by a number of variables and assumptions made when analyzing a control strategy, including:

- Where would low sulfur gasoline be required? The size of the program (national, regional, local) will have an impact on the net costs to the refining industry. This is due to many factors, including the varied capabilities of refineries located in different parts of the country to produce low sulfur gasoline.

- What level of sulfur reduction would be required? Reduction of sulfur in gasoline requires the installation of capital equipment as well as increased operating expenses. The greater the level of reduction, the greater cost per gallon.

- Is the inhibiting effect of sulfur on motor vehicle catalysts reversible? An irreversible emissions impact could mean that motor vehicles that are fueled with a high sulfur gasoline may have permanent catalyst damage, and thus higher emissions, even when refueled on very low sulfur gasoline. This would be a reason for considering a national sulfur reduction program. In contrast, if the effect were largely or wholly reversible upon the use of low sulfur gasoline, sulfur reductions could be targeted to those areas most in need of emission reductions.

- Does sulfur affect motor vehicle onboard diagnostic systems? If high sulfur levels are found to cause substantial interference with OBD systems, causing illumination of the malfunction indicator lights, it may be more appropriate to establish a national sulfur program to avoid such illumination. However, if such illuminations are not substantial or can be remedied through other means, than a national approach to sulfur control may not be needed to appropriately address the problem.

There is great interest in determining whether changes can be made to catalyst designs and fuel control strategies of those vehicles that prove to be highly sensitive to sulfur inhibition.

Presently, there are no catalyst designs that are fully sulfur tolerant. Data from laboratory, engine dynamometer testing and vehicle fleet studies show that all automotive catalyst designs have some inhibition in performance resulting from sulfur. EPA will investigate the latest work being done on the developing of sulfur resistant catalyst technology and attempt to determine the feasibility, cost, and effectiveness of such technology.

There are many other factors that impact the final costs to the refining industry and additional issues to be considered. For example, the availability of new technologies to reduce gasoline sulfur at less cost than current technologies will make it more attractive and less burdensome to the industry to reduce sulfur levels. However, some refiners, particularly small refiners, may have difficulty in raising the capital necessary to invest in new equipment. All of these issues and concerns will be addressed during the processes of evaluating Tier 2 standards and sulfur control programs.

Appendix A

FUTURE OZONE NONATTAINMENT PROJECTIONS

A. EPA Ozone NAAQS Analyses

In support of the revised ozone NAAQS, EPA projected future ambient ozone levels in 2010 to estimate the level of potential non-compliance with the revised standards. Baseline ozone air quality concentrations in 2010 were estimated using a Regional Oxidant Model (ROM) extrapolation methodology. Baseline in this context means that the only emission controls presumed were those already implemented or mandated by the CAA, with two exceptions. These two exceptions were that the projections also included the emission reductions from both the anticipated regional NOx emission control in the eastern U.S., which is discussed in the next section, and the National LEV program.

ROM air quality modeling information for 1990 and 2007 was used in combination with 1990 historical ozone air quality monitoring data to develop baseline 2007 ozone air quality for the 37 Eastern U.S. states. For the Western U.S. states, EPA reviewed available urban scale modeling. The 2007 predicted air quality was then adjusted to account for 2007/2010 emissions inventory differences and additional ozone modeling and monitoring information (1993 - 1995 Aerometric Information Retrieval System (AIRS) monitoring data, ROM and Urban Air Shed Modeling-V (UAM-V) air quality modeling data) to yield 2010 baseline ozone air quality data. Because this future air quality is based on counties with monitoring data in 1990, the centroid model was used to develop air quality for non-monitored counties through geographic interpolation. Initial nonattainment areas for alternative ozone standards were identified based on these modeled values for counties with ozone monitors in 1990. At the national level, nine areas were predicted to be in initial nonattainment of the current one-hour ozone standard; an additional 10 areas (19 total areas) were predicted to violate the 0.08 ppm NAAQS. These 19 areas encompassed a total of 203 counties with a total 1990 population of 78.6 million people.

B. OTAG SIP Call NPRM Analyses

EPA's proposed OTAG SIP Call relied in part upon ozone modeling performed as part of the OTAG process. The OTAG process projected ozone levels in calendar year 2007. This year reflects the ozone NAAQS attainment deadline for a number of the severe ozone nonattainment areas within the OTAG region. OTAG performed baseline modeling which projected ozone levels in 2007 based on estimates of emissions which would occur in 2007 under established control programs. Included in the 2007 baseline are the net effects of growth and specific control programs prescribed by the 1990 Clean Air Act Amendments. The control measures included in the 2007 baseline are listed in Table A-1.

Table A-1. OTAG 2007 Baseline Control Measures	
Emission Source Category	Control Programs
UTILITY	Title IV Controls (phase 1 & 2 for all boiler types) 250 Ton PSD and NSPS RACT & NSR in non-waived nonattainment areas (NAAs)
NON-UTILITY POINT/OTHER AREA	RACT at major sources in non-waivered NAAs 250 Ton PSD and NSPS CTG & Non-CTG RACT at major sources in NAAs & in Ozone Transport Region
OTHER AREA	Two Phases of Consumer & Commercial Products & One Phase of Architectural Coatings State 1 & 2 Petroleum Distribution Controls in NAAs Autobody, Degreasing & Dry Cleaning Controls in NAAs
NONROAD MOBILE	Federal Phase II Small Engine Standards Federal Marine Engine Standards Federal HDV (>= 50 hp) Standards - Phase I Federal RFG II (statutory and opt-in areas) 9.0 RVP maximum elsewhere in OTAG
HIGHWAY MOBILE	Tier 1 LDV and HDV Standards Federal RFG II (statutory and opt-in areas) High Enhanced I/M (serious and above areas) Low Enhanced I/M for rest of OTR Basic I/M (mandated areas) Clean Fuel Fleets (mandated areas) 9.0 RVP maximum elsewhere in OTAG On-board Vapor Recovery

Overall, OTAG estimated that domain-wide emissions of NOx in the 2007 baseline are approximately 12 percent lower than 1990 while emissions of VOC are approximately 20 percent lower. The procedures for developing both 1990 and 2007 baseline inventories are described by Pechan.[1] The key findings from comparing the model predictions for the 2007 baseline to the 1990 base case scenario are:

- ozone levels are generally reduced across most of the region, including nonattainment areas;
- some increases in ozone are predicted in areas where higher economic growth is expected to occur, especially in the South;
- ozone levels aloft along regional "boundaries" are reduced, but average concentrations above 100 ppb and peak concentrations above 120 ppb are still predicted on several days; and

[1] *See* OTAG Emission Inventory Final Technical Report.

- ozone concentrations above the 1-hr and/or 8-hr NAAQS may still occur in the future under similar meteorological conditions in many of the counties currently violating either or both of these NAAQS.

The 2007 baseline emissions were reduced in an initial set of sensitivity modeling performed to assess several broad strategy-relevant issues. All of these model runs involved "across-the-board" emissions reductions (i.e., no source category-specific reductions). Based upon the findings of the sensitivity runs, OTAG subsequently developed and simulated source-specific region-wide control strategies in two rounds of modeling. These strategies were derived from a range of control measures applied to individual source categories of VOC and NOx. The controls were grouped into various levels of relative "stringency". The round-1 and round-2 modeling consisted of strategies that contained various combinations of controls from the least to most stringent for each source category.

The round-1 modeling was a "bounding analysis" with runs that ranged from the lowest level of control on all source categories (Run 1) to the highest level of control on all sources (Run 2). Runs 3 and 4b were included to isolate the effects of the most stringent OTAG controls on utilities only, versus this level of control on the other source categories. In the round-2 modeling, eight runs were simulated to examine the relative benefits of progressively increasing the level of control on utilities, under two alternative levels of control applied to area, nonroad and mobile sources.

The findings from the round-1 and round-2 OTAG strategy modeling that are particularly relevant are:

- Clean Air Act programs will likely provide a reduction in ozone concentrations in many nonattainment areas; however, some areas currently in nonattainment will likely remain nonattainment in the future and new 8-hr nonattainment and/or maintenance problem areas may develop as a result of economic growth in some areas;
- NOx reductions from elevated and low-level sources are both beneficial when considered on a regional basis; and,
- Further mitigation of the ozone problem will require regional NOx-oriented control strategies in addition to local VOC and/or NOx controls necessary for attainment in individual areas.

Because it models a regional control strategy for NOx similar to that proposed in the Ozone SIP Call NPRM and because control strategies for other sources are generally kept at Clean Air Act Amendment levels, Run 5 of the Round 2 modeling is a principal focus for both the current OTAG analyses and the Tier 2 air quality assessment. The controls applied in Run 5 (shown in Table A-2) are believed to be the best current representation in the available modeling of the most likely scenario of control strategies to be in place in the time frame of potential Tier 2 emission standards.

Table A-2. OTAG Round 5 Control Strategies		
	Mandated CAA controls	Additional controls
UTILITY	* Acid Rain Controls (Phase 1 & 2 for all boiler types) * RACT & NSR in nonattainment areas (NAAs) without waivers	* OTC NOx MOU (Phase II) * 85 percent reduction from 1990 rate or rate-base of 0.15 lb/mbtu for all units, whichever is less stringent
NON-UTILITY POINT SOURCES	* RACT at major sources in NAAs without waivers * 250 Ton PSD and NSPS (not modeled) * NSR in NAAs without waivers (not modeled) * CTG & Non-CTG RACT at major sources in NAAs & throughout OTC * New Source LAER & Offsets for NAAs (not modeled) * "9 percent by 99" ROP Measures (VOC or NOx) for serious and above areas	* NOx Controls based on cost per ton of reduction (< $1,000 per ton) - primarily low NOx burner technology
NONROAD MOBILE	* Federal Phase II Small Engine Standards * Federal Marine Engine Standards * Federal HDV (>=50 hp) Standards-Phase 1 * Federal RFG II (statutory and opt-in areas) * 9.0 RVP maximum elsewhere in OTAG * "9 percent by 99" ROP Measures(VOC or NOx) for serious and above areas	* Federal Locomotive Standards (including rebuilds) * HD Engine 4 g/bhp-hr Standard
HIGHWAY MOBILE	* Tier 1 light-duty and heavy-duty Standards * Federal reformulated gas (RFG II) (statutory and opt-in areas) * High Enhanced I/M (serious and above areas) * Low Enhanced I/M for rest of OTR * Basic I/M (mandated areas) * Clean Fuel Fleets (mandated areas) * 9.0 RVP maximum elsewhere in OTAG * On board vapor recovery	* National LEV * Heavy Duty Vehicle 2 g/bhp-hr Standard * Federal Test Procedure (FTP) revisions * "9 percent by 99" ROP Measures (if substitute for VOC) in serious and above areas
OTHER AREA SOURCE CONTROLS	* Two Phases of Consumer & Commercial Products & One Phase of Architectural Coatings * Stage 1 & 2 Petroleum Distribution Controls-NAAs * Autobody, Degreasing & Dry Cleaning Controls in NAAs * "9 percent by 99" ROP Measures (VOC or NOx)(serious and above areas)	None

In support of the proposed OTAG SIP Call, EPA developed procedures to project which counties would exceed the 1-hour and 8-hour ozone standards in 2007 based on 1993-1995 ambient ozone data and the benefits of future emission controls included in the OTAG strategy Run 5. This approach involved several steps that apply the ozone reductions predicted for Run 5 to ambient data to estimate the expected impacts of this strategy on ozone concentrations. In summary, the steps are:

(1) Calculate 1-hour and 8-hour ozone design values based on 1993-1995 monitoring data for each county;
(2) Use 1990 and 2007 OTAG model predictions in a relative sense to estimate the change in 1-hour and 8-hour ozone levels expected as a result of the controls in Run 5;
(3) Apply the predicted percentage changes in 1-hour and 8-hour ozone to the 1993-1995 ambient design values to adjust these values to reflect the effects of the controls in Run 5; and
(4) Compare the adjusted design values to the level of the 1-hour or 8-hour NAAQS (i.e., 0.12 and 0.08 ppm) to estimate whether the Run 5 controls would provide for attainment.

This analysis projected that 12 counties in the OTAG area would be expected to remain in nonattainment with the ozone 1-hour standard after the Run 5 emission controls were applied described above. These nonattainment counties contribute, in whole or in part, to eight specific Consolidated Metropolitan Statistical Areas (CMSA) or Metropolitan Statistical Areas (MSA). For the purpose of this study, a list of metropolitan areas that contain counties projected to have an 1-hour ozone nonattainment problem was developed and is presented in Table A-3, along with the 1990 populations of the metropolitan areas. Clearly, while the Run 5 controls are projected provide significant air quality benefits, the areas remaining in nonattainment and the populations affected are significant.

Table A-3. Areas and Populations Projected to Exceed 1-Hour and 8-Hour Ozone NAAQS after Run 5 Controls (1990 Census Populations)		
Metropolitan Area	1-Hour	8-Hour
Atlanta, GA MSA	2,959,500	2,959,500
Baton Rouge, LA MSA	528,261	— *
Charlotte-Gastonia-Rock Hill, NC-SC MSA	—	1,162,140
Chicago-Gary-Kenosha, IL-IN-WI CMSA	—	8,239,820
Cincinnati-Hamilton, OH-KY-IN CMSA	—	1,817,569
Dallas-Fort Worth, TX CMSA	—	4,037,282
Houston-Galveston-Brazoria, TX CMSA	3,731,029	3,731,029
Manitowoc County, WI (not assigned to a metropolitan area)	82,507	82,507
Memphis, TN-AR-MS MSA	—	1,007,306
Milwaukee-Racine, WI CMSA	1,607,183	1,607,183
Nashville, TN MSA	—	985,026
New Haven-Bridgeport-Stamford-Waterbury-Danbury, CT NECMA	1,631,864	1,631,864
New York-No. New Jersey-Long Island, NY-NJ-CT-PA CMSA	17,830,586	17,830,586
Philadelphia-Wilmington-Atlantic City, PA-NJ-DE-MD CMSA	5,893,019	5,893,019
Pittsburgh, PA MSA	—	2,394,811
St. Louis, MO-IL MSA	—	2,492,348
Washington-Baltimore, DC-MD-VA-WV CMSA	6,726,395	6,726,395
Total Population	40,990,344	62,598,385

* Not projected to be in nonattainment with the NAAQS

EPA also projected that 39 counties in the OTAG area would be expected to remain in nonattainment with the ozone 8-hour standard after the Run 5 emission controls were applied described above . These nonattainment counties contribute, in whole or in part, to specific Consolidated Metropolitan Statistical Areas or Metropolitan Statistical Areas. The resulting list of metropolitan areas that contain counties projected to have an 8-hour ozone nonattainment problem are presented in Table A-3, along with the population of the metropolitan area. As can be seen, there are significantly more projected ozone nonattainment areas in 2007 under the 8-hour ozone standard than under the 1-hour standard.

At least three caveats apply to these ozone projections. First, these projections are based on air quality data from 1993-95. The data from this period will not be the basis for nonattainment area designations for the 8-hour ozone standard. Those designations will be made in the 2000 time frame and will be based on the most recent air quality data available at that time (1997-1999). Therefore, while EPA expects that the vast majority of new counties will attain as a result of the SIP Call regional NOx control strategy, the number of new counties may be more or less than the number indicated above.

Second, the estimate of which counties will attain the 8-hour standard is based on the specific assumptions made by the OTAG Group in Run 5. Because the NOx controls proposed by EPA in the OTAG NPRM are similar but not identical to those contained in Run 5, the estimate may change when this rule is final and implemented. Therefore, the estimate of which areas will attain the standards through the final regional NOx strategy may be higher or lower than the number indicated above.

Third, the OTAG model only covers the eastern two-thirds of the nation. Specifically, Arizona and California are not covered. Phoenix and numerous areas in California were projected in the ozone NAAQS rule to exceed the 1-hour and 8-hour ozone standards in the future. While the SIP Call analysis can be considered an update of the ozone NAAQS rule analysis for the eastern portion of the nation, only the NAAQS rule addressed the western part of the U.S. Therefore, the NAAQS rule projections for the west need to be added to those of the SIP Call analysis in order to provide a complete projection of future ozone nonattainment in the U.S.

C. Future Particulate Matter Nonattainment Projections

EPA recently established new NAAQS for particulate matter (62 FR, July 18, 1997). EPA revised the existing NAAQS for inhalable PM (PM_{10}) and established new NAAQS for fine PM ($PM_{2.5}$). The existing NAAQS for PM_{10} were a 24-hour average of 150 $\mu g/m^3$, with one exceedance allowed per year, and an annual average of 50 $\mu g/m^3$. The annual average standard was left unchanged, as was the numerical level of the 24-hour standard. However, compliance with the 24-hour standard was changed from allowing one exceedance per year to a 99th percentile level (i.e., a statistical analysis of daily PM_{10} levels must show that the 99th percentile is 150 $\mu g/m^3$ or less).

The new NAAQS for $PM_{2.5}$ have a similar statistical form as the new NAAQS for PM_{10}. The differences are that the 24-hour standard is 50 $\mu g/m^3$ (98% percentile level), while the annual standard is 15 $\mu g/m^3$.

In support of these new NAAQS, EPA projected future ambient PM levels in 2010 to estimate the level of potential non-compliance with the new standards. Baseline 2010 emissions were projected from 1990 by application of sector-specific growth factors (e.g., 1995 Bureau of Economic Analysis estimates) and Clean Air Act-mandated controls to 1990 base year emissions. Total 2010 emissions of VOC, NOx, SO_2 and secondary organic aerosols were estimated to decrease from 1990 levels; however, emissions of primary PM_{10} and $PM_{2.5}$ were estimated to increase.

In addition to the 2010 projection just described, future ambient PM levels were also estimated after implementation of a more stringent SO_2 emission cap on utilities. This emission cap is 60% more stringent than the Phase 2 SO_2 cap under Title IV of the CAA. For the purpose of the Tier 2 study, the most relevant projections are those prior to implementation of the SO_2

emission cap. The more stringent SO_2 emission cap on utilities has not yet been implemented, and PM emission reductions from the Tier 2 standards could reduce the need for further PM emission control envisioned in the SO_2 cap.

Baseline particulate matter air quality concentrations in 2010 were estimated using the Phase II Climatological Regional Dispersion Model (CRDM). Initial nonattainment counties (i.e., prior to application of the more stringent SO_2 emission cap on utilities) for each PM_{10} and $PM_{2.5}$ standard were estimated based on these modeled air quality predictions for counties with PM monitors during 1993 - 1995. At the national level, 45 counties were estimated to be in nonattainment of the current PM_{10} standards (50/150- 1 expected exceedance) in 2010, while only 11 counties were estimated to be in initial nonattainment of the revised PM_{10} standards (50/150- 99th percentile). Before applying the more stringent SO_2 emission cap, 102 counties were estimated to violate the selected $PM_{2.5}$ standard (15/65- 98th percentile) incremental to the current PM_{10} standard in 2010.

For the purpose of the Tier 2 study, EPA developed the following list of counties expected to exceed the revised PM_{10} NAAQS. Metropolitan areas are shown when the definition of the current PM_{10} nonattainment area consists of the entire CMSA or MSA. Only the county is shown when the definition of the current PM_{10} nonattainment area only consists of a county.

Table A-4. Projected PM_{10} Nonattainment Areas in 2010 and their 1990 populations

State	N/A Area or County	1990 Population
California	Imperial Valley	109,303
	Inyo County	18,281
	Kings County	101,469
	San Bernardino County	1,418,380
	San Diego County	2,498,016
	South Coast Air Basin	12,443,900
Iowa	Scott County	150,973
Montana	Park County	14,484
Pennsylvania	Pennsylvania County	1,585,577
Texas	Harris County	2,818,199
Washington	Walla Walla County	48,439
Total		22,899,442

D. Revisions to MOBILE5b

This section describes the four types of modifications which were made to MOBILE5b. A more detailed description of the modifications made to MOBILE5b can be found in a separate EPA report.[2]

1. In-use Emission Deterioration Rates

Vehicle emissions in-use tend to increase with vehicle age and mileage. This is referred to as emission deterioration and is often a significant factor in determining the in-use emissions performance of real-world vehicles.

When MOBILE5 was developed, the latest model vehicles in-use were certified to the Tier 0 emission standards. The projections of in-use emission deterioration in MOBILE5 for these vehicles were based on the testing of in-use Tier 0 vehicles which hd not yet been through an inspection and maintenance (I/M) program. The rate of emission deterioration for Tier 1 vehicles and LEVs had to be projected from emission data on Tier 0 vehicles.

In the process of developing MOBILE6, EPA is reviewing in-use emission data from both later Tier 0 vehicles and Tier 1 vehicles. EPA believes that the in-use emission deterioration rates proposed for these vehicles (and LEVs) in MOBILE6 will be significantly lower than those in MOBILE5. However, the proposed MOBILE6 estimates were not available at the time of this analysis. In lieu of the MOBILE6 estimates, rates, basic emission rates (zero-mile emissions plus emission deterioration rates) from California's CALIMFAC model were substituted into MOBILE5. The CALIMFAC basic emission rates are much lower than those in MOBILE5 and are consistent directionally with the basic emission rates expected to be used in MOBILE6.

The basic emission rates from CALIMFAC without I/M are plotted versus mileage in Figures A-1 through A-3, along with those from MOBILE5.

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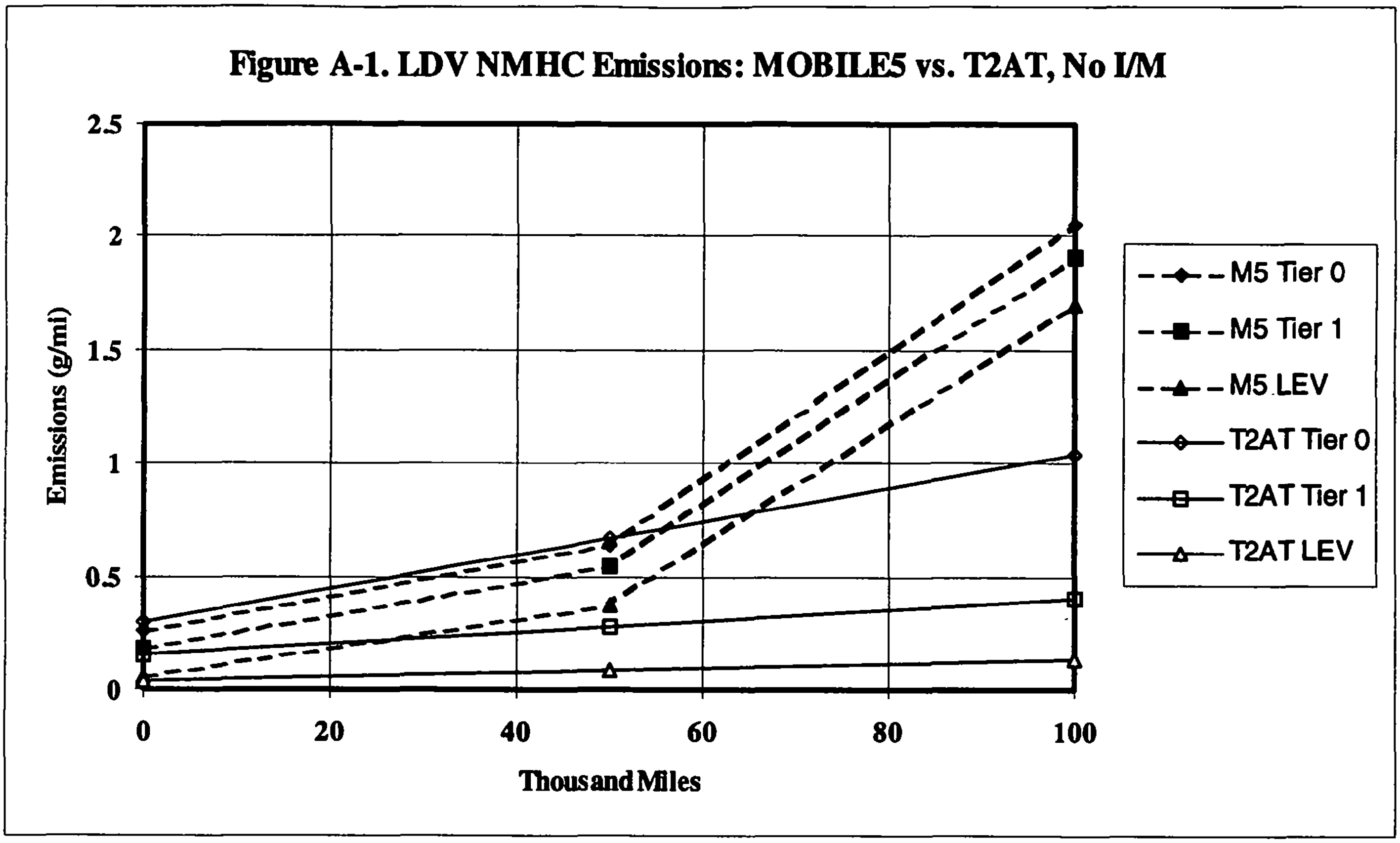
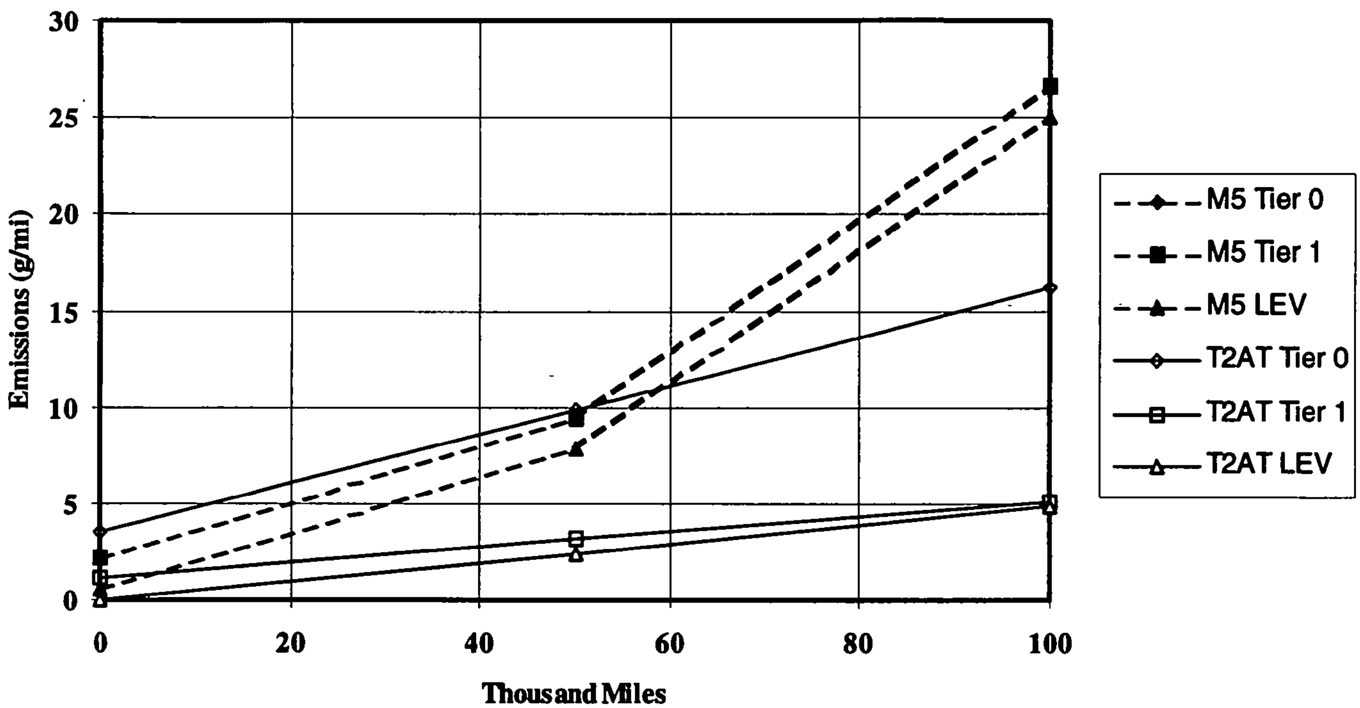
[2] "Methodology for Modifying MOBILE5b in the Tier 2 Study", EPA Technical Report, April, 1998.

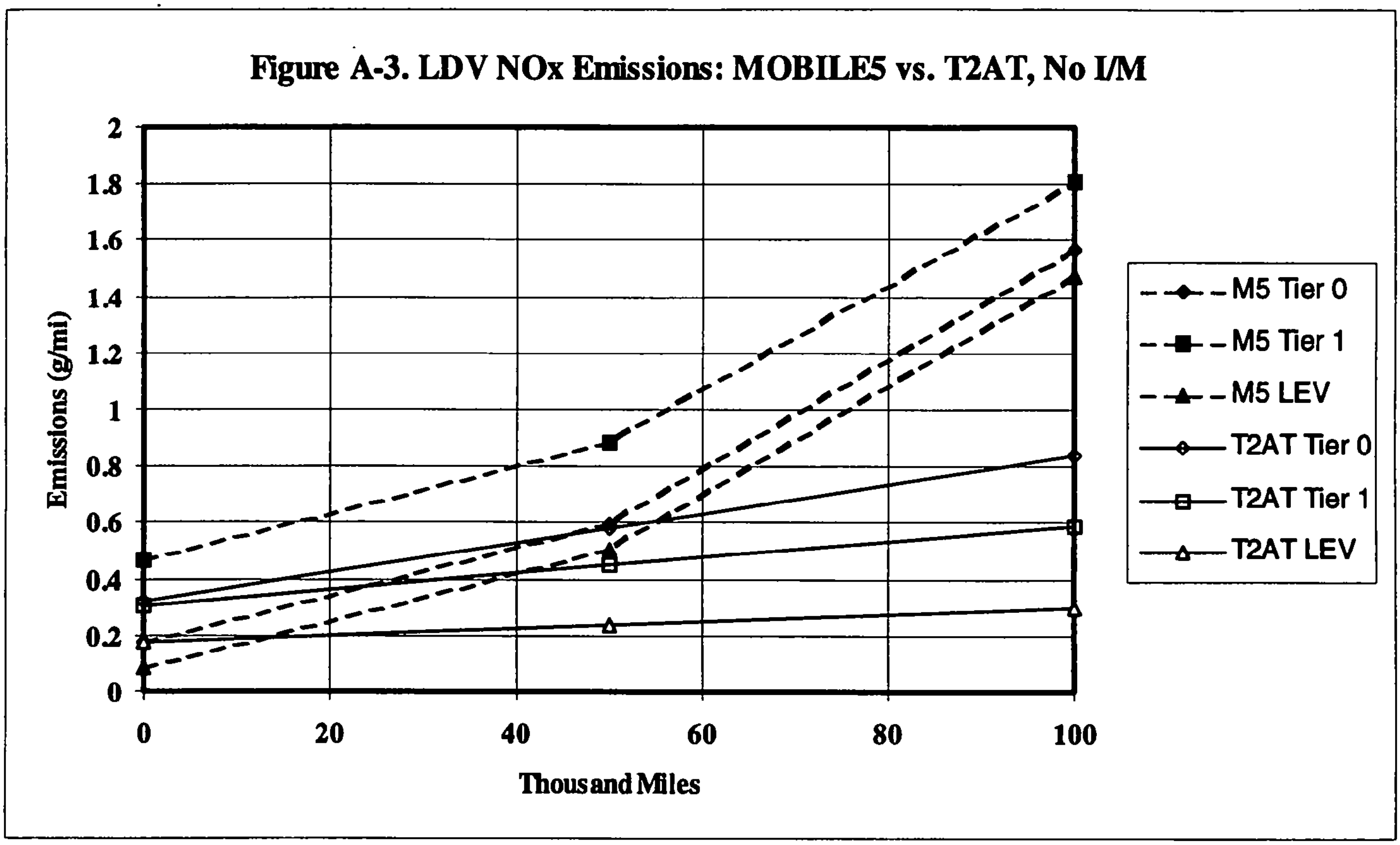


Note: "T2AT" means "Tier 2 Analysis Tool."

Figure A-2. LDV CO Emissions: MOBILE5 vs. T2AT, No I/M



Note: "T2AT" means "Tier 2 Analysis Tool."



Note: "T2AT" means "Tier 2 Analysis Tool."

As can be seen, the CALIMFAC rates for all three types of vehicles are much lower than those from MOBILE5. The emission factors with I/M are not shown. With I/M, however, the CALIMFAC emission factors for Tier 0 and 1 vehicles are still much lower than those from MOBILE5. With enhanced I/M, the CALIMFAC and MOBILE5 emission estimates for LEVs are much more similar.

2. Off-cycle Emission Effects and Their Control

"Off-cycle" emissions are those that occur during driving conditions not included in EPA's historical certification driving cycle, the LA-4 cycle. EPA promulgated emission standards for two specific off-cycle driving conditions in 1996, which will be effective starting with the 2000 model year. These two conditions are aggressive driving (high speeds and high accelerations) and driving with the air conditioner on. California implemented similar standards for vehicles meeting its LEV standards.

MOBILE5 does not include estimates of these off-cycle emissions, nor the effectiveness of off-cycle emission standards. MOBILE6 will contain such factors. However, as was the case for emission deterioration, the MOBILE6 off-cycle emission factors are not yet available. For this study, EPA developed estimates of these off-cycle emissions both before and after the implementation of off-cycle emission standards. These factors are based on EPA emission data obtained for the development of MOBILE6, as well as EPA and CARB analyses associated with their respective off-cycle emission rules. These off-cycle factors are in the form of multiplicative factors which are applied to the basic emission rates in MOBILE5b, which are based on emission measurements over the LA-4 cycle.

The off-cycle factors for a typical high ozone day are shown in Table A-5.

Table A-5. Off-Cycle Adjustment Factors

	HC	CO	NOx
Prior to Off-Cycle Emission Control			
Tier 0 LDV/LDT1	1.24	2.24	1.70
Tier 0 LDT2/LDT3/LDT4	1.21	2.10	1.68
Tier 1 & LEV LDV/LDT1	1.78	2.90	1.75
Tier 1 & LEV LDT2/LDT3/LDT4	1.73	2.73	1.74
After Off-Cycle Emission Control			
Tier 1 LDV/LDT1	1.07	1.39	1.22
Tier 1 LDT2/LDT3/LDT4	1.08	1.46	1.20
LEV LDV/LDT1	1.03	1.46	1.11
LEV LDT2/LDT3/LDT4	1.04	1.48	1.10

As can be seen, the off-cycle emission factors for all types of vehicles prior to off-cycle emission control are quite substantial for all three pollutants. The implementation of off-cycle emission controls dramatically reduces the impact of these off-cycle conditions on in-use emissions. The EPA off-cycle standards eliminate roughly 70-90% of the off-cycle emission impact for Tier 1 vehicles. The CARB off-cycle standards eliminate roughly 80-95% of the off-cycle emission impact for LEVs.

3. Effect of Fuel Sulfur on Emissions

In the Draft Study, EPA presented an estimate of the effect of sulfur on emissions from LEVs based on data gathered from MOBILE5b and the CALIMFAC model. The analysis has subsequently been revised, and was included in EPA's Staff Paper on Gasoline Sulfur Issues. For completeness, a summary of that analysis is presented here.

Two test programs evaluating the impact of sulfur on emissions from LEVs and ULEVs were recently completed by the Coordinating Research Council (CRC) and the auto industry.[3] The CRC program consisted of twelve 1997 LEV passenger cars, representing six different

[3] CRC is a research organization sponsored by automobile manufacturers and oil companies.

models from five different vehicle manufacturers. The vehicles were tested with fuel sulfur levels of 40 (the baseline level to represent California certification and in-use fuel sulfur levels), 100, 150, 330, and 600 ppm. The remaining properties of the fuel represented national averages. The vehicles were first tested in an "as received" condition (average vehicle mileage of 10,000 miles) and with the catalysts bench-aged to simulate 100,000 miles of operation (although the oxygen sensors were original, low mileage sensors).

The auto industry testing was performed by members of the American Automobile Manufacturers Association (AAMA) and the Association of International Automobile Manufacturers (AIAM). The AAMA/AIAM program consisted of 13 production and production-intent LEV and ULEV LDVs and eight LEV and ULEV light-duty trucks (LDTs). A total of ten vehicle manufacturers participated in the program. The vehicles were tested at the same sulfur levels as the CRC program. The other fuel properties were those of California Phase II certification fuel. All vehicles were equipped with aged components to simulate 100,000 miles.

The results of the CRC and AAMA/AIAM programs have been combined.[4] Table A.6 shows the percent increase in emissions associated with increasing the fuel sulfur level from 40 ppm to 150 ppm and 330 ppm, respectively, for both LDVs and LDTs designed to meet the LEV and ULEV standards. Only the 100,000-mile data are presented. For comparison, the sulfur impact on Tier 0 and Tier 1 vehicles, obtained from data generated by the Auto/Oil Air Quality Improvement Research Program ("Auto/Oil") is also presented in the table.

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[4] The test results from each pair of LEVs in the CRC test program were averaged and assumed to represent a single vehicle. The results for vehicles from the same model line and certified set of emission standards which were tested in both the CRC and AAMA/AIAM test programs were also averaged and assumed to represent a single vehicle.

Table A.6 Increase in Emissions with Fuel Sulfur Increases from Baseline (40 ppm) for LEVs and ULEVs (LDVs and LDTs) and Older Vehicles [Source: CRC and AAMA/AIAM Test Programs]						
Pollutant	NMHC		CO		NOx	
Sulfur, ppm	150 ppm	330 ppm	150 ppm	330 ppm	150 ppm	330 ppm
LEV and ULEV, LDVs and LDTs						
All LDV/LDT1	26.7%	43.0%	58.0%	75.8%	65.7%	136%
All LDT2/LDT3	23.0%	26.4%	12.5%	31.2%	33.7%	65.5%
Tier 1 LDVs						
Normal Emitters	---	20.9%	---	21.1%	---	13.6%
Tier 0 LDVs and LDTs						
Normal Emitters	5.9%	16.3%	5.7%	15.8%	6.4%	13.8%
High Emitters	-0.6%	-1.6%	4.7%	12.9%	2.8%	7.6%

These results indicate that emission control technologies being utilized on current LEV and ULEV LDVs are, on average, much more sensitive to sulfur than Tier 0 or Tier 1 technology. For example, the percentage increases in NOx emissions for LEV and ULEV LDVs are roughly 10 times greater than those for Tier 0 and 1 vehicles. Emissions from the LEV and ULEV LDTs are also more sensitive than the Tier 0 and Tier 1 vehicles tested earlier, but to a much lesser extent. The LDTs had a higher level of base emissions on 40 ppm sulfur fuel, which may indicate that their technology differs less dramatically from the Tier 1 LDVs tested earlier.

4. Characterization of the LDT Fleet

Sales of LDTs have risen steadily over the past several years, significantly increasing market share and VMT relative to LDVs. As a result, the default VMT mix in MOBILE5 under-predicts the LDT share of both the in-use vehicle fleet and VMT. EPA is updating these factors in MOBILE6, but the updated estimates are not yet available. Therefore, an update of the contribution of LDTs to the in-use vehicle fleet and VMT was developed for the purpose of this study.

The basis for the updated LDT registration and mileage distributions, as well as the LDT fraction of LDV and LDT VMT, was a recently developed EPA model characterizing the growth in LDT sales and usage (hereafter referred to as the VMT model).[5] The LDT VMT fraction was

[5] German, John., "VMT and Emission Implications of Growth in Light Truck Sales", EPA Report.

further sub-divided between LDT1/LDT2s and LDT3/LDT4's using data from R.L. Polk.[6] As the VMT model also produced a revised registration distribution for LDVs, this was included in the modified MOBILEE5b model, as well.

The resultant VMT fractions for LDVs and LDTs are shown in Table A-7 below.

Table A-7. Light Duty VMT Fractions						
Year	LDV		LDT1/2		LDT3/4	
	MOBILE5b	T2AT	MOBILE5b	T2AT	MOBILE5b	T2AT
2000	0.614	0.503	0.191	0.257	0.086	0.122
2005	0.600	0.450	0.197	0.293	0.087	0.139
2007	0.595	0.435	0.199	0.303	0.087	0.144
2010	0.589	0.415	0.201	0.317	0.088	0.150
2015	0.581	0.398	0.204	0.328	0.089	0.156
2020	0.575	0.391	0.207	0.333	0.089	0.158

As can be seen, the fraction of LDV VMT in the modified MOBILE5b model is much lower than was projected in MOBILE5b. (The emission factors from the modified MOBILE5b model are labeled "T2AT" in the chart, which is an acronym for Tier 2 Analysis Tool.) For example, by 2020, LDVs will represent less than 40% of combined LDV/LDT driving, while MOBILE5b projected nearly 60%. Most of the growth is in the LDT1 and LDT2 group, which includes small pick-ups, minivans and smaller sport utility vehicles. (MOBILE5b refers to this group as LDT1, while MOBILE5b refers to the LDT3/LDT4 group as LDT2. This is a carryover from the Tier 0 standards, where there were only two categories of LDTs.)

Directionally, the changes in VMT mix and age distribution serve to increase overall emission inventory estimates relative to MOBILE5b. Since trucks have higher emission rates than vehicles and older trucks are dirtier than newer trucks, an increase in truck VMT and a flattened age distribution will increase the relative contribution of older trucks to overall inventory.

3. LDV/LDT Emissions in Urban Areas

The above modifications to MOBILE5b affect the projected emission factors of in-use light-duty vehicles. While the ultimate goal of this section is to project future motor vehicle emission inventories and ozone impacts, it is first useful to compare the gram per mile emission estimates from MOBILE5b with and without the above four modifications. Once these emission factors have been determined, they can be combined with local estimates of VMT for the various

[6] Accurex Environmental Corporation, "Update of Fleet Characterization Data for Use in MOBILE6", Report for EPA, May 1997.

vehicle classes to develop local emission inventories. From there, airshed models can be used to assess ozone impacts.

To do this, EPA used MOBILE5b with and without the above mentioned modifications to estimate motor vehicle emission factors for three sets of local vehicle-related control strategies. These three control strategies generally represent the range of controls projected to be implemented in future ozone nonattainment areas in the OTAG and EPA regional ozone modeling described above. The three strategies are:

1) Federal Phase 2 RFG, National LEV program in 1997 and high enhanced I/M (applies to 2007 ozone nonattainment areas in the Northeast, such as New York City, Philadelphia, Washington, D.C. and Baltimore)

2) Federal Phase 2 RFG, National LEV program in 2001 and high enhanced I/M (applies to 2007 ozone nonattainment areas such as Houston, Chicago, Phoenix, Milwaukee, and Dallas)

3) Conventional gasoline, National LEV program in 2001 and high enhanced I/M (applies to 2007 ozone nonattainment areas, such as Atlanta, St. Louis, Charlotte, Nashville, Pittsburgh, and Cincinnati)

In addition to these three control scenarios, EPA evaluated a fourth scenario indicative of an area that is both in attainment with the ozone NAAQS and outside of any ozone transport region. Such an area would not have an I/M program, nor require RFG. However, they would be part of the National LEV program, as this program applies in all states outside of California which have not adopted the California LEV program.

MOBILE5b was run for calendar year 2007 for each of these four scenarios to approximate the emission factors which were used in the regional ozone modeling. Vehicle speed was assumed to be 24.7 miles per hour (the approximate average in-use speed) and the ambient temperature range was assumed to be 72-96 °F.

These emission factors only approximate those used in the regional ozone modeling. In the regional ozone modeling, separate MOBILE5 runs were made for each hour of a several day ozone transport period. Each run had different ambient temperatures and may have used varying vehicle speeds and VMT distributions across vehicle classes. Duplicating this methodology was beyond the scope of this study and, in any event, should not have affected the overall outcome of the comparison being made herein. The modifications to MOBILE5b described in the previous section apply at all vehicle speeds and ambient temperatures. Therefore, the relationship between the MOBILE5b and modified MOBILE5b exhaust emission factors should not be sensitive to the vehicle speed or ambient temperatures used in the model. The specific inputs used here were selected to be representative of average in-use vehicle speeds in urban areas and temperatures occurring on high ozone days.

Both MOBILE5b and the modified MOBILE5b were run for a range of calendar years (2000, 2005, 2007, 2010, 2015 and 2020) in order to indicate the change in emissions over time, as well as a direct comparison against MOBILE5b in 2007. Figures A-5 through A-7 present the NOx, NMHC, and CO emission factors for MOBILE5b with and without the modifications for the Northeast emission control scenario for all vehicles. The curves shown in the figures are simple least-square polynomial regressions. The MOBILE5b/Modified MOBILE5b comparison is very similar for the other two control scenarios which include high enhanced I/M.

Figure A-5. Fleet-wide NMHC Emissions OTR NLEV with RFG and I/M

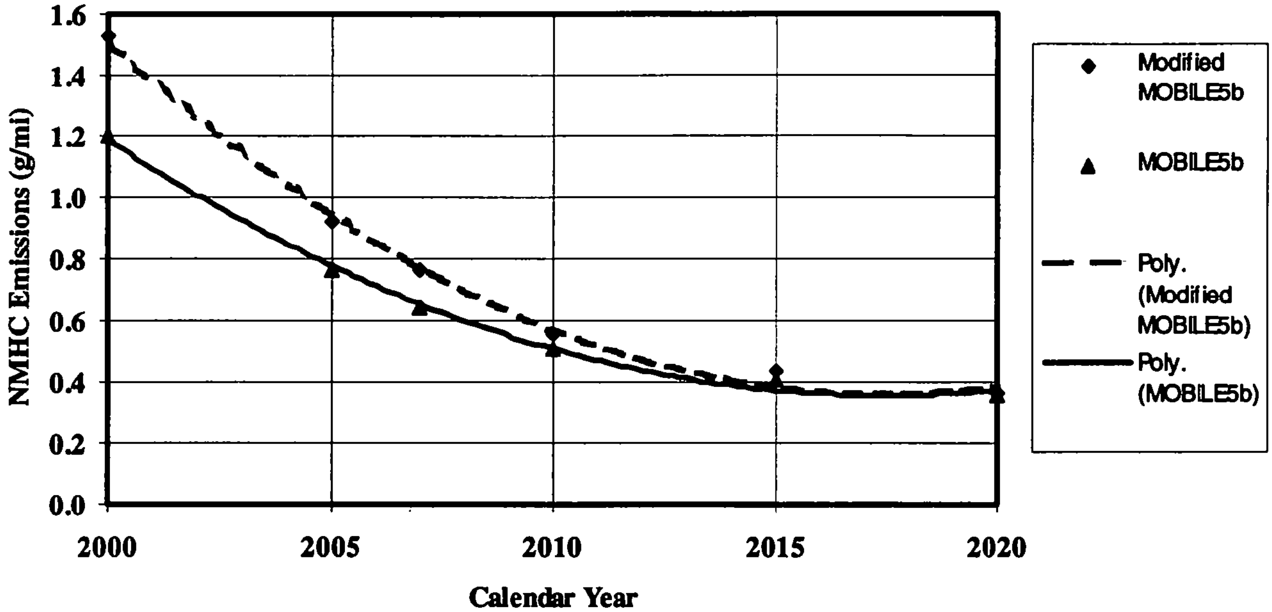
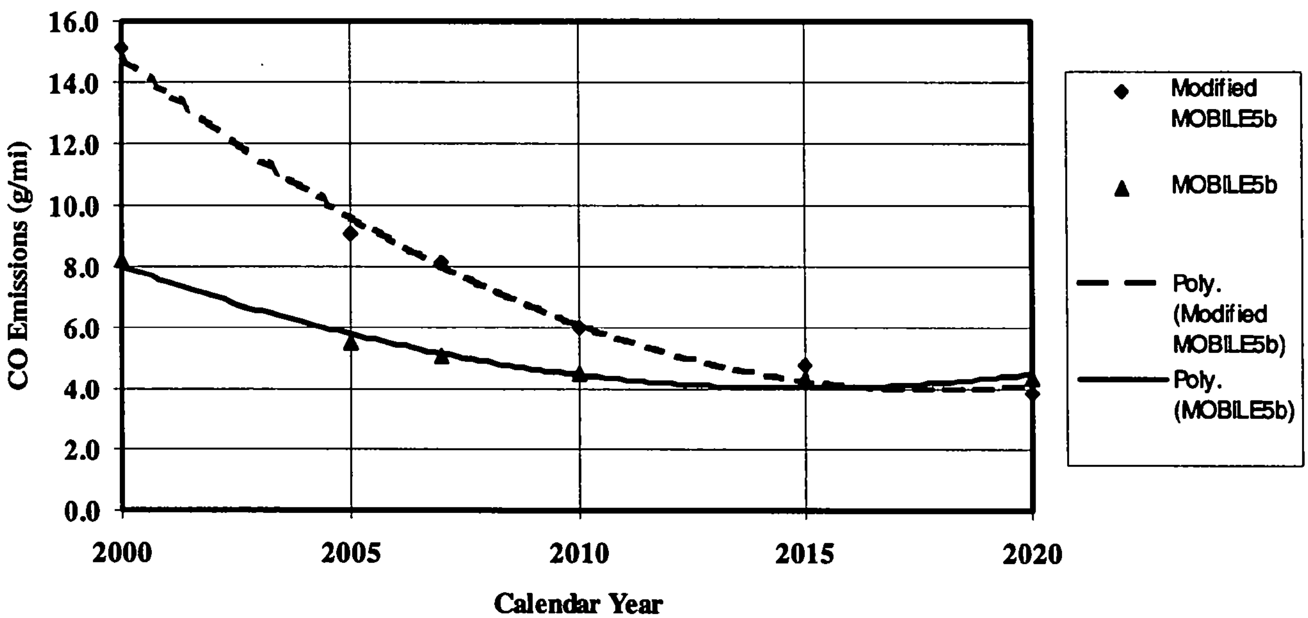
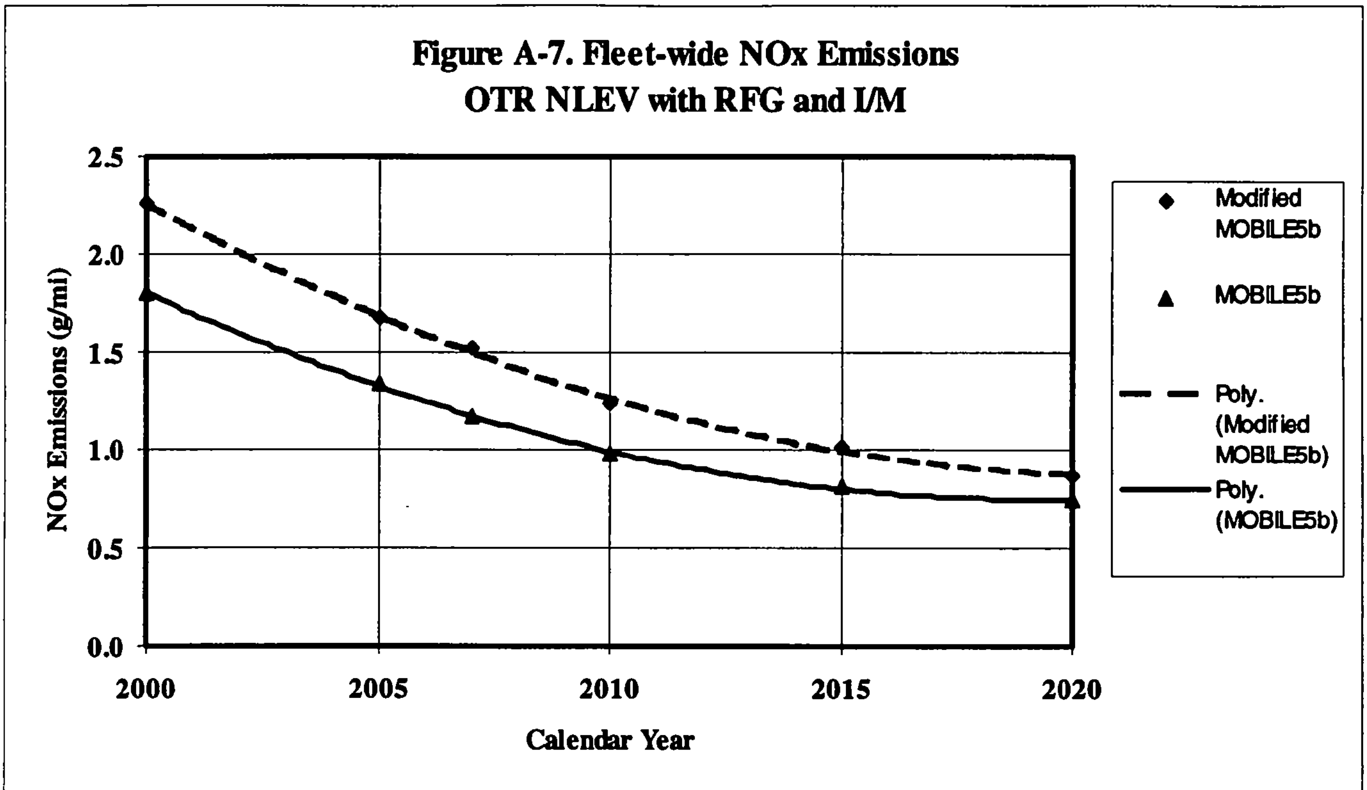


Figure A-6. Fleet-wide CO Emissions OTR NLEV with RFG and I/M





As can be seen, the modified MOBILE5b model projects that NOx, NMHC, and CO emissions in 2007 will be roughly 18-15%, 61% and 30% higher, respectively, than as projected by MOBILE5b. This indicates that the effects of adding off-cycle emissions, an increased sulfur sensitivity for LEVs and updated LDT usage is greater than the effect of lower in-use deterioration rates.

Figures A-8 through A-10 present the emission factors for typical ozone attainment areas outside of ozone transport regions using both the modified and unmodified MOBILE5b models. In this case, the modified MOBILE5b model projects higher CO and NOx emission factors and lower NMHC emission factors in 2007 than MOBILE5b. NOx emissions with the modified MOBILE5b model fall below those of MOBILE5b after roughly 2008. The primary reason for the differences between this case and the Northeast ozone nonattainment case is the absence of high enhanced I/M in this case. The MOBILE5b projections for LEV emissions are very sensitive to the presence of high enhanced I/M. With high enhanced I/M, LEVs essentially meet their emission standards in-use. Without this degree of I/M, LEVs emit substantially above their standards.

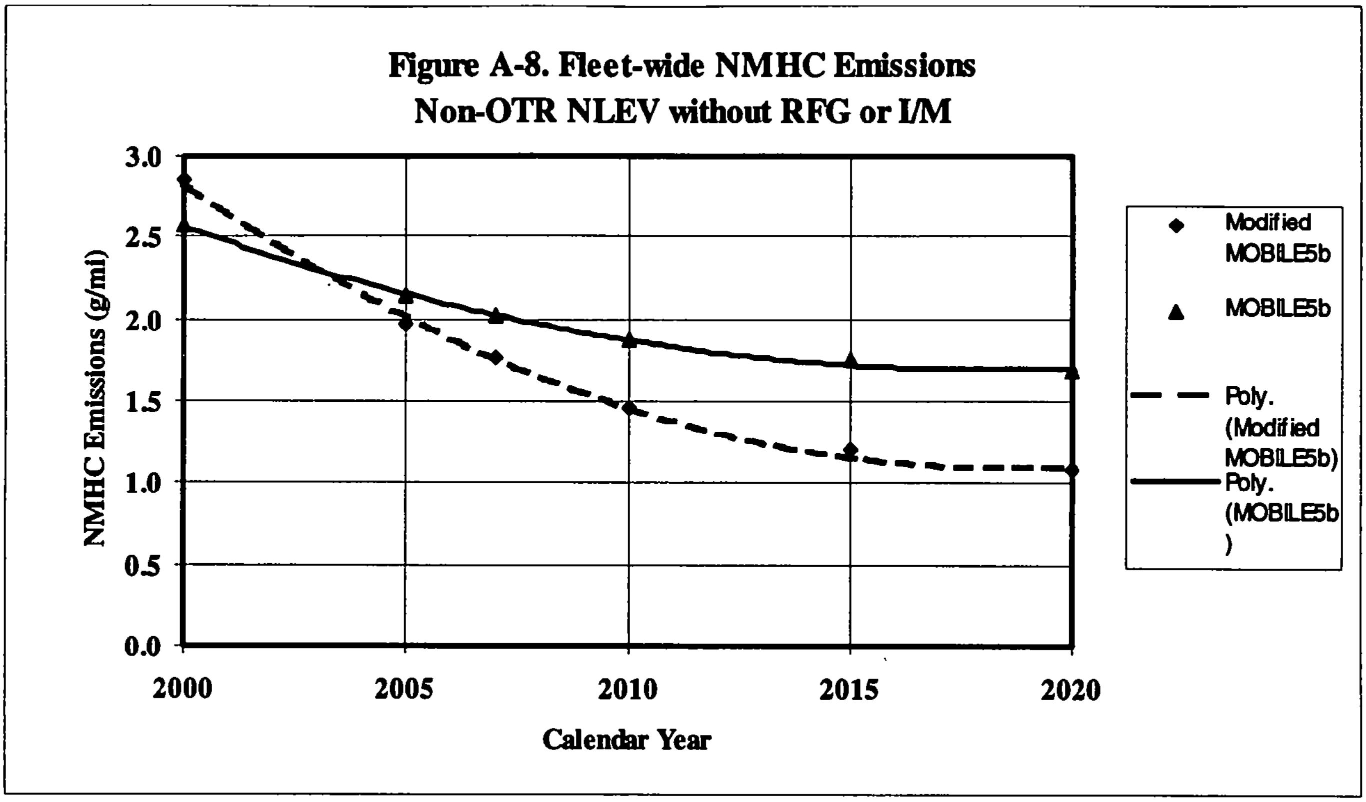


Figure A-8. Fleet-wide NMHC Emissions
Non-OTR NLEV without RFG or I/M
NMHC Emissions (g/mi)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
2000
2005
2010
2015
2020
Calendar Year
Modified MOBILE5b
MOBILE5b
Poly. (Modified MOBILE5b)
Poly. (MOBILE5b
)

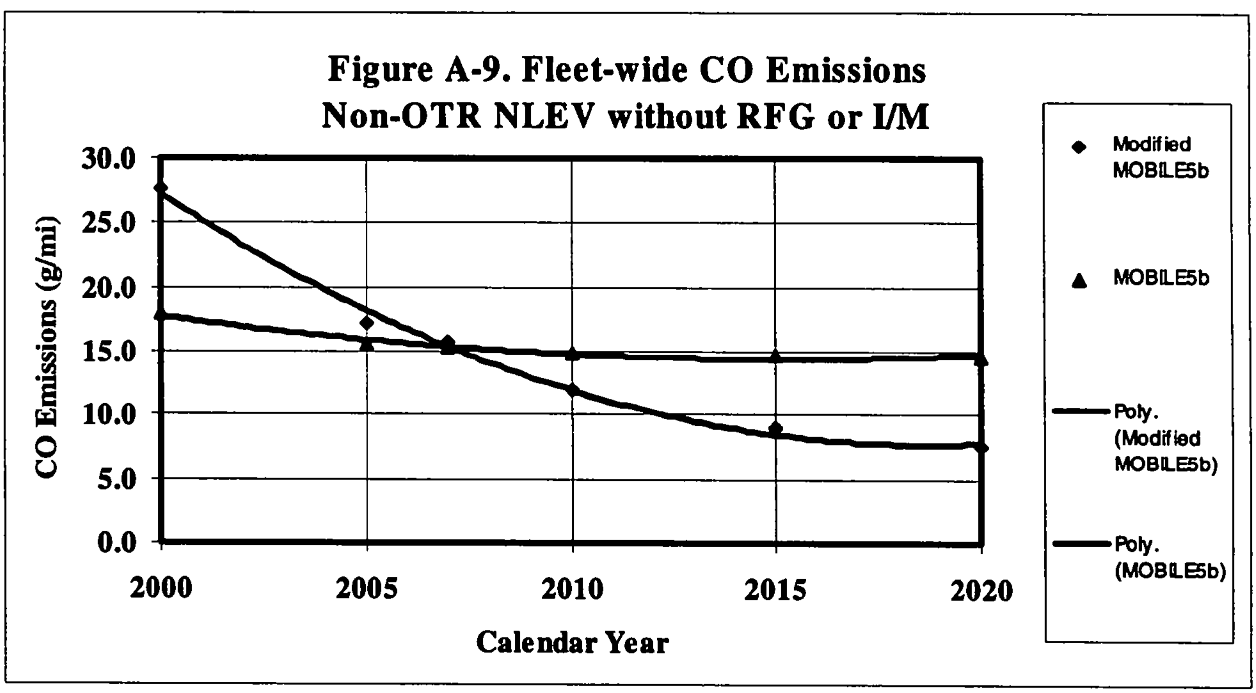
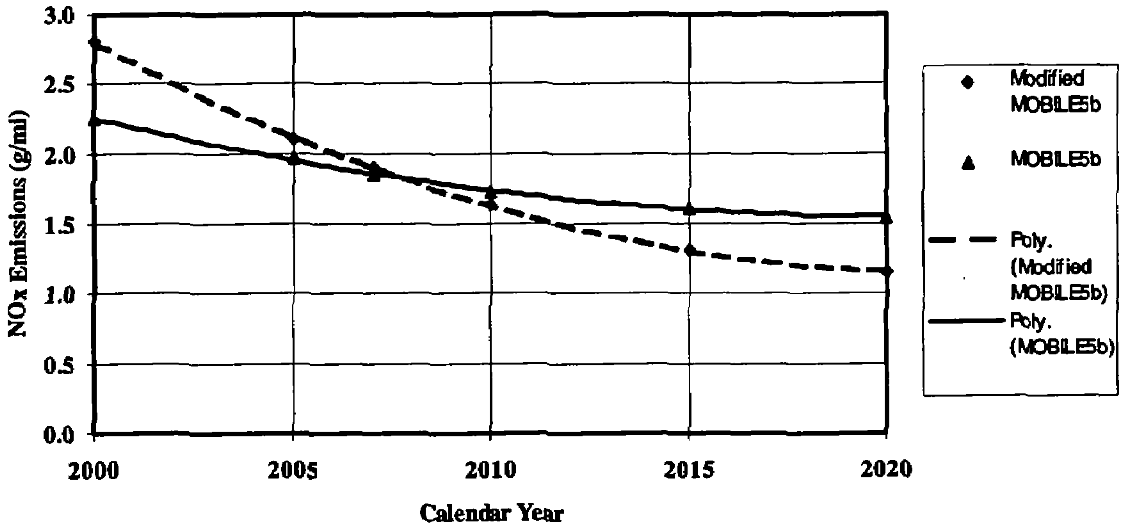


Figure A-9. Fleet-wide CO Emissions
Non-OTR NLEV without RFG or I/M
CO Emissions (g/mi)
30.0
25.0
20.0
15.0
10.0
5.0
0.0
2000
2005
2010
2015
2020
Calendar Year
Modified MOBILE5b
MOBILE5b
Poly. (Modified MOBILE5b)
Poly. (MOBILE5b)

Figure A-10. Fleet-wide NOx Emissions
Non-OTR NLEV without RFG or I/M



With the lower in-use emission deterioration rates included in the modified MOBILE5b model, LEVs emit very close to their emission standards even without I/M. Therefore, there is very little difference in projected LEV emissions between the modified and unmodified MOBILE5b models when high enhanced I/M is present. In this case, the off-cycle, sulfur and truck-related effects dominate and emissions are higher with the modified model. However, without high enhanced I/M, the modified model projects much lower in-use emission deterioration rates for LEVs. These lower deterioration rates dominate the other factors and the modified model projects lower in-use emissions.

Thus, the modified MOBILE5b model projects higher emissions in ozone nonattainment areas which were projected to have high enhanced I/M in the OTAG modeling and sometimes lower, sometimes higher emissions elsewhere. One of the findings of OTAG was that a given amount of emissions occurring in or near the ozone nonattainment area had a greater ozone impact than emissions further upwind. The impact of upwind emissions was found to be significant, just not as significant as local emissions on a ton for ton basis. Given that emissions in the local ozone nonattainment areas are projected to be much higher with the modified model, the projected ozone levels in these areas are also likely to be higher, despite the possibility of lower emissions upwind.

An important factor in determining the impact of Tier 2 emission standards on ambient ozone is the relative contribution of LDV and LDT emissions in urban ozone nonattainment areas. The LDV/LDT inventory contribution will be estimated here for four such areas: New York City, Chicago, Atlanta, and Charlotte. The first three areas represent the three greatest ozone air quality challenges in the eastern U.S. according to the OTAG ozone modeling. Charlotte represents a smaller, but growing area with a growing ozone problem.

VOC and NOX emission inventories for high ozone days were developed as part of the OTAG modeling. Total emission inventories are available, as well as those for all on-road motor vehicles. However, separate emission inventories for light and heavy-duty vehicles were not made available. Because the VMT distributions by vehicle class used in the ozone modeling may have differed from the MOBILE5b default assumptions used in the previous section, separating the emissions from the two basic types of vehicles is not straightforward.

EPA estimated separate light and heavy-duty emissions in each of the four areas using a five step process.

1) A fleet-wide NOX emission factor applicable to the OTAG modeling of each specific area was determined by dividing the motor vehicle emission inventory by the total VMT used in developing the OTAG inventory.
2) The split between light and heavy-duty VMT was estimated by adjusting this ratio until the fleet-wide NOX emission factor from the unmodified MOBILE5b run described above matched that determined in step 1. In performing this match-up, the distribution of light-duty VMT between LDVs, LDT1s, and LDT2s was held constant, as was the distribution of heavy-duty VMT between gasoline and diesel vehicles.
3) Updated fleet-wide NMHC and NOX emission factors were estimated using the vehicle-class specific emission factors from the modified MOBILE5b runs and the VMT distributions determined in step 2.
4) Updated motor vehicle emission inventories were estimated by multiplying the OTAG inventories by the ratio of the fleet-wide emission factors determined in step 3 to the original OTAG emission factor estimated in step 1.
5) The LDV/LDT emission inventories were derived from the total motor vehicle inventories using the vehicle-class specific emission factors from the modified MOBILE5b model and the VMT distributions by vehicle class from step 2.

The results of this analysis for the four cities are shown in Tables A-8 through A-10. Emission inventories are shown for both light-duty and all motor vehicles. These are shown based on MOBILE5b both with and without modification. Also shown are total VOC, CO and NOX emission inventories from all sources. The non-motor vehicle emissions were taken directly from the OTAG Round 2 Run 5 emission inventories. As the non-motor vehicle CO emission inventories were not available from OTAG, these are not shown below.

Table A-8. VOC EMISSIONS - OTAG RUN 5 (tons/day)				
Metropolitan Area	Emission Model	Motor Vehicles		All Sources
		Light-Duty	Total	
Atlanta, GA MSA				
	MOBILE5b	65	92	389
	Modified MOBILE5b	81	109	406
Charlotte-Gastonia-Rock Hill, NC-SC MSA				
	MOBILE5b	33	58	235
	Modified MOBILE5b	42	67	243
Chicago-Gary-Kenosha, IL-IN-WI CMSA				
	MOBILE5b	107	146	908
	Modified MOBILE5b	137	176	938
New York-N. New Jersey-Long Island, NY--NJ-CT-PA CMSA				
	MOBILE5b	170	225	1,361
	Modified MOBILE5b	219	273	1,410

Table A-9. CO EMISSIONS - OTAG RUN 5 (tons/day)				
Metropolitan Area	Emission Model	Motor Vehicles		All Sources
		Light-Duty	Total	
Atlanta, GA MSA				
	MOBILE5b	591	815	-
	Modified MOBILE5b	1,160	1,384	-
Charlotte-Gastonia-Rock Hill, NC-SC MSA				
	MOBILE5b	204	340	-
	Modified MOBILE5b	399	535	-
Chicago-Gary-Kenosha, IL-IN-WI CMSA				
	MOBILE5b	946	1,220	-
	Modified MOBILE5b	1,781	2,054	-
New York-N. New Jersey-Long Island, NY--NJ-CT-PA CMSA				
	MOBILE5b	1,742	2,164	-
	Modified MOBILE5b	3,238	3,660	-

Table A-10. NOX EMISSIONS - OTAG RUN 5 (tons/day)				
Metropolitan Area	Emission Model	Motor Vehicles		All Sources
		Light-Duty	Total	
Atlanta, GA MSA				
	MOBILE5b	78	165	394
	Modified MOBILE5b	131	218	447
Charlotte-Gastonia-Rock Hill, NC-SC MSA				
	MOBILE5b	27	81	185
	Modified MOBILE5b	45	100	203
Chicago-Gary-Kenosha, IL-IN-WI CMSA				
	MOBILE5b	144	263	877
	Modified MOBILE5b	243	362	977
New York-N. New Jersey-Long Island, NY--NJ-CT-PA CMSA				
	MOBILE5b	257	437	1,204
	Modified MOBILE5b	430	611	1,377

The next two tables show the light-duty motor vehicle contribution to total emissions and the total motor vehicle contribution to total emissions for VOC and NOX.

Table A-11. VOC EMISSIONS - CONTRIBUTION TO TOTAL EMISSIONS (%)			
Metropolitan Area	Emission Model	Motor Vehicles	
		Light-Duty	All
Atlanta, GA MSA			
	MOBILE5b	17%	24%
	Modified MOBILE5b	20%	27%
Charlotte-Gastonia-Rock Hill, NC-SC MSA			
	MOBILE5b	14%	25%
	Modified MOBILE5b	17%	27%
Chicago-Gary-Kenosha, IL-IN-WI CMSA			
	MOBILE5b	12%	16%
	Modified MOBILE5b	15%	19%
New York-N. New Jersey-Long Island, NY--NJ-CT-PA CMSA			
	MOBILE5b	12%	17%
	Modified MOBILE5b	16%	19%

Table A-12. NOX EMISSIONS - CONTRIBUTION TO TOTAL EMISSIONS (%)			
Metropolitan Area	Emission Model	Motor Vehicles	
		Light-Duty	All
Atlanta, GA MSA			
	MOBILE5b	20%	42%
	Modified MOBILE5b	29%	49%
Charlotte-Gastonia-Rock Hill, NC-SC MSA			
	MOBILE5b	15%	44%
	Modified MOBILE5b	22%	49%
Chicago-Gary-Kenosha, IL-IN-WI CMSA			
	MOBILE5b	16%	30%
	Modified MOBILE5b	24%	37%
New York-N. New Jersey-Long Island, NY--NJ-CT-PA CMSA			
	MOBILE5b	21%	36%
	Modified MOBILE5b	31%	44%

As can be seen, based on MOBILE5b, the light-duty contribution to total emissions ranges from 12-17% for VOC and 15-21% for NOx. The light-duty contribution to total emissions increases to 15-20% for VOC and 22-31% for NOx based on the modified MOBILE5b model. The contribution of all motor vehicles is roughly 4-11% higher for VOC and 14-29% higher for NOx. The contribution of LDVs and LDTs to these emission inventories is substantial and merits further control, to the degree that it is cost effective.

Appendix B

VEHICLE TECHNOLOGY

The purpose of this appendix is to further expand upon the technical discussion that was presented in *Chapter IV. Assessment of Technical Feasibility.* For the purpose of continuity, some of same text from Chapter IV is included in this appendix.

Vehicle exhaust emissions can be reduced by a number of technologies, but the most potential for improvement exists in reductions to base engine-out emissions, improvement in air-fuel ratio control, better fuel delivery and atomization, and continued advances in exhaust aftertreatment.

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. It is important to point out that the use of all of the following technologies is not required to further reduce emissions. 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. As noted above, with the exception of a few technologies, many of these technologies are used in some Tier 1, TLEV, LEV and ULEV vehicles already in production.

In order to have a more complete understanding of the latest technologies, including the state of development and current production usage of the various technologies, EPA contracted Energy and Environmental Analysis, Inc. (EEA), to conduct a study evaluating the potential availability of emission control technology to meet more stringent emission standards for light-duty vehicles and light-duty trucks. The report is titled "Benefits and Cost of Potential Tier 2 Emission Reduction Technologies." EPA also used as references, the staff report on "Low-Emission Vehicle and Zero-Emission Vehicle Program Review," published in November 1996 by the State of California Air Resources Board (CARB), and information from the Manufacturers of Emission Controls Association (MECA) and numerous vehicle manufacturers.

A. 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 HCs 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 listed under 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.

1. Combustion Chamber Design

Unburned fuel can be trapped momentarily in crevice volumes (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" (distance between the top of the piston and the first piston ring). The reduction of crevice volume is especially preferable for vehicles with larger displacement engines, since they typically produce greater levels of engine-out HC than smaller displacement engines. EEA estimates the emission reduction of reducing crevice volumes in the combustion chamber to 3%-10% for NMHC, with negligible effects for NOx.

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 surface finishes for 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. According to CARB and EEA, virtually all vehicles meeting LEV and ULEV standards, will have to incorporate features to reduce oil consumption.

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. 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. According to CARB and EEA, most vehicle manufacturers 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").

2. 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[7] percent, resulting in a 15 to 20 percent reduction in engine-out NOx emissions.

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

CARB projects that all LEV and ULEV vehicles will utilize electronic EGR systems in lieu of mechanical systems. 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.

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

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

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[7] 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.

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 estimate emission reductions of 3%-10% 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 CARB to become even more common. CARB also projects that in order to meet LEV and ULEV standards, more vehicles will have to make improvements to the induction system, including the use of variable valve timing.

4. 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, 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 provide reduced emissions. CARB and EEA project that vehicle manufacturers will continue to incorporate leak-free exhaust systems as emission standards become more stringent.

B. Improvements in Air-Fuel Ratio Control

Modern three-way catalysts require the air-fuel ratio (A/F) to be as close to stoichiometric operation (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% deviation in A/F or roughly ± 0.15). Contemporary vehicles have been able to maintain stoichiometric, or very close to it, operation 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, 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.

1. 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.

2. 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 what the magnitude of the A/F actually is. 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. Some vehicle manufacturers have estimated emission reductions attributed to the use of a UEGO sensor to be 5% for NMHC and 23%-35% for NOx. EPA feels that the estimate for NMHC seems low.

Although some manufacturers are currently using UEGO sensors, EEA claims 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 have a thimble design that is considerably lighter than conventional designs. The main benefits are faster heat-up time and sensor response.

3. 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 that amount of fuel delivered. 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. Some vehicle manufacturers have estimated the potential emission reductions for individual cylinder A/F control to 22% for NMHC and 3% for NOx, but EPA feels that based on conversations with other manufacturers, that the estimate for NOx reduction is too low.

4. 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 drive ability and an increase in NOx emissions.

Adaptive transient fuel control is already being utilized by some manufacturers across their entire product line. CARB expects the use of adaptive transient fuel control to be incorporated in virtually all LEVs and ULEVs.

5. 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 drive ability 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 in 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.

C. 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.

1. 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 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.

2. 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. EEA estimates a reduction in NMHC emissions of 3%-10% for air-assisted fuel injection. At least three manufacturers are currently using air-assisted injection in some of their models.

D. 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 (Pd) 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.

1. 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 is likely to continue as the noble metal of choice for close-coupled applications and will start to see more use in 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 EEA, it is expected that Pd catalysts will be used in the close-coupled locations while conventional or tri-metal (Pd/Pt/Rh) catalysts will continue to be used in underfloor applications. Some manufacturers have suggested that they will use Pd/Rh in lieu of tri-metal or conventional Pt/Rh catalysts for underfloor applications. As palladium technology continues to improve, it may be possible for a single close-coupled catalyst to replace both catalysts. If fact, at least one vehicle manufacturer currently uses a single Pd-only catalyst for one of their models. According to EEA, new Pd-only catalysts are now capable of withstanding exposure to temperatures as high as 1050°C and, as a result, can be moved very close to the exhaust manifold to enhance catalyst light-off performance.

In addition to reliance on Pd and tri-metal applications, catalyst and vehicle manufacturers have developed "layered" catalysts. Typically, conventional catalysts have a single washcoat layer applied to the catalyst substrate. The washcoat is the material that contains the noble metals and numerous other substances such as base metals, stabilizers, etc. By applying the washcoat in layers (one layer on top of another) and using slightly different washcoat and noble metal formulations for the various layers, manufacturers have found that emissions can be further reduced from single layer applications and, in some cases, reduced significantly.

Manufacturers are developing catalysts with substrates that 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 increase catalyst surface area). The cells are coated with washcoat which contain the noble metals which perform the catalysis on the exhaust pollutants. The greater the number of cells, the more surface area with washcoat that exists, meaning there is more of the catalyst available to convert emissions (or that the same catalyst surface area can be put into a smaller volume). Cell densities of 600 cells per square inch (cpsi) have already been commercialized, and research on 900 cpsi catalysts has been progressing. Typical cell densities for conventional catalysts are 400 cpsi.

The largest source for HC continues to be from cold start operation where the combination of rich A/F operation and the ineffectiveness of a still relatively cool catalyst result in excess HC emissions. One of the most effective strategies for controlling cold start HC emissions is to reduce the time it takes to increase the operating temperature of the catalyst immediately following engine start-up. The effectiveness or efficiency of the catalyst increases as the catalyst temperature increases. One common strategy is to move the catalyst closer to the exhaust manifold where the exhaust temperature is greater (a close-coupled catalyst). Another strategy is to use an electrically-heated catalyst. The EHC consists of a small electrically heated catalyst placed directly in front of a conventional catalyst. Both substrates are located in a single can or container. The EHC is powered by the alternator, or solely from the vehicle's battery, or from a combination of the alternator and battery. The EHC is capable of heating up almost immediately, assisting the catalyst that directly follows it to also heat up and obtain light-off temperature (the catalyst temperature where catalyst efficiency is 50%) quickly. Manufacturers indicate that EHCs will probably only be necessary for a limited number of LEV/ULEV engine families, mostly larger displacement V-8s where cold start emissions are difficult to control. According to EEA, EHCs can reduce NMHC emissions by ≥10% and NOx emissions by 5%-10%, and with continuing improvements in conventional catalyst light-off time, thermal durability, and overall activity, EHCs will become unnecessary for any vehicle to meet the LEV/ULEV standards the next few years.

2. Adsorbers/Traps

Other potential exhaust aftertreatment systems that are used in conjunction with a catalyst or catalysts, are the HC and NOX adsorbers/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 that holds onto the HC. Once the catalyst is warmed up, the trapped HC are released from the adsorption material and directed to the fully functioning downstream three-way catalyst. There are three principal methods for incorporating the 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 trap 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. Several vehicle manufacturers estimate reductions in HC of greater than 10%.

NOX adsorbers have been researched, but, according to EEA, 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.

3. *Secondary Air Injection*

Secondary injection of air into exhaust ports after cold start 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. This is one of the oldest and most established emission control technologies in use, yet over the past 5 to 10 years it has disappeared from most vehicles, except for those with the largest displacement engines. With LEV and ULEV requirements, however, secondary air is again becoming a valuable emission control technology, especially in conjunction with EHC's and adsorbers.

4. 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 for aiding 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. CARB projects that all LEV and ULEV vehicles will utilize insulted exhaust systems, however, EEA claims that as catalyst technology advances and the catalyst is moved closer to the engine, the benefits of insulated exhaust systems diminish rapidly.

E. 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's the software and, more specifically, 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 suggest that manufacturers believe emissions can be further reduced by improving and updating their calibration techniques. As computer technology and software continues to advance, so does the ability of the automotive engineer to use these advancements in ways to better optimize the emission control systems. For example, as processors become faster, it is possible to perform calculations quicker, thus allowing for faster response times for things such as fuel and spark control. 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.

F. Particulate Emissions

Particulate emissions from gasoline-fueled vehicles consists of both carbon- and sulfur-containing compounds. The carbonaceous particulate is produced from both the gasoline fuel and engine lubricating oil. Available data indicate that particulate emissions are highest during cold starts, and lower during hot starts and warmed up operation.

Technology aimed at reducing gaseous NMHC emissions tends to reduce carbonaceous particulate emissions, as well. Examples are modifications to pistons and rings to reduce oil consumption, close-coupled catalysts to reduce cold start emissions, advanced catalyst technology and improved air-fuel ratio control. EPA is not aware of any particulate emission control techniques for gasoline vehicles that is not also being considered for NMHC emission control. As indicated in the previous chapter, the need to reduce NMHC emissions from gasoline vehicles appears to be greater than the need to reduce carbonaceous particulate emissions. Therefore, carbonaceous particulate emission control from gasoline vehicles will likely accompany required NMHC emission control.

The predominant form of sulfur-containing particulate from motor vehicles is sulfuric acid (commonly referred to as sulfate). This sulfate is produced in both the engine and the exhaust system by the oxidation of sulfur dioxide. The amount of sulfate emissions is generally directly proportional to the amount of sulfur in the fuel, though more than 98% of the fuel sulfur is emitted as sulfur dioxide. Sulfate emissions can also be affected by the air-fuel ratio of the engine and the type of catalyst employed. The addition of excess air into an oxidation catalyst can especially increase sulfate emissions. However, the current approach of operating engines as close to stoichiometric as possible coupled with advanced three-way catalysts appears to keep sulfate emissions at very low levels. Therefore, the primary technique available for reducing sulfate emissions is to reduce gasoline sulfur levels.

Diesel particulate emissions also consist of both carbonaceous and sulfate particulate. Unlike gasoline emissions, carbonaceous particulate and NMHC emissions from a diesel engine are not as directly related. Engine-related techniques for reducing particulate emissions include higher fuel injection pressures, electronic engine control of injection timing, rate and duration, and turbo charging/aftercooling. Exhaust aftertreatment techniques include the use of an oxidation catalyst or a trap. The oxidation catalyst primarily reduces the heavy organic portion of the carbonaceous particulate, which usually represents 30-50% of total carbonaceous particulate emissions. Traps can reduce both organic and solid carbon particulate and are capable of controlling 70-90% of carbonaceous particulate emissions.

Diesel-powered LDVs and LDTs produced in the late 1980s were capable of meeting particulate emission standards in the range of 0.1-0.2 g/mi without the use of exhaust aftertreatment. One manufacturer also produced some vehicles equipped with traps. A few light-duty diesel models are currently being certified to the current Tier 1 standards of 0.1-0.12 g/mi without the need for aftertreatment.

Sulfate emissions from a diesel engine form primarily in the engine and generally represent 2% of the total sulfur in the fuel. The primary method to reduce sulfate emissions is to reduce the sulfur content of diesel fuel. The use of an oxidation catalyst or a catalyst-containing trap can increase sulfate emissions.

G. Advanced Technology

Thus far, the technology assessment performed in this study focused on conventional emission control technology for vehicles with gasoline-powered spark ignition engines. There are a number of advanced technologies in the near horizon that may be capable even further reductions in emissions. Examples of such technologies are fuel cells, electric vehicles, and hybrid vehicles.

Fuel cell technology converts such fuels as methanol, natural gas, and gasoline into electrical energy without generating the pollutants associated with internal-combustion engines. A fuel cell is made of a thin plastic film sandwiched between two plates. Hydrogen fuel and oxygen from the air are electrically combined in the fuel cell to produce electricity. Typically, the only by-products are heat and water vapor. A fuel cell coupled with an electrically powered drive-train is essentially a quiet, zero-emissions vehicle.

Electric vehicles use electric motors to power the wheels. The electric motors are powered by packs of batteries stored underneath the vehicle. These vehicles use many newer technologies, such as advanced charging and regenerating systems as well as vehicle structural design. Battery technology, which has been the major technical limitation to date, has been and will be the focus of much developmental work. Improved nickel-metal hydride and lithium ion batteries are two of the battery types being analyzed for use in electric vehicles produced in the near future.

Hybrid vehicles are typically powered by a combination of two powertrain systems. There is usually a low or zero-emitting main powertrain system (e.g., battery-powered electric motors) that powers the vehicle during steady-state operation, when power demands are low. When more power is required to accelerate or drive up a hill, an axillary powertrain, usually a small displacement internal combustion engine, is used. The engine may be diesel-powered, or some derivative thereof, or an alternative-fuel powered spark ignition engine that is low emitting. Because the engine used is small and low polluting, and the majority of operation uses the non-engine powertrain, hybrid vehicles have the potential to be very low emitting vehicles.

Appendix C

EMISSION REDUCTIONS, COSTS AND COST EFFECTIVENESS

The discussion in *Appendix B. Vehicle Technology* demonstrates that there are numerous emission control technologies currently available, and, in many cases in use, capable of reducing emissions below Tier 1 standards. The purpose of this appendix is to expand upon the discussion in *Chapter V. Assessment of Cost and Cost Effectiveness* on estimating the emission benefits and costs associated with emission control technologies capable of reducing emissions below Tier 1 standards.

As discussed earlier, the sources for the benefits and costs of the various emission control technologies were the EEA report, the CARB report, MECA, API and confidential information from vehicle manufacturers. Of these sources, only EEA, CARB and several vehicle manufacturers supplied information on costs. Consequently, these are the sources that are primarily used for establishing cost effectiveness.

It was also stated earlier that it was not necessary to incorporate all of the technologies discussed above in order to produce vehicles capable of emitting below Tier 1 levels. The choices and combinations of technologies will depend on several factors, such as current engine-out emission levels, effectiveness of current emission control technologies, and individual manufacturer preferences. It was noted that there are four technological areas that have the greatest potential for further reducing emissions. For the purposes of this study, EPA will present estimates for emission benefits and costs using six technological approaches.

- Improved A/F control
- Increased catalyst volume and loading
- Improved catalyst washcoat/substrate designs
- Close-coupled catalyst
- Advanced catalyst design
- Increased EGR rates

These technologies are the main technologies being used by vehicle manufacturers to meet LEV, and soon, National LEV standards. Although there are currently only a few vehicles certified to ULEV standards (one of which is a compressed natural gas vehicle), it is anticipated that these same technologies will be used to meet ULEV requirements as well. The LEV standards represent a reduction (from Tier 1 standards) of 70% for NMHC and 50% for NOx. The default Tier 2 standards represent a 50% reduction for NMHC and NOx, respectively, while the ULEV standards represent a 84% reduction in NMHC and a 50% reduction in NOx. The emission reduction estimates used in the study, and based on the above six technologies, results in emission reductions of up to 77% for NMHC and up to 80% for NOx.

For the purposes of this study, EPA projects that tighter A/F ratio control can be achieved by using a combination of faster response fuel injectors, a faster PCM microprocessor, improved HEGO sensor design (planar design), the use of dual HEGO sensors and adaptive transient fuel control, and improved calibration strategies. The estimates of emission benefits for tighter A/F control through the use of the technologies/strategies vary. Information from MECA and two vehicle manufacturers suggest that NOx emission benefits can range from 20% to 70%, while EEA estimated emission reductions of greater than 10% (no upper limit was provided) for HC and NOx. They stressed, however, that the upper range of the estimates could only be achieved through more sophisticated calibration strategies used in conjunction with the above mentioned technology, and that these strategies were not yet available. Based on this information, EPA projects that the emission benefits resulting from tighter A/F control to be 10% for NMHC and 20% for NOx.

Estimates for emission benefits of modest increases in catalyst loading and volume were consistent among the various sources. EEA estimates a benefit of 10% for HC and 10% or greater for NOx. MECA and several vehicle manufacturers concurred with these estimates. Thus, EPA projected a benefit of 10% for NMHC and 20% for NOx. For improvements to catalyst formulations and substrate designs, the estimates were a consensus of 10% for HC and NOx. Therefore, EPA projected benefits of 10% for both NMHC and NOx. The benefits of using a close-coupled catalyst were estimated by various vehicle manufacturers to range from 50% to 70% for HC, while estimates for NOx were lower at approximately 10%. EPA projected the emission benefits for close-coupled catalysts at 50% for NMHC and 10% for NOx. Finally, information from the American Petroleum Institute suggested that for catalysts utilizing advanced (tri-metal and multi-layer) designs, emission reductions ranging from 20% to 37% can be achieved for HC and 30% to 50% for NOx. EPA projected advanced catalyst design emission benefits of 37% for NMHC and 50% for NOx.

EEA estimated the emission benefit for increased EGR rates (most likely occurring from the use of electronic EGR) to be 10% or greater for NOx (EGR does not reduce NMHC or CO). Several vehicle manufacturers also indicated that increased EGR could result in reductions of 10% or greater. Based on this information, EPA has projected NOx emission benefit resulting from increased EGR rates to be 20%.

The total emission benefits estimated by EPA for tighter A/F control, improvements to catalyst designs, and increased EGR rates, as mentioned earlier, are up to 77% for NMHC and up to 80% for NOx. Table C.1 lists the projected Tier 2 technologies used in the study and their associated emission reductions.

Table C.1 List of Potential Tier 2 Technologies and Associated Emission Reductions

Technology	Percent Emission Reduction	
	NMHC	NOx
Improved A/F Control	10%	20%
Increased Catalyst Volume and Loading	10%	20%
Improved Catalyst Washcoat/Substrate	10%	10%
Close-Coupled Catalyst	50%	10%
Advanced Catalyst Design	37%	50%
Increased EGR	0%	20%
Total	77%	80%

These estimates were determined by combining the percent emission reduction for the respective technologies in a multiplicative fashion as seen below.

NMHC = 100% - (100%-10%)*(100%-10%)*(100%-10%)*(100%-50%)*(100%-37%)*(100%-0%) = 77%

NOx = 100% - (100%-20%)*(100%-20%)*(100%-10%)*(100%-10%)*(100%-50%)*(100%-20%) = 80%

Table C.2 lists the estimated costs for the respective technologies. Cost estimates are presented for NMHC, NOx, and NMHC+NOx for LDV and LDT. The costs associated with each technology are estimates of the manufacturing costs. In assessing the cost to consumers of emission control equipment, EPA uses a "markup" approach to estimate the retail price equivalent (RPE) for an emission control component from an estimate of the component's direct manufacturing cost. Given this methodology, the difference between the RPE and the direct manufacturing cost includes allocated overhead costs, profit margins, and other indirect cost estimates at several stages in the production and marketing process. The current RPE factor being used by EPA is 1.26. The last row of table C.2 is the total estimated retail price equivalent cost (i.e., total manufacturing cost x RPE factor (1.26)).

Table C.2 Estimated Costs for Respective Technologies

	Cost per vehicle ($)					
	LDV/LDT1			LDT 2/3/4		
Technology	NMHC	NOx	NMHC+NOx	NMHC	NOx	NMHC+NOx
Improved A/F Control	$2.65	$2.65	$5.30	$3.05	$3.05	$6.10
Increased Catalyst Volume and Loading	$6.50	$6.50	$13.00	$7.60	$7.60	$15.20
Improved Catalyst Washcoat/Substrate	$6.20	$6.20	$12.40	$7.20	$7.20	$14.40
Close-Coupled Catalyst	$10.15	$10.15	$20.30	$10.15	$10.15	$20.30
Advanced Catalyst Design	$20.00	$20.00	$40.00	$27.50	$27.50	$55.00
Increased EGR	$0.00	$17.00	$17.00	$0.00	$17.00	$17.00
Total	$45.50	$62.50	$108.00	$55.50	$72.50	$128.00
Total x RPE (1.26)	$57.33	$78.75	$136.05	$69.93	$91.35	$161.28

All cost estimates for different engine sizes are based on information supplied by EEA, CARB, MECA, and various vehicle manufacturers. For all of the technologies except increased EGR, cost estimates are dependant upon engine size. As engine size increases, so do costs. Engine size was defined as 4-cylinder, 6-cylinder, and 8-cylinder. A single cost estimate for each technology was developed by weighting the three individual costs by 1996 sales. Because costs for 4-cylinder technologies is lower, combined with the fact that LDVs have a higher percentage of 4-cylinder engines, LDVs have lower costs than LDTs. Conversely, because larger engines have higher costs, and LDTs have a higher percentage of large engines, LDTs have higher costs than LDVs.

EEA estimated the cost of improved A/F control to be $10.60 for LDV and $12.20 for LDT, while CARB estimated this action could be done at little or no additional cost, because they argued that improvements to A/F would only constitute software changes only with no additional hardware cost. EPA believes that some vehicles would only require software changes while others will require hardware modifications. Therefore, EPA estimated the cost of A/F control to be the average of the EEA and CARB estimates, or $5.30 for LDV and $6.10 for LDT. Note that CARB has estimated that a portion of their ULEV fleet would utilize improved fuel preparation, such as air-assisted injection, at a cost of $8-12 for such vehicle.

The cost estimates for increased catalyst volume and loading, as well as improvements to catalyst washcoat and substrate, were taken directly from EEA estimates and were $13.00 for LDVs and $15.20 for LDTs and $12.40 for LDVs and $15.20 for LDTs, respectively.

The cost estimates of $40.00 for LDVs and $55.00 for LDTs for advanced catalyst design were taken from proprietary information supplied by several vehicle manufacturers.

Cost estimates for close-coupled catalysts came from CARB. They estimated the cost to be the same for all engine sizes, however, they estimated that a number of Tier 1 vehicles equipped with 4-cylinder engines already use close-coupled catalysts. Therefore, the incremental cost for 4-cylinder engines is less than for the larger engines.

Estimates for increased EGR rates came directly from EEA. However, as stated above, costs for EGR were the same for all engine sizes and were not sales weighted.

Cost Effectiveness Calculation

EPA estimated the lifetime costs and emissions benefits on a per vehicle basis. Cost effectiveness is represented as the dollar cost per ton of emissions reduced ($/ton). The cost component, the numerator, is taken directly from the above discussion of vehicle costs, using $136 per vehicle for LDVs and $161 for LDTs.

Conceptually, the benefit calculation is derived by taking an estimate of in-use emissions for Tier 1 vehicles and applying the percent reduction estimates of 77% for NMHC and 80% for NOx. The resulting benefit is thus the difference between the Tier 1 level and the "Tier 2 control" level.

The Tier 1 in-use level is based on the modified version of MOBILE5 discussed in Appendix A. The CALIMFAC zero mile emission factor and average in-use deterioration factor[8] were adjusted for the effect of off-cycle driving patterns on emissions (Step 1). The resulting Tier 1 in-use emission rate is then multiplied by the percent emission reductions estimated for Tier 2 controls, 77% for NMHC and 80% for NOx . The emission benefit is the difference between the Tier 1 level and Tier 2 control level (Step 2).

The next step is to convert the gram per mile emission benefit into a per vehicle lifetime emission benefit. This is achieved by multiplying the gram per mile emission benefit by average lifetime miles. The lifetime miles are discounted using a standard discount rate of seven percent in order to discount the emission benefits by the number of years in the future in which they are realized.[9] The last step is to convert the grams into tons (Step 3). Dividing the per vehicle cost by the per vehicle emission benefits yields the dollar per ton cost effectiveness estimate (Step 4).

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[8]The mileage applied to the deterioration factor is the average in-use mileage weighted by the fleet travel fraction to account for higher usage rate for new vehicles. The average for LDVs and LDT1s is 68,000 miles, while LDT2 is 81,000 miles, and LDT3 and LDT4 was 100,000 miles.

[9]For LDVs the lifetime mileage used is 132,000 miles discounted to 90,000 miles. The lifetime mileage used for LDTs is 154,000 discounted to 97,000 miles.

Step 1: (Zero mile emission rate + (deterioration rate * average mileage))*(off-cycle effect) = in-use emission rate

Step 2: Tier 1 in-use emission rate * (percent reduction) = Tier 2 emission benefit (g/mi)

Step 3: (Tier 2 emission benefit (g/mi))*(discounted life time mileage)/(grams per ton conversion factor)= per vehicle Tier 2 emission benefit (tons)

Step 4: Per vehicle cost ($)/ per vehicle emission benefit (tons)= Cost effectiveness estimate ($/ton)

The tables below provide the specific values used in carrying out the four steps discussed above.

Table C.3. Tier 1 NMHC Emission Rates and Per Mile Benefits			
	LDV/LDT1	LDT2	LDT3/ LDT4
Zero Mile HC Emissions (g/mi)	0.1569	0.1440	0.1402
HC Emission Deterioration Rate (g/mi per 1,000 miles)	0.00142	0.00161	0.0016
Average In-Use Mileage	68,000	81,000	100,000
HC Emissions @ Average Mileage (g/mi)	0.2535	0.2744	0.3002
NMHC Fraction of HC Emissions	0.868	0.868	0.868
Off-Cycle Emission Adjustment Factor	1.07	1.07	1.07
Average In-Use NMHC Emissions (g/mi)	0.2354	0.2549	0.2788
Emission Control (%)	0.77	0.77	0.77
Average In-Use NMHC Emission Reduction (g/mi)	0.1813	0.1962	0.2147

Table C.4. Tier 1 NOx Emission Rates and Per Mile Benefits			
	LDV/LDT1	LDT2	LDT3/ LDT4
Zero Mile Emissions (g/mi)	0.3091	0.3009	0.2976
Emission Deterioration Rate (g/mi per 1,000 miles)	0.00188	0.00205	0.00202
Average In-Use Mileage	68,000	81,000	100,000
Emissions @ Average Mileage (g/mi)	0.4369	0.4670	0.4996
Off-Cycle Emission Adjustment Factor	1.208	1.208	1.208
Average In-Use Emissions (g/mi)	0.5278	0.5641	0.6035
Emission Control (%)	0.80	0.80	0.80
Average In-Use Emission Reduction (g/mi)	0.4223	0.4513	0.4828

Table C.5. Cost Effectiveness of NMHC Emission Control				
	LDV	LDT1	LDT2	LDT3/LDT4
In-Use Emission Reduction (g/mi)	0.1813	0.1813	0.1962	0.2147
Lifetime VMT (miles)	132,000	154,000	154,000	154,000
Lifetime Emission Reduction (tons)	0.0264	0.0307	0.0333	0.0364
Discounted Lifetime VMT (miles)	90,000	97,000	97,000	97,000
Discounted Lifetime Emission Reduction (tons)	0.0180	0.0194	0.0210	0.0229
Cost ($ per vehicle)	$57.33	$57.73	$69.93	$69.93
Cost Effectiveness ($ per ton)	$3,191	$2,981	$3,336	$3,049
Cost Effectiveness for LDV/LDT1 and LDT2/3/4 ($ per ton)	$3,151		$3,212	

Table C.6. Cost Effectiveness of NOx Emission Control				
	LDV	LDT1	LDT2	LDT3/LDT4
In-Use Emission Reduction (g/mi)	0.4223	0.4223	0.4513	0.4828
Lifetime VMT (miles)	132,000	154,000	154,000	154,000
Lifetime Emission Reduction (tons)	0.0614	0.0716	0.0765	0.0819
Discounted Lifetime VMT (miles)	90,000	97,000	97,000	97,000
Discounted Lifetime Emission Reduction (tons)	0.0419	0.0451	0.0482	0.0516
Cost ($ per vehicle)	$78.75	$78.75	$91.35	$91.35
Cost Effectiveness ($ per ton)	$1,882	$1,746	$1,895	$1,771
Cost Effectiveness for LDV/ LDT1 and LDT 2/3/4 ($ per ton)	$1,858		$1,842	

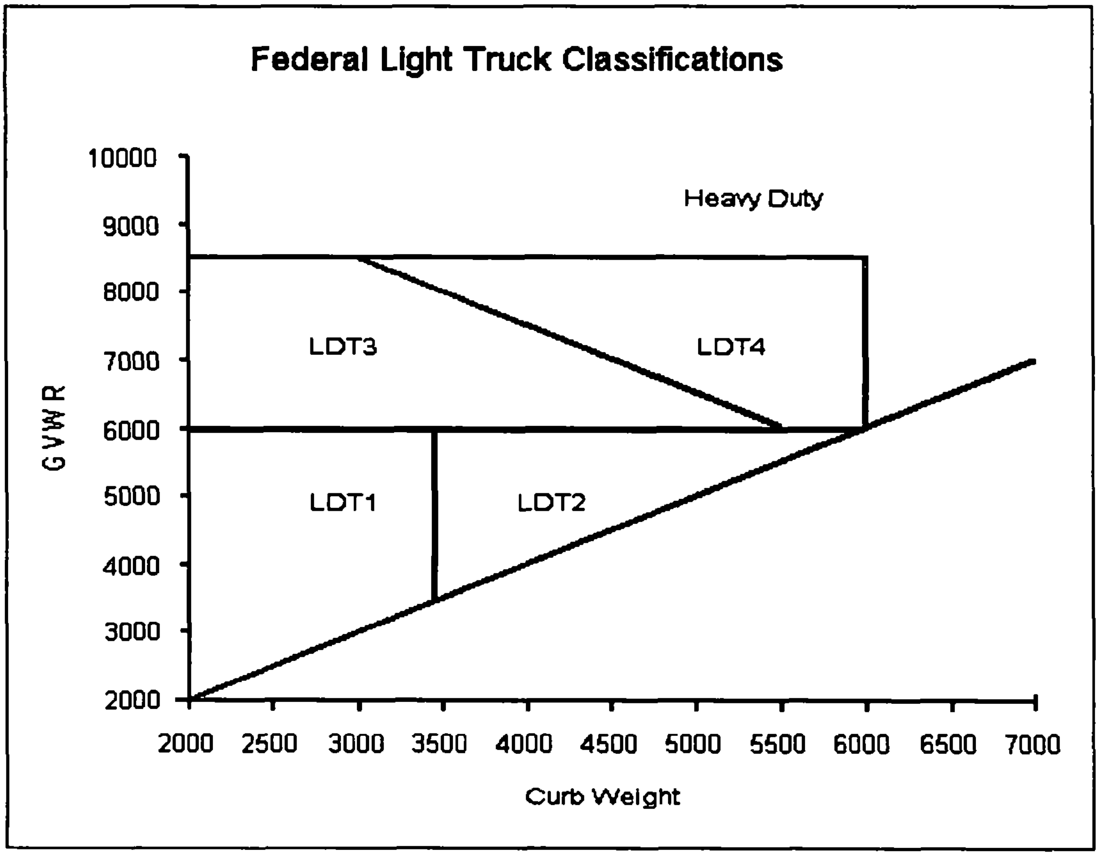
Table C.7. Cost Effectiveness of NMHC+NOx Emission Control				
	LDV	LDT1	LDT2	LDT3/LDT4
In-Use Emission Reduction (g/mi)	0.6035	0.6035	0.6475	0.6975
Lifetime VMT (miles)	132,000	154,000	154,000	154,000
Lifetime Emission Reduction (tons)	0.0877	0.1024	0.1098	0.1183
Discounted Lifetime VMT (miles)	90,000	97,000	97,000	97,000
Discounted Lifetime Emission Reduction (tons)	0.0598	0.0645	0.0692	0.0745
Cost ($ per vehicle)	$136.00	$136.00	$161.00	$161.00
Cost Effectiveness ($ per ton)	$2,273	$2,109	$2,328	$2,161
Cost Effectiveness for LDV/LDT1 and LDT 2/3/4 ($ per ton)	$2,245		$2,256	

Appendix D

CLASSIFICATION OF LDTs

In the Clean Air Act Amendments of 1990, Congress required that the smallest LDTs (LDT1s)[10] meet the same emission standards as LDVs. However, the emission standards for LDT2s, LDT3s and LDT4s remained less stringent than the LDV/LDT1 standards. The primary distinction between these LDT sub-categories and between the LDT and heavy-duty vehicle (HDV) categories is GVWR. Figure D-1 describes the definition of the four LDT sub-classes and HDVs.

Figure D-1:



Because of this incentive, many LDT models have migrated to heavier categories with higher numerical emission standards. For example, 57% of all LDTs certified in 1987 would

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[10] LDTs with a curb weight of 3450 pounds or less and a gross vehicle weight rating (GVWR) of less than 8500 pounds.

have fallen into the lightest current LDT sub-category (LDT1). This would have included the Chrysler minivans, the Jeep Cherokee and Wrangler and most Bronco II and Blazer models. By 1996, only 16% of all LDTs certified were LDT1s. Essentially all minivans are now LDT2s, as are all compact sport utility vehicles.

Also, a number of previous LDTs now have GVWRs which exceed 8500 pounds, which moves them into the HDV category. Examples are many Ford F250 and all F350 pick-ups, the GMC 3500 full-sized van and the GMC Suburban 2500.

Table D.1 shows the current 100,000-mile, California LEV standards for LDVs and LDTs (vehicle categories as defined by EPA). Also shown are the fleet-wide average standards using the in-use VMT fractions developed in Chapter III. As can be seen, the fleet-average NMHC and NOx standards are nearly 50% higher than the LEV standards for LDVs.

Table D.1 LEV Emission Standards (g/mi @ 100,000 miles)			
	NMHC[11]	NOx	NMHC+NOx
LDV	0.09	0.3	0.39
LDT1	0.09	0.3	0.39
LDT2	0.13	0.5	0.63
LDT3 (MDV2)	0.23	0.6	0.83
LDT4 (MDV3)	0.28	0.9	1.18
Weighted Average	0.138	0.437	0.575

Table D.2 compares the emission reduction potential of equating the LDV and LDT standards at the LDV LEV level with that resulting from a 50% reduction in all of the current LEV standards (e.g., 0.045 and 0.10 g/mi NMHC and NOx for LDVs, respectively). As can be seen, the two strategies yield almost equivalent reductions in in-use emissions. This highlights the need to address the relationship between the LDV and LDT standards in the process of considering tighter emission standards for both vehicle classes.

Table D.2 Emission Reductions Associated with Various LDV/LDT Control Strategies (g/mi)			
	NMHC	NOx	NMHC+NOx
Baseline			
LDTs Meet LDV Standards	0.048	0.137	0.185
50% Reduction from LEV Standards	0.045	0.150	0.195

[11] The California standards are actually in terms of non-methane organic gases, or NMOG, which is nearly equivalent to NMHC.

Appendix E

SUMMARY AND RESPONSE TO COMMENTS ON DRAFT STUDY

The Agency received numerous comments on the Draft Tier 2 Study, released for public comment on April 23, 1998. The comments enabled EPA to better define and understand the various issues. The vast majority of comments pertained to Tier 2 rulemaking issues rather than to the analyses and conclusions of the Draft Study. For example, many of the comments addressed regulatory issues raised in the Draft Study to help the Agency better outline a potential Tier 2 emission standards rulemaking. EPA also received many comments on the topic of gasoline sulfur control. While this topic was raised in the Draft Study, gasoline sulfur control was the primary topic of a separate staff paper issued shortly after the Draft Tier 2 Study. EPA has summarized these comments on regulatory issues in *Appendix F*, including those on gasoline sulfur control. EPA will address these comments as it develops the proposed Tier 2 and gasoline sulfur rulemaking, as their resolution is outside of the scope and purpose of the Tier 2 Study. The following sections summarize and respond to those comments directly related to the analyses and conclusions of the Draft Study.

The majority of the comments on the Draft Study were supportive and none of the comments provided a substantive challenge to the three primary questions of need, feasibility, and cost effectiveness addressed in the Study. All of the comments are summarized in the following section, categorized by chapter, then topic. EPA's response to the comments immediately follows the summary of each comment. Although the Agency is only required by the CAA to summarize the comments, EPA feels that it is appropriate to respond as well to comments directly related to the study. Overall, the comments resulted in only minor changes to the Draft Study.

ASSESSING THE AIR QUALITY NEED

Response to Comments on Air Quality Issues

<u>General Comments</u>

Overall, most commenters agreed with the conclusions of the air quality assessment, at least for ozone: that additional emission reductions from motor vehicles are required to assist in attainment of the NAAQS. Supporting this position were import auto manufacturers (AIAM, Toyota, and Nissan), the oil industry (API, NPRA, Exxon, Sunoco, Sinclair), state organizations and individual states, and environmental groups. AAMA disagreed with this point, however, stating that EPA had not met the requirement laid out in the Clean Air Act to demonstrate an air quality need for ozone reductions.

Beyond this fundamental issue, the various groups were divided. Commenters from the oil industry stressed that the need for nationwide ozone control was not demonstrated, as well as the need for control of PM, CO and toxics. Conversely, state and environmental groups stressed that PM, CO, toxics and considerations such as greenhouse gas emissions and visibility should receive elevated treatment from the Agency. The detailed comments primarily addressed the version of the Agency's inventory model used in the study, known as Modified MOBILE5b, the use and application of the OTAG and NAAQS air quality modeling in the study, regulatory issues related to air quality, and the issues mentioned above. Each are discussed in the following sections.

Modified MOBILE5b model: Overview

In support of the draft study, the Modified MOBILE5b model was developed to improve the emission projections of MOBILE5b. Modifications were made where adequate data had become available since the development of MOBILE5b and which were relevant to the estimation of exhaust emissions from LDVs and LDTs. Modified MOBILE5b incorporates lower vehicle deterioration, off-cycle emissions and their control, fuel sulfur effects on LEVs, and increases in light-duty truck VMT and survival rate. Comments were received on detailed elements of this model from STAPPA/ALAPCO, Toyota, AAMA and API.

Fuel Sulfur Adjustments

Comments: STAPPA/ALAPCO commented that the factors used to account for the impacts of fuel sulfur on LEV emissions reflected smaller emission impacts than those presented in EPA's Gasoline Sulfur Paper.

Response: The factors used to reflect the impact of sulfur on NOx emission from LEVs in Modified MOBILE5b were much smaller than those presented in the Gasoline Sulfur Paper. The statistical procedure used to develop the Modified MOBILE5b factors was found to underestimate such impacts when the effect is large (i.e., greater than 30%). The impact of sulfur on LEV emissions for future versions of the Modified MOBILE5b model will be estimated using methods similar to those employed in the Gasoline Sulfur paper. This correction was not made for the final study, however, as qualitatively it will increase out-year emission projections, serving to more strongly reinforce the conclusions made in the draft study. This modification will be reflected in the emission projections made to support any proposed Tier 2 and gasoline sulfur standards.

High Emitter Treatment

Comments: API had two comments related to the treatment of high emitters: 1) the Agency should perform a more rigorous analysis on the impacts of lower vehicle standards on high emitters, rather than relying on CALIMFAC's assumptions, and 2) the off-cycle correction factors were developed based on normal emitters only, but applied to high emitters as well.

Toyota echoed the latter point, and commented that in general high emitters should be accounted for correctly in MOBILE6 before assessments can be made for future regulations

Response: EPA is continuing to evaluate available emission data in order to more accurately estimate in-use emissions from both normal and high emitting vehicles. However, EPA still believes that the CALIMFAC emission factors are closer to those likely to arise from this evaluation for 1988 and later model year vehicles than those contained in MOBILE5b currently. Likewise, EPA is continuing to evaluate off-cycle correction factors and their application to both normal and high emitters. Unfortunately, emission data on high emitting vehicles certified to lower standards (Tier 1 and later) are extremely scarce, making the estimation of off-cycle emissions from these vehicles highly uncertain. However, the applicability of Inspection and Maintenance programs in areas with significant ozone problems minimizes the influence of high emitters in the emission projections. Therefore, whether the off-cycle correction factors are applied to all vehicles or just normal emitters would have little impact on the total emissions projected in these areas and would not change the basic conclusions of the study.

Emission Trends

Comments: AAMA commented that the Agency's conclusion that vehicle emissions would increase after the turn of the century as a result of VMT growth is not consistent with the results of the modified model.

Response: The Modified MOBILE5b model used in the study projects that reductions in gram per mile emissions from the in-use vehicle fleet will continue through 2020 due to the turnover of the fleet to vehicles certified to tighter emission standards. These reductions appear to be sufficient to counter the impact of moderate levels of VMT growth (e.g., 2%) through at least 2015-2020. However, as discussed above, this model underestimates the impact of sulfur on NOx emissions from LEVs. Higher LEV sulfur sensitivity will increase future emissions more than current emissions, as the fleet becomes more dominated with LEVs. Thus, the fleetwide emission reductions occurring over time will decrease. EPA estimates that with the higher LEV emission sulfur sensitivity, VMT growth would begin to counter reductions in per mile light-duty emissions in the 2015 timeframe. More importantly, emissions from the light-duty fleet will continue to be a significant source of emissions in ozone nonattainment areas for the foreseeable future even after the implementation of LEV and SFTP standards.

Other Issues

API made several comments on details of the Modified MOBILE5b model, addressed below:

Comment: Non-sulfur fuel corrections on LEVs should be reconsidered, since the MOBILE5-based corrections are based on 1990 and earlier vehicles, and sulfur corrections on pre-LEVs should be reconsidered

Response: Both are valid issues, but would have only a minor impact on Modified MOBILE5b results because existing MOBILE5b estimates for both issues are not expected to change significantly in MOBILE6. Addressing these issues would not impact the conclusions of the study; however, they will be considered for future versions of the model.

Comment: MOBILE6's proposed start/running separation will impact the sulfur correction factors, since sulfur effects are likely different on each mode.

Response: The sulfur corrections applied in Modified MOBILE5b are based on FTP emissions, so a representative weighting of start and running emissions are inherent to the correction factors. As mentioned above, EPA is still in the process of developing revised basic emission rates for late model year vehicles, including separate emission estimates for starts and warmed up operation. Once these emission rates are available, separate sulfur correction factors could be developed for the two types of vehicle operation. However, as long as the breakdown of start and warmed up operation in-use is near that of the FTP, there should be no net change to the impact of sulfur on emission.

Comment: Changes planned for MOBILE6 to evaporative emission estimates may increase overall evaporative inventory; these changes are not reflected in Modified MOBILE5b, which may lead to inaccurate representation of Tier 2 benefits and overall emission inventories.

Response: Updated estimates of in-use evaporative emissions are still under development. It is uncertain how projections of evaporative emissions will change. Therefore, it is not clear whether the projected evaporative emission inventory in the future will increase or decrease relative to MOBILE5b. However, changes to the evaporative estimates should not impact the conclusions of the study, which primarily apply to exhaust emissions. Changes in projected evaporative emissions will only modestly affect the base ozone levels. EPA will include any available revised projections of in-use evaporative emissions in its Tier 2 related analyses as they become available.

Comment: Modified MOBILE5b predicts that light truck sales will continue to increase, when in fact they are likely to stabilize in the near future.

Response: Modified MOBILE5b predicts that light-duty truck vehicle miles traveled (VMT) will continue to increase, not sales. This projection assumes a stabilization of LDT sales in 2002 at roughly 50% of overall LDV and LDT sales. LDT VMT continues to increase beyond this point, however, due to fleet turnover (LDT fraction of light-duty VMT would eventually stabilize, but beyond 2020).

Comment: In using the CALIMFAC basic emission rates, Modified MOBILE5b should account for differences in ARB and EPA standards.

Response: As mentioned in Appendix A, the CALIMFAC rates were used as a general approximation for the revised basic emission rates (zero-mile emissions plus emission deterioration rates) that EPA expects to use in MOBILE6. This is true despite slight differences in California and Federal emission standards. Because of the uncertainty in these future rates, altering the CALIMFAC rates to match the Federal standards wasn't considered critical. However, if this modification were made it would primarily increase NOx emissions for Tier 0 vehicles. This would increase the overall emission projections of the model and further support the conclusions drawn in the Draft Study. As mentioned above, EPA is in the process of developing revised basic emission rates using recent in-use emission data and will incorporate these revised rates into Modified MOBILE5b as soon as they are available.

Application of OTAG/NAAQS Ozone Modeling: Overview

The air quality assessment presented in the study relies primarily on modeling performed by the Ozone Transport Assessment Group (OTAG). OTAG's projections of the number of areas (and population within those areas) in nonattainment of the Ozone NAAQS (assessed separately for the 1-hour and 8-hour standards) in 2007 with existing controls were used in the study as the basis for determining the need for additional control. A set of control scenarios evaluated as part of the OTAG process known as Run 5 of Round 2 was used to estimate the emission controls most likely to exist at the time which the Tier 2 standards would be implemented (i.e., 2004). OTAG used a modified version of MOBILE5a for on-highway emission projections which reflected most, if not all of the modifications subsequently included in MOBILE5b. (The differences between MOBILE5a and MOBILE5b are not significant for the purposes of this analysis, in any event.)

In the Tier 2 Study, Modified MOBILE5b was used to provide a more accurate estimate of future on-highway emissions in four ozone nonattainment areas relative to MOBILE5b. The OTAG ozone modeling runs were not re-run with Modified MOBILE5b. Modified MOBILE5b projected higher emissions relative to MOBILE5b in the year 2007, the year of the OTAG ozone projections. This should increase the level of ozone projected in the future and increase the number of projected ozone nonattainment areas. As such, it would only serve to strengthen the evidence of the need for further VOC and NOx emission reductions.

Several comments were received, primarily from the auto manufacturers, regarding the applicability of the OTAG work to the determination of need for lower vehicle emission standards.

Consideration of Existing Motor Vehicle Control Programs

Comments: AAMA, NADA, AIAM and Toyota all commented to the effect that reliance on Round 2 Run 5 of the OTAG work did not account for the benefits of existing motor vehicle control programs such as On-Board Diagnostics (OBD), I/M, enhanced evaporative test procedures, SFTP and the effects of improved durability. Toyota added that a comprehensive assessment of air quality requires the corroboration of the real world impacts of these regulations prior to consideration of additional regulation.

Response: As mentioned above, the OTAG modeling used a modified version of MOBILE5a, which was roughly equivalent to MOBILE5b. Contrary to the comments received, this model accounted for most of the motor vehicle control programs mentioned in the above comments, such as enhanced evaporative control, OBD, NLEV and I/M. SFTP controls are not accounted for in either MOBILE5a or MOBILE5b, but off-cycle emissions, which the SFTP standards seek to reduce, are also not included. The much greater sensitivity of LEVs to sulfur is also not accounted for by these models. MOBILE5a's and MOBILE5b's in-use emission deterioration rates for late model year vehicles reflect the data available in the early 1990's. These rates now appear to be lower.

Many of these changes tend to balance one another. The inclusion of off-cycle emissions increases emission estimates from pre-2000 model year vehicles, while the sensitivity of LEV emissions to sulfur tends to increase emissions from post-2000 model year vehicles. Greater LDT sales and usage (relative to LDVs) tend to increase emissions, while lower basic in-use emission deterioration rates tend to decrease emissions from all vehicles. The net result of these differences are therefore smaller than might be expected by a simple examination of the individual effects.

As mentioned above in the overview of this section, Modified MOBILE5b projected higher emissions relative to MOBILE5b in the year 2007, the year of the OTAG ozone projections. This should increase the level of ozone projected in the future and increase the number of projected ozone nonattainment areas. As such, changing the modeling would only serve to strengthen the evidence of the need for further VOC and NOx emission reductions.

Regarding Toyota's comment on the need for real world assessment, a full assessment of motor vehicle-based requirements such as enhanced evaporative control, SFTP and OBD would require evaluation of in-use emissions for several years after the implementation of each rule. EPA is currently evaluating all the available exhaust and evaporative emission data available in order to develop improved estimates of fleetwide in-use emissions. These improved estimates will be incorporated into Modified MOBILE5b as they are available.

Impact of Modified MOBILE5b on OTAG Ozone Projections

Comments: AAMA commented that Modified MOBILE5b should have been utilized to determine the change in air quality need relative to that projected in the OTAG work. They contend that Modified MOBILE5b would predict a larger decrease in emissions between 1990 and 2010 than MOBILE5b (AAMA reported reductions of 86% for VOC and 57% for NOx for Modified MOBILE5b, compared to 77% and 38% using MOBILE5b).

Response: The degree of emission reduction between 1990 and 2007 is relevant to the projection of future ozone levels, as performed in support of EPA's proposed OTAG SIP Call. However, the modifications included in Modified MOBILE5b were oriented towards future vehicles. That is why EPA only presented emission projections for 2000 and beyond. To illustrate this point, basic emission rates in Modified MOBILE5b were only reduced to reflect lower deterioration back to 1988; if reductions in basic emission rates prior to 1988 were made, estimates of 1990 emission levels would decrease. Given this and the underestimation of the impact of sulfur on LEV emissions, the difference in 1990-2010 emission reductions between MOBILE5b and Modified MOBILE5b cited by AAMA are likely overestimated. Thus, it is inappropriate to use Modified MOBILE5b to estimate emissions in 1990, or to use this model to estimate the change in emissions between 1990 and some future year. As improved estimates of in-use emissions are available for all relevant model year vehicles, EPA will incorporate any changes into its MOBILE model. At this time, EPA does not believe that any such changes are likely to be substantial.

Consideration of Local Sources

Comments: AAMA, AIAM, and Toyota commented that the impact of other existing control measures, in particular local control measures, should be taken into consideration before determining the need for tighter vehicle emission standards. Specifically, AAMA and AIAM commented that controls which will be in place under the 1-hour ozone and PM_{10} SIPs were not included in Round 2 Run 5 of the OTAG work, as well as additional controls listed in the 8-hour ozone and $PM_{2.5}$ NAAQS RIA as potential approaches for meeting these standards. The OTC commented, however, that despite the implementation of several additional local controls by member states, attainment of the ozone NAAQS will not be achieved. This latter point was also made by New York, who stated that additional reductions will be necessary beyond the wide range of local controls already imposed.

Response: The ozone projections developed under Round 2 Run 5 included the benefits of local emission control measures mandated by the Clean Air Act, and any additional local controls which had been established by the time of these analyses (roughly 1996-1997). In a few cases, states are implementing further local controls as part of their 1-hour ozone SIPs. Directionally, these controls will decrease the number of future ozone nonattainment areas. However, as indicated by the ozone NAAQS RIA, implementation of all local controls costing $10,000 per ton of VOC or NOx had a very small impact on the number of projected nonattainment areas. Therefore, the absence of these additional planned local controls in the OTAG projections should not substantially affect the projected number of ozone nonattainment areas. Comments by the Ozone Transport Commission and the State of New York support this conclusion, indicating that even with the imposition of a multitude of local controls, further reductions in motor vehicle emissions are necessary to achieve attainment with the NAAQS.

With regard to the comments on local emission controls needed to attain the 8-hour ozone and $PM_{2.5}$ NAAQS, the potential control measures suggested for attainment with these standards have to be considered on equal footing with potential Tier 2 standards, as such measures have not yet been adopted. This being the case, it is not appropriate to account for the impact of these potential "future" control measures prior to assessing the air quality need for Tier 2 standards.

Population Statistics

Comments: AAMA commented that the population statistics quoted in the study may be misleading, since they reflect the number of people who live in a nonattainment area, and are thus exposed to unhealthy levels of air pollution less frequently than would be presumed by some unfamiliar with the subject. Sinclair commented that some quotations of the populations statistics included population in California, which should be excluded from the totals quoted in the study.

Response: The population statistics cited in the Draft Study reflect the number of people who may be exposed to unhealthy levels of ambient ozone and particulate matter, as defined under the implementation provisions of the ambient air quality standards. This is the proper figure to be considering in assessing whether further reductions need to be made to these harmful pollutants. The definitions of nonattainment areas for specific pollutants consider the general extent of each pollutant's elevated levels, as well as other factors.

For example, ozone nonattainment areas are generally defined as the metropolitan or consolidated metropolitan statistical area due to the regional nature of high ozone levels. PM_{10} nonattainment areas, on the other hand, are generally counties, as the geographical extent of elevated PM10 levels is generally more limited.

Regarding Sinclair's comment, the majority of the benefit from Tier 2 standards will undoubtably fall outside of California. However, there will be some benefit within California due to the migration and travel of Federal vehicles into California. The study does break out the California population where appropriate.

Fuel Control Considerations

Comments: AAMA commented that air quality need should first take into account nationwide fuel sulfur control (then local controls, as previously discussed) before determining the need for additional vehicle control. Sunoco and NPRA commented that OTAG found the benefits of fuel control to be small, adding that OTAG did not include fuel controls in its final recommendations.

Response: The purpose of the Tier 2 Study as outlined by Congress is to assess the need for further emission reductions from LDVs and LDTs via Tier 2 standards. The Study also identified gasoline sulfur levels as an important factor in setting any Tier 2 standards. EPA's Gasoline Sulfur Paper went further in assessing the potential emission benefits and costs of reducing gasoline sulfur levels in-use. EPA recognizes the interaction between fuel quality and vehicle emission controls. As EPA proceeds with the Tier 2 rulemaking, it will review any potential Tier 2 standards in conjunction with potential changes in gasoline sulfur requirements. In fact, the relative cost and effectiveness of fuel and/or vehicle controls will be a critical factor in the development of the Tier 2 rulemaking.

Regarding Sunoco's and NPRA's comments, the OTAG work did not incorporate the recently established effects of sulfur on LEV emissions. Thus, OTAG's past projections of the benefits for fuel control would necessarily be much smaller than those developed now. Thus, any past OTAG conclusions regarding the benefit of fuel control are no longer considered accurate.

Other Issues

Comments: AAMA and NADA commented on two more general issues related to the OTAG work. First, the OTAG modeling is meant to assess transport rather than nonattainment. Second, that OTAG (and hence the draft study) does not adequately deal with the issue of "NOx disbenefit," the phenomena in which reduced NOx levels can actually increase ambient ozone levels. Toyota commented on the latter issue in a more general way, saying that a comprehensive ozone reduction strategy is needed, rather than simply pursuing reductions in both VOC and NOx. Related to this issue, the OTC commented that their review of OTAG's work concluded that reductions in VOC and NOx provide additional reductions in ozone, with NOx reductions being more effective. Massachusetts commented that their own modeling indicates that reductions in "low level" NOx (for which vehicles are the primary contributor) are effective in reducing ambient ozone levels.

Response: The OTAG ozone modeling did find that reductions in NOx emissions sometimes resulted in increased, rather than decreased ozone levels. However, the geographic extent of these increases were orders of magnitude less than the area showing decreased ozone. Also, the ozone increases only occurred on selected days of the ozone episodes evaluated and generally were not on the days when ozone was the highest. Evaluated from the opposite perspective, increasing NOx emissions is clearly not an effective ozone reduction strategy. Reductions in NOx emissions are clearly effective in reducing ozone over wide geographical areas and clearly comprise a critical part of the nation's overall ozone control strategy. In fact, as NOx emissions are further controlled, the degree and extent of any NOx disbenefit diminishes and eventually disappears. The key role of NOx control is corroborated by the comments from the OTC and Massachusetts.

Areas which reflect such NOx disbenefits are also generally very sensitive to VOC emission reductions (i.e., reductions in VOC emissions are very effective in reducing ozone). Any reductions in VOC emissions from potential Tier 2 standards would mitigate and possibly eliminate any limited NOx disbenefit which might occur.

The focus of OTAG and its ozone models was clearly on transport rather than on the demonstration of ozone nonattainment in any particular local area. The grid sizes used in the OTAG ozone model are much larger than that used in SIP-level ozone modeling. The ozone episodes used by OTAG represented atmospheric conditions conducive to ozone transport and not necessarily the highest absolute ozone levels in any particular area. However, the OTAG ozone models are useful in projecting the ozone impacts of VOC and NOx emission controls implemented over broad regions of the country. When coupled with historic ozone measurements, as was done in support of EPA's proposed OTAG SIP Call, the model can be used to project the general degree of ozone nonattainment existing across the nation in the future. This projection does not have the same degree of confidence as is needed to demonstrate attainment in a SIP. However, SIP level assessments are not normally conducted to justify national vehicle nor fuel standards. The combination of historic ozone data and the OTAG ozone modeling represent a much more sophisticated tool compared to previous mobile source assessments.

Need for Nationwide Ozone Control

Comments: Comments from the oil industry, represented by API and several individual oil companies, stated in general that the Agency had not demonstrated the need for nationwide reductions in ozone. In particular, API commented that the need for control in "15%" ozone areas (i.e. those areas within 15% under the NAAQS) was questionable, due to the large amount of VOC and NOx increase needed to push these areas into nonattainment, and the uncertainty of health effects associated with lower ambient ozone levels.

Response: Given steady economic and VMT growth, reductions in base emission rates are required for areas close to nonattainment to ensure that they remain in attainment. Regarding health effects, the NAAQS dictate the level at which exposure to ozone is unhealthy. Reduced VOC and NOx levels are needed to ensure compliance with the NAAQS for areas currently in attainment. EPA will further evaluate these issues and the relative merits of national and regional programs in the context of the rulemaking process.

API did not provide any technical support for their claim that large increases in VOC and NOx emissions would be needed to cause ozone levels to increase 15%. If the only emission source assumed to increase was motor vehicles, then the percentage increase required would likely be large. However, economic growth can cause upwind emissions to increase, so background ozone can increase over time. Economic growth can also cause local emission from sources other than motor vehicles to increase, as well. SIPs place absolute emission caps on some sources, but not all. Therefore, 15% is not large compared to economic and VMT growth of 2-3% per year.

In addition to providing room for continued economic growth, nationwide emission controls provide valuable environmental benefits not related to ozone. Tier 2 standards would reduce ambient levels of nitrate PM and air toxics. PM10 nonattainment areas are scattered throughout the U.S. (including the West), and people are exposed to toxics and their associated cancer risk wherever vehicles are driven.

Need for Diesel Control

Comments: EMA commented that the Agency did not adequately assess the need for control of diesel LDTs. With regard to air quality issues, they commented that Modified MOBILE5b was not used to assess the air quality impact of diesel penetration, and that the Agency should perform a thorough inventory analysis to determine the impact of diesel LDTs before determining whether Tier 2 standards are required.

Response: The inventory estimates presented in the study from Modified MOBILE5b include the impacts of diesel LDVs and LDTs. The intent of the study's air quality assessment is to establish the need for further control from LDVs and LDTs as a whole. However, as gasoline vehicles dominate the light-duty fleet, the air quality assessment was, practically, an assessment of the impact of gasoline-fueled LDVs and LDTs. Because of their current low market share, light-duty diesels have a relatively small contribution to total motor vehicle emissions. However, in the heavier vehicle classes, where the penetration of diesels is substantial or dominant, the contribution of diesels to the overall emission inventory is significant.

If a need exists to reduce emissions from the gasoline-dominated light-duty fleet in order to achieve the NAAQS for ozone or PM10, then there is similarly a need to prevent any increases in emissions resulting from a further dieselization of the light-duty fleet. The technical feasibility and cost of diesels achieving Tier 2 emission standards and equity considerations are other important factors in any determination that Tier 2 standards for diesels are appropriate. These issues were discussed in a broad fashion in the section of the Draft Study on regulatory issues and will be addressed in detail as any Tier 2 standards are developed and proposed.

PM, CO, Toxics and other considerations

Comments: The oil industry in general commented that the need for Tier 2 standards should focus on ozone reduction, and that need for control of PM, CO and toxics had not been established. With regard to PM, API commented that the number of people living in PM nonattainment areas and the contribution of motor vehicles to PM inventory was small. In addition, API commented that the assessment of secondary PM (caused by formation of particulates from gaseous emissions) is complex and requires further testing and modeling by EPA to better understand the issue. These points were generally echoed by Sunoco. Regarding CO, Sunoco commented that there was no need for further control since attainment goals had been achieved, and will continue with fleet turnover. Sunoco and API commented that toxics should not be considered in determining the need for Tier 2 standards, due to cost ineffectiveness. Sinclair added that visibility should not be a consideration in determining air quality need, since the Agency's charge from Congress was to base need on attainment of the NAAQS.

By contrast, state and local organizations, as well as individual states, called for EPA to increase the relative importance of PM, CO and toxics in determining air quality need. STAPPA/ALAPCO commented that the Agency should place equivalent emphasis on PM emissions, including secondary PM, and consider the impact of motor vehicle emissions on other issues such as acid rain, visibility and greenhouse emissions They also commented that EPA should focus more on the need for CO control, given the delay in assessing Cold CO Phase II standards and CO problems in warm weather climates. Alaska and Washington reiterated these points, particularly with regard to PM and CO.

Response: The ozone impacts of LDV and LDT emissions will continue to be a central consideration in the development of the Tier 2 rulemaking . However, the Agency is not constrained to look only at criteria pollutants in determining appropriate motor vehicle standards. The need for reductions to meet and maintain NAAQS levels is only a "part of the study" that EPA must undertake under section 202(i) regarding "whether or not further reductions in emissions from [LDVs and LDTs] should be required." Moreover, EPA has independent authority under section 202 (in particular subsections (a) and (l)) to regulate pollution beyond that specified in section 202 (i).

Thus, the Agency considers PM, CO and toxics (as well as other issues raised by commenters) to be very relevant in the consideration of Tier 2 standards. Health and welfare concerns are associated with each of the pollutants; the need for (and benefits of) controlling each of these pollutants will be considered in the development of the Tier 2 rulemaking.

<u>Regulatory Issues</u>

Modeling for the Tier 2 Rulemaking

Comments: AIAM encouraged the Agency to conduct airshed modeling to determine adequate Tier 2 standards in the OTC region. Sunoco made a similar comment, recommending that air quality modeling be performed to quantify vehicle-fuel system impacts. AIAM also commented that it is imperative for MOBILE6 to be complete in time for the final Tier 2 rule.

Response: The Agency does not intend to duplicate the extensive air quality modeling work done as part of the NAAQS or OTAG processes for the Tier 2 rulemaking. This work, as laid out in the study, clearly shows the need for ozone control in nonattainment areas. With regard to ozone, Tier 2 standards will be based on the cost effectiveness of precursor control, given the need to address the existing ozone problem.

As the Agency moves forward in the Tier 2 rulemaking, it intends to utilize the best available estimates of in-use light-duty motor vehicle emission. As such, EPA will continue to update the Modified MOBILE5b model as additional data and analyses become available.

ASSESSMENT OF TECHNICAL FEASIBILITY

Chapter IV of the Tier 2 Draft Study examined the technical feasibility of controlling light-duty emissions beyond the level of control provided by Tier 1 emission standards. The Study reviewed and described a variety of technologies capable of reducing emissions from Tier 1 levels. The Study also estimated the emission reductions of selected technologies and concluded that many of the technologies discussed in the Study are technically feasible. The Study discussed currently feasible vehicle emission control technologies, as well as advanced technologies.

EPA received a number of comments on the Agency's assessment of technical feasibility. The vast majority of the comments centered around the methodology and associated assumptions used by EPA to determine emission reduction estimates for individual technologies and for an overall vehicle. It should be noted, however, that the Agency did not receive any comments that challenged the Draft Study's conclusion that it is technically feasible to reduce emissions from Tier 1 or LEV levels. In fact, EPA received numerous comments from state, environmental and oil industry commenters agreeing that such reductions were feasible.

All of the comments received are summarized in the following section. Response to comments are included where appropriate.

Emission Reduction Benefits

Comments: There were several comments critical of the way EPA estimated emission reduction benefits. All of these comments were from members of the automotive industry. The American Automobile Manufacturers Association (AAMA) stated that the Draft Study did not adequately assess the technological feasibility of obtaining further reductions in emissions from LDVs and LDTs because EPA used unsubstantiated emission reduction benefits of individual technologies, and the benefits were derived with an overly simplistic, unexplained calculation.

AAMA argued that the only valid method for determining the true reduction potential of technologies is to perform emission testing of actual hardware on a representative sample of vehicles. They were also critical of the fact that EPA used the percent emission reductions for individual technologies and projected a system emission benefit with what they deemed an "unsubstantiated" multiplicative formula. Toyota also expressed concern over EPA assessing technologies in an add-on fashion, rather than as an integrated and complete emission control system. AAMA stated that the interactive effects of individual emission control technologies are complex and analysis requires extensive testing and research. AAMA felt that EPA's approach did not account for product variation.

Finally, Toyota and AIAM commented that EPA's inclusion of increasing palladium (Pd) content in the catalyst raises questions about future supply and price of the precious metal. The use of Pd in vehicles is predicted to increase dramatically in the future and the stockpiles will be depleted, possibly resulting in a severe shortage of Pd in the future. Toyota stated that EPA needs to take this factor into consideration prior to setting stringent emission standards, especially stringent NMHC standards that can only be met with electrically-heated catalysts or close-coupled Pd catalysts.

Response: AAMA argues that the only valid method for determining emission reduction potential of various technologies is through emission testing of actual hardware. The emission reductions presented in the Draft Study are all tied to actual emission testing results. The sources for emission reduction estimates used in the Study by EPA were CARB, MECA, API, several vehicle manufacturers, and the EEA report. All of the information presented to EPA from these sources were either directly derived from emission testing, or in the case of the EEA report, from correspondence with auto manufacturers, which is also based on emission test results.

EPA does not agree the Study used an overly simplistic and "unsubstantiated" multiplicative formula for determining overall vehicle emission reduction estimation. First, the multiplicative method used by EPA recognizes the fact that once a specific technique has been applied to reduce emissions, there are fewer emissions left to reduce further. Using this method, two techniques which are both capable of reducing emissions by 50% are projected to together reduce emissions by 75% (50% for the first, plus 25% (50% of the remaining 50%) for the second), rather than by 100%, which would be the simply sum of the two control efficiencies. The only remaining question is whether the second and subsequent techniques are still effective after the previous techniques have been applied. This is clearly the case for combining controls which address engine out emissions and those which address emissions in the tailpipe. When a number of engine-out emission control techniques or a number of tailpipe emission control techniques were being combined, EPA developed estimates which represented the incremental emission control available after implementation of the other techniques.

EPA agrees that there can be the potential for over- or under-estimating emission reduction potential when combining a number of individual control technologies on a single vehicle. Emission reductions achieved can also differ between manufacturers and between various models. Because of the difficulty in predicting variances in hardware design and the synergistic effect of combining multiple control technologies, EPA used engineering judgement in selecting emission reduction estimates. In some cases where the available projections varied widely, EPA selected reduction levels that were in the middle or lower end of the range of available estimates to be conservative.

Toyota and AIAM raised concern about the potential for Tier 2 emission standards to result in a shortage of Pd. As Toyota pointed out, vehicle catalysts are already the single largest use of Pd worldwide and much of the supply is coming from limited worldwide stockpiles. The demand for Pd has been steadily increasing with the advent of California's LEV program and is anticipated to increase even more with NLEV, LEV II, and Tier 2 requirements in the U.S. and more stringent emission standards being implemented in Europe. This is an important issue that

EPA is currently investigating. EPA will consider the results of this investigation in the Tier 2 rulemaking.

Diesel Technology

Comment: The Engine Manufacturers Association (EMA) felt that the study neglected to prove feasibility of diesel technology to meet tighter emission standards. EPA performed an analysis for gasoline-powered vehicles, but not for diesel-powered vehicles, which have unique combustion characteristics and emission control technologies. EPA based its case for technical feasibility for diesels on gasoline vehicles. The State of Washington also commented that EPA should perform a detailed analysis of the capability of diesel engines to meet more stringent PM standards based upon projected diesel technology.

Response: The LDV and LDT new and in-use fleets are overwhelmingly dominated by the gasoline engine. Therefore, EPA focused the technical feasibility and cost effectiveness portions of the Tier 2 study on gasoline-fueled vehicles. The conclusions of the Tier 2 Study correspondingly flow from the analysis of gasoline vehicles.

EPA devoted a section of the study to the issue of the relationship between the potential Tier 2 emission standards for gasoline and diesel vehicles and presented various options for setting Tier 2 standards for diesels. The role of the diesel engine and its future air quality impact are uncertain at this time. However, this issue, including any concerns regarding technological feasibility of controls for diesel engines, will be fully addressed when EPA reviews potential Tier 2 standards for both vehicle types.

Truck Technology

Comment: AAMA and the National Automobile Dealers Association (NADA) argued that the functional capabilities of trucks must be considered when evaluating technological feasibility. They felt that the Draft Study focused on a fixed percentage reduction for all vehicles without regard for their functional capabilities. They stated that truck standards should be set based on feasibility demonstrated using similar emission control technologies as cars. They also commented that trucks are designed to meet customer demands for increased functionality. Trucks have heavier structures, larger tires, axles, brakes, vehicle inertias, and experience greater drive train losses. Trucks also experience greater aerodynamic drag forces because of larger frontal areas and higher ground clearances. These differences increase the amount of work required of trucks, which increases the vehicle's exhaust volume and emissions.

Response: EPA recognizes that there are some aspects of the design of LDVs and LDTs which are inherently different. Some of these aspects, like weight and frontal area, inherently increase fuel consumption and can increase emission. However, the Tier 1 standards for most LDTs are numerically higher than those for LDVs. Therefore, EPA judged that was appropriate to project that specific emission control technologies could achieve the same emission reductions, in percentage terms, for LDVs and LDTs relative to the Tier 1 standards. This implies that the resulting emission levels for LDTs are still numerically higher than those for LDVs. EPA is not aware of any information which indicates that the technologies it identified in the Draft Tier 2 Study cannot be applied to LDTs.

Further, evidence exists that the current gap between LDV and LDT emissions should be able to be narrowed considerably, again assuming the use of the same technology on both types of vehicles. The Manufacturers of Emission Controls Association (MECA) commented that LDTs currently have looser air-to-fuel (A/F) ratio control, less use of close-coupled catalysts, proportionally lower catalyst volumes and precious metal loadings, and less sophisticated catalyst substrates than LDVs. Historically, one of the biggest problems in reducing LDT emissions to LDV emission levels has been the potential for thermal damage to the catalyst if it was placed as close to the engine as typically occurs with LDVs. Because trucks are heavier, have larger displacement engines, and, at times, necessarily operate under high load conditions (e.g., when carrying a load or hauling a trailer), catalyst operating temperatures can reach high, potentially damaging levels. MECA commented that the thermal durability of three-way catalysts has greatly expanded in the past five years from 900 °C to nearly 1100 °C. Thus the higher temperatures that might have been seen with some LDT operating conditions is no longer a barrier.

As stated above, EPA feels that there is minimal to no difference between the technology available and its associated emission reduction performance for LDVs and LDTs. The only inherent differences that continue to exist are related to basic vehicle design, such as size and weight, which can still affect engine load and emissions. EPA will consider these differences in assessing the technical feasibility and cost as it develops its proposal for the Tier 2 rulemaking.

Assumptions Regarding Technological Capabilities and Advanced Technologies

Comment: There was a strong division among the commenters regarding the assumptions that the Agency should be making about the capability of vehicle and truck manufacturers to mass produce advanced emission control technologies that can reduce emissions substantially below Tier 1 levels. For instance, API and several individual refiners indicated that the Agency should be relying on the best technologies which are currently available and are already in commercial use. These vehicle technologies, they argue, are capable of reducing emissions below Tier 1 levels, and their sole consideration avoids the problems associated with setting vehicle standards based on unproven technology. In contrast, several state organizations, environmental and public advocacy groups indicated that Tier 2 emission standards must take into account new and emerging technologies that are expected to be available by the time the Tier 2 standards go into effect (nominally 2004) and that the Tier 2 study should have reflected in greater detail these technologies.

Response: Congress mandated that EPA assess in the Tier 2 study whether technology would be available which would meet, no earlier than the 2004 model year, more stringent standards than those listed in section 202 (g) and (h) of the Act. In answering this question, EPA focused on technologies and systems that are generally currently available. As the study shows, these technologies can be utilized in a manner which achieves significant emissions reductions. The study discussion on technologies that might be utilized for Tier 2 vehicles was not meant to be an exclusive list of technologies, but instead showed a variety of technologies that manufacturers might incorporate in their vehicles. The Tier 2 rulemaking will analyze more fully the costs and benefits of technologies discussed in the study, including advanced technologies like fuel cells and hybrid vehicles, as part of EPA's determination on the appropriate level of potential Tier 2 emissions standards.

Comment: AIAM felt that the Draft Study should mention gasoline direct injection (GDI) engines in the discussion of advanced technologies. These engines can offer a 15-20% decrease in CO_2 emissions and should be considered by EPA.

Response: The advanced technologies discussion in the study was included to highlight the fact that there is significant research and development as well as production work being done on vehicle technologies, including technologies for alternatively-fueled vehicles, that could lead to significant emission reductions. This discussion was not intended to be an exclusive list of such technologies and EPA will continue to analyze these technologies, or others that are identified, as part of the Tier 2 rulemaking.

Cost Estimates of Technology

Comments: The commenters seemed to be split as to their opinion of the cost estimates used in the Draft Study for the respective emission control technologies. The National Park Service (Department of the Interior), the State of Alaska, and STAPPA/ALAPCO all agreed with the conclusions on cost estimates presented by EPA in the Draft Study and also agreed that history has proven that past cost estimates have been too high. The National Automobile Dealers Association (NADA) and AAMA, while not disagreeing with EPA's cost estimates, felt that the Study's cost estimates were much lower than those presented in the EEA report, which was done specifically for EPA. NADA said that EPA's cost estimates were 2-3 times lower than the EEA report, and the study appears to ignore the estimates provided by EEA and any costs associated with 8-cylinder engines. AAMA also was concerned that EPA did not provide any justification for the methodology used to estimate the non-hardware costs of vehicle production (e.g., engineering and design, development, validation, manufacturing, and overhead costs). Toyota echoed similar concerns saying that EPA did not appear to estimate costs for software, maintenance, etc.

Response: In developing cost estimates for the Draft Study, EPA used several sources. EPA had cost information available from some vehicle manufacturers, CARB, and a report done for the Agency by Energy and Environmental Analysis, Inc. (EEA) titled "Benefits and Cost of Potential Tier 2 Emission Reduction Technologies." As EPA developed cost estimates for the various emission control technologies projected for lowering emission levels beyond Tier 1 levels, engineering judgement was used to determine which pieces of cost information were the most appropriate. This meant reviewing information from all of the sources and making a determination as to what costs seemed the most realistic. In doing so, EPA was not obligated to only use cost information supplied by EEA. For example, EEA estimated a cost of $10.60 for improving A/F control for LDVs which included the use of fast response fuel injectors, planar oxygen sensors, and a faster microprocessor. CARB, on the other hand, estimated this action could be done at little or no cost, because improvements to A/F would only constitute software changes with no additional hardware costs. EPA felt that some level of hardware would be necessary, but also agreed with CARB that significant improvements to A/F control would result from improvements to fuel control calibrations. Thus, EPA choose to take the average of EEA's and CARB's estimates. In the case of cost estimates for increased catalyst volume and loading, as well as improvements to catalyst washcoat and substrate, the study used EEA's estimates directly. The technologies EPA included in its estimate are all currently available and EPA does not expect any additional costs associated with maintenance of these technologies.

Comments: AAMA and NADA also expressed some concern that the study did not consider the cost estimates for 8-cylinder engines.

Response: The Study considered cost estimates as a function of engine size; 4-cylinder, 6-cylinder, and 8-cylinder engines were all considered. A single cost estimate for each technology was developed by weighting the three individual costs by 1996 sales. EPA used data from MECA, CARB, and discussions with auto manufacturers in making its projections for 8-cylinder engines.

Comments: AAMA and Toyota suggested that EPA did not provide any justification for the methodology used to estimate the non-hardware costs of vehicle production (e.g., engineering and design, development, validation, manufacturing, and overhead costs).

Response: The methodology used by EPA to estimate the non-hardware costs of vehicle production is referred to as the "retail price equivalent" (RPE). RPE is often utilized by the auto-industry as an indicator of the average price impact to consumers. The estimation of RPE requires a detailed knowledge of the economics of the auto industry, and a number of approaches have been developed to best characterize the various cost elements that go into an RPE estimate. Typically, RPE attempts to estimate the factory overhead and general overhead for administration, sales, marketing, and research and development. The Study used an RPE of 26% or a factor of 1.26. This is the current factor being used by the Agency for regulations.

Safety, Lead-Time, and Energy Impacts

Comments: The oil industry and AAMA pointed out that the study neglected to address the issues of safety, lead-time, and energy impacts with respect to technological feasibility.

Response: The issues of safety, lead-time, and energy impacts on technological feasibility were not explicitly addressed in the draft study. No commenters mentioned any safety or energy impacts associated with the specific emission control technologies identified in the study. Likewise, EPA has no information that would indicate any such impacts. All of the technologies are currently used on at least one vehicle model already in production. These issues are addressed in the final study (see chapter IV) and will continue to be considered and addressed in any proposal the Agency develops for the Tier 2 rulemaking. Leadtime issues are also discussed in chapter IV of the final study.

COST EFFECTIVENESS

EPA's Overall Approach to Cost-Effectiveness

Comments: While not necessarily disagreeing with the study's conclusions, a number of commenters criticized the nature of the study's approach to cost-effectiveness as being simplistic and listed several neglected issues. For instance, AAMA and several refiners commented that the vehicle and the fuel must be considered together when the cost-effectiveness of a Tier 2 program is being evaluated because of the link between vehicle-related and fuel-related emissions and controls. EMA, on the other hand, pointed to the exclusion of a separate cost-effectiveness analysis for diesel light-duty vehicles and trucks, decrying the EPA's assertion that the cost-effectiveness calculations based on light-duty gasoline vehicles would also apply to light trucks. Finally, Sunoco recommended that the EPA define the enforcement provisions that would accompany Tier 2 and any associated gasoline sulfur regulations, and incorporate the enforcement-related costs into the cost-effectiveness assessment. Other comments on specific aspects of the study's cost-effectiveness analysis are discussed separately below.

Response: The study made use of a nationwide, annual, per vehicle approach to cost-effectiveness, which is consistent with many past analyses of motor vehicle control programs. This approach was deemed to be particularly appropriate in the Tier 2 study, because the purpose of the study was only to determine if "Tier 2" standards (i.e., standards more stringent than Tier 1) were cost effective. The purpose of the study was not to develop and evaluate specific Tier 2 standards, nor to evaluate specific regulatory frameworks for a Tier 2 program. The study only evaluated the potential for advanced technologies to provide cost-effective reductions in emissions of criteria pollutants. See chapter VI for a more complete discussion of the regulatory issues associated with the Tier 2 rulemaking.

As regards the inclusion of potential fuel changes in the evaluation of cost-effectiveness, the study focused on vehicle technology because the Clean Air Act's requirements for the study focused on vehicle standards. EPA addressed the impact of gasoline sulfur on post-Tier 1 vehicles in a separate staff paper. The emissions associated with the selection of vehicle technologies which were used in the study's cost-effectiveness analysis are representative of operation on low sulfur gasoline, consistent with the low sulfur content of current certification fuel (currently 30 - 100 ppm). Thus, the cost effectiveness estimates presented in the study are most representative of a scenario in which in-use sulfur levels have been reduced to the levels of federal certification fuels (30-100 ppm). EPA expects that the application of these vehicle technologies would also produce substantial emission reductions at higher sulfur levels. EPA will fully integrate fuel and vehicle emission controls in its evaluation of cost-effectiveness in the NPRM planned for later this year.

With regard to gasoline-fueled LDTs, the study projected that the same technology which could be applied to LDVs could be applied to LDTs, with generally the same percentage effectiveness. The study also found evidence that improvements in emission control technology had eliminated many of the historically inherent differences between LDV and LDT emissions. No data was received from any commenter refuting these findings.

The Agency did not specifically assess the cost effectiveness of Tier 2 standards for diesel vehicles or trucks. The new and in-use LDV and LDT fleets are currently dominated by the gasoline engine. Therefore, EPA focused the technical feasibility and cost effectiveness portions of the Tier 2 study on gasoline-fueled vehicles. This approach was sufficient to fulfill the Clean Air Act mandate that EPA assess whether Tier 2 standards were technically feasible and cost effective.

EPA devoted a section of the study to the issue of the relationship between the potential Tier 2 emission standards for gasoline and diesel vehicles and presented various options for setting Tier 2 standards for diesels. This issue will be fully addressed when EPA proposes specific Tier 2 standards for both vehicle types.

Many of the comments highlighting shortcomings in the study's cost-effectiveness calculations appear to arise from a misunderstanding of the per-vehicle approach taken by the Agency. There are generally two approaches to calculating the costs and benefits of a control program. The calendar year approach adds up all the costs and benefits projected to occur over a specific time frame. This time frame is usually fairly long (e.g., 33 years), so that startup costs are included, but do not dominate the result. Another approach is the per vehicle or per engine approach. This approach has been commonly used by the Agency in analyses of national motor vehicle and engine controls where the bulk of the costs and benefits can be associated with a particular vehicle or engine throughout or at specific times in its life. The two approaches yield approximately the same result when common cost and benefit inputs are used. The per vehicle approach is simpler to conduct, when it can be applied. It also ensures that the costs and benefits of the program are properly accounted for by considering all the benefits accrued over the lifetime of the vehicle as well as the control costs which usually occur once at the time of vehicle or engine purchase.

The annual accounting of benefits is consistent with the approach used in other programs in accounting for NOx and VOC benefits. Although some commenters, such as API, NPRA, and several individual refiners, indicated that NOx and VOC benefits should only be accounted for in the summer when ozone is an issue, the accounting of benefits on an annual basis allows for a direct comparison of the cost-effectiveness of Tier 2 vehicles to the cost-effectiveness of other programs. While ozone benefits generally occur primarily in the summer months, there are in fact other environmental benefits, such as ambient PM and toxic reductions, which occur year-round. The Agency restricted its comparison of the cost effectiveness of potential Tier 2 standards to other programs which had also been assessed on a year round basis to ensure consistency.

Cost-Effectiveness Showing

Comments: There was a strong division among the commenters regarding whether the study's cost-effectiveness analysis provided a reasonable basis for concluding that Tier 2 vehicles can be cost-effective. The Department of the Interior's National Park Service, several environmental commenters, the States of Massachusetts and Alaska, and MECA all agreed with the study's conclusion that Tier 2 vehicles can be cost-effective. In contrast, a number of other commenters, including both API and AAMA, indicated that the study falls short in assessing the potential cost-effectiveness of Tier 2 vehicles because it does not provide sufficient comparisons to other programs. AAMA also provided its own estimate of the cost-effectiveness of potential Tier 2 standards at $12,000 - $16,000 per ton NOx + VOC, stating that these values fall far above the maximum criteria for a cost-effective program.

Response: The study did in fact compare the cost-effectiveness of Tier 2 vehicles to the cost-effectiveness of other control programs. For instance, the study included a range of cost-effectiveness values (in terms of $/ton) for single pollutants for other control measures implemented since passage of the Clean Air Act Amendments of 1990, including those for stationary sources. In comparing the cost-effectiveness of Tier 2 vehicles with the cost-effectiveness of those previous programs, it appears that Tier 2 vehicles would in fact be cost-effective. The study also made comparisons to other potential control measures which had not yet been implemented. The cost-effectiveness of these latter programs was evaluated in detail in the Regulatory Impact Analysis (RIA) associated with the revised NAAQS for ozone. Again the Agency concluded that, in comparison to these other potential control measures, Tier 2 vehicles could be cost-effective since the $/ton values estimated for Tier 2 vehicles was comparable to the $/ton values estimated for those other control programs.

EPA determined AAMA used cost estimates of $232 for a four cylinder engine and $306 for six cylinder engines (incremental to the Tier 1 standards) based on information AAMA found in the EEA report. AAMA also projected a VOC+NOx reduction of 0.0189 tons per vehicle, derived from emission rates which AAMA believes may be used in EPA's upcoming MOBILE6 model. Dividing $232 by 0.0189 tons yields $12,275/ton and dividing $306 by 0.0189 tons yields $16,190/ton, yielding the cost effectiveness range cited by AAMA in their comments.

In estimating vehicle costs, AAMA did not assume use of the same technologies as EPA cited in the draft study. The primary difference between the technologies selected by AAMA and EPA is that AAMA included an electric air pump system at a cost of $125 for four cyclinder engines and $160 for six cylinder engines. However, AAMA did not modify the projected emission reductions based on the use of this additional technology. Specifically, electric air pumps are designed to speed up catalyst light-off, which primarily reduces HC emissions. EPA projected the use of some technologies not used on current LEVs, but not electric air pumps, in calculating the 77% VOC reduction identified in the study.

If EPA had included the cost of an electric air pump system, the costs for LDVs and LDTs would have increased by $179 and $197, respectively. These costs include sales weighting the above costs by the fraction of 4, 6 and 8 cylinder engines in the two vehicle classes, and multiplying by the Retail Price Equivalent (RPE) factor of 1.26. Total costs would thus have increased to $315 for LDVs and $358 for LDTs. These cost estimates are even higher than those estimated by AAMA, due to the inclusion of the RPE factor and other smaller differences in the technologies selected by EPA and AAMA. EPA acknowledges that there are many different combinations of technology that can be used to lower emissions, and the list of technologies presented in the Tier 2 study may be expanded once Tier 2 standards have been developed. However, EPA chose to include technologies it believes would provide cost effective emission control, based on currently available information.

AAMA's estimated per-vehicle VOC+NOx benefit of 0.019 tons is a factor of three lower than the benefit of 0.06 tons estimated for LDVs by EPA in the study. EPA's analysis was based on in-use emission rates from California's CALIMFAC model, used in the Modified MOBILE5b model to estimate planned changes in the MOBILE6 basic emission rates. Emission rates for MOBILE6 are currently under development, and thus have not been proposed; as such, the CALIMFAC rates are still EPA's most current estimate of how MOBILE6 will project in-use emission levels. AAMA's estimates are presumably based on emission rates which were merely under deliberative consideration for MOBILE6. The rates used by AAMA have not been proposed for use in MOBILE6, and as such cannot be considered updated MOBILE6 (or Modified MOBILE5b) emission rates. An additional likely reason for AAMA's lower benefit estimate is that they did not appear to consider benefits from off-cycle driving, which are included in EPA's analysis.

Thus, EPA does not believe a change to the cost effectiveness estimates made in the study is appropriate.

Comment: Some commenters suggested that other factors be taken into account in evaluating cost-effectiveness in addition to, or in lieu of, comparisons to other programs. For instance, the International Center for Technology Assessment suggested that any control program costing $10,000 per ton or less ought to be considered "cost-effective."

Response: For the purposes of the study, the Agency has determined that comparative assessments of cost-effectiveness are the most appropriate means for evaluating potential Tier 2 standards, rather than assessments measured with respect to a fixed $/ton limit. The Agency has determined that the evaluated options for Tier 2 are cost-effective when compared to other programs.

Comment: A few commenters, including the State of Alaska and the Department of the Interior's National Park Service, reiterated the study's recognition that past cost estimates have often proven to be too high once the program was actually underway. These commenters suggested that the Agency accept higher $/ton estimates in the study as a result.

Response: Comparative assessments of cost-effectiveness as generally based on pre-implementation cost estimates, such that lower in-use costs are not accounted for. Thus the comparative cost-effectiveness assessments summarized in the study provide the best means for determining whether to establish Tier 2 standards.

Point of Comparison for Cost-Effectiveness Calculations

Comment: Marathon Oil suggested that cost-effectiveness should be measured with respect to LEVs rather than Tier 1 vehicles, since LEVs will already be commercially available by the time Tier 2 vehicles go into effect. The technology has already been developed for LEVs, so no new costs will be imposed on them from any Tier 2 standards, and the emission benefits attributable to LEVs will already be accruing by the time Tier 2 standards would go into effect.

Response: The Clean Air Act envisioned that the Tier 2 standards would be compared to the Tier 1 standards, which were to be the existing standards prior to the promulgation of the Tier 2 standards. The Act did not envision a voluntary NLEV program. Recognizing this, the study focused on the cost effectiveness of emission controls beyond Tier 1, but also provided cost effectiveness estimates for control beyond NLEV. The Agency determined that Tier 2 standards can be cost-effective with respect to either baseline.

Comment: Several commenters highlighted the fact that the study estimates the costs and benefits associated with a conglomerate of emerging emission control technologies, questioning whether this was appropriate. API and Marathon Oil, for instance, suggested that cost-effectiveness be determined on an incremental basis that allows a $/ton value to be determined in stepwise fashion for each new type of technology that is added to a Tier 1 vehicle. The Ozone Transport Commission, on the other hand, suggested that, instead of making its own judgements regarding which technologies are most likely to be used in Tier 2 vehicles and the benefits associated with those technologies, the EPA should instead use either the default Tier 2 standards in the Clean Air Act or California's LEV-II standards as the basis for estimating the benefits of Tier 2 vehicles.

Response: The study included an incremental cost effectiveness analysis. The study's "conglomerate" approach, in which a selection of technologies was chosen as a means towards estimating the potential benefits of Tier 2 vehicles, was intended to provide an initial estimate of the types of emission controls which are technologically feasible and cost effective. In order to most accurately estimate the additional costs and emission benefits of Tier 2 vehicles, it is necessary to first investigate what is technologically feasible. Beginning with a set of emission standards and then estimating the set of technologies that can attain those standards is analogous to putting the cart before the horse. Additionally, synergisms exist between a number of the control technologies and it is more realistic to evaluate these technologies together than separately. For example, many of these technologies are found together on current California LEV and ULEV vehicles. The purpose of this portion of the study was to evaluate whether emission control beyond the Tier 1 standards was cost effective. The study was not designed to select the level of Tier 2 emission control which was most cost effective, or marginally cost effective relative to other programs. The technology necessary to achieve the California LEV-II standards has not yet been clearly quantified. In addition, the Agency deemed it inappropriate to use the default Tier 2 standards from the Clean Air Act as the basis for the cost-effectiveness calculations, since the NMOG standards applicable to existing LEVs are already more stringent than the default Tier 2 NMHC standard. Thus the "conglomerate" approach provides a better description of potential Tier 2 standards than either the Clean Air Act's default Tier 2 standards or California's LEV-II standards.

The study did not include an incremental cost effectiveness analysis for each technology. Such analysis will be addressed fully in the proposed Tier 2 rulemaking.

Accounting of Costs and Benefits

Comment: API, NPRA, and several individual refiners commented that the benefits associated with Tier 2 vehicles should not be summed annually and nationally. Instead, they indicated that benefits should only be accounted for during times and in places where they actually have an impact on air quality. Thus NOx and VOC benefits should only be accounted for during the summer in ozone nonattainment areas and ozone transport regions.

Response: As discussed above, the study made use of a per-vehicle approach to cost-effectiveness that necessarily results in $/ton values which represent an annual accounting of benefits. The annual accounting of NOx and VOC benefits is consistent with the approach used in other programs, and thus the study's approach provides for a direct comparison of the cost-effectiveness of Tier 2 vehicles to the cost-effectiveness of other programs. The study's per-vehicle approach to cost-effectiveness also means that the $/ton values represent the cost-effectiveness of a single Tier 2 vehicle operating in an area where low sulfur standards apply, which is generally where NOx and VOC benefits are deemed beneficial to air quality. Whether low sulfur standards will apply regionally or nationally is a regulatory issue that will be addressed in the NPRM.

Comments: Many commenters provided suggestions for which benefits should be accounted for in the cost-effectiveness calculations, and how. Beyond NOx and VOC emissions, several commenters suggested that reductions in CO, particulate matter, and toxic pollutants also be taken into account, though most commenters did not specify whether this should be accomplished through a simple mass sum of all reductions, or through an alternative means such as crediting the costs of implementing Tier 2 vehicles. Other commenters, such as STAPPA/ALAPCO and the International Center for Technology Assessment, suggested that the study also take credit for such incidental benefits as reductions in acid rain, better visibility, and fewer greenhouse gas emissions in its cost-effectiveness calculations. Sinclair Refining, on the other hand, specifically identified visibility as an example of a benefit that should not be taken into account because it is unrelated to attaining or maintaining any NAAQS. In similar fashion, Sunoco Oil questioned whether any benefits of Tier 2 vehicles beyond NOx and VOC should be taken into account in the cost-effectiveness analysis.

Response: The Clean Air Act identifies attainment and maintenance of the NAAQS as "a part of" the Tier 2 study regarding "whether or not further reductions in emissions from [LDVs and LDTs) should be required." It is also appropriate to review other economic and environmental benefits associated with the Tier 2 standards. For instance, if fuel economy were projected to increase or decrease because of the standards, it would be appropriate to include the added cost and/or benefit. Likewise, if the incidence of cancer is projected to increase or decrease, the value of these health impacts should also be included. The same is true for visibility, acid precipitation, etc. In addition, the inclusion of benefits associated with reductions in other criteria pollutants would be consistent with the Act's charge. The cost effectiveness analysis included in the study did not quantitatively include these other benefits, as the Tier 2 controls evaluated appear to be cost-effective without their consideration. EPA plans to include appropriate public health and environmental benefits in evaluating the Tier 2 standards in the NPRM.

Comment: In the context of assessing the NOx and VOC benefits for Tier 2 vehicles, several commenters disagreed with the study's approach of using a mass sum of the two pollutant categories. For instance, API indicated that the overall cost-effectiveness should be based on ozone reduction benefits estimated through air quality modeling rather than relying on the mass of ozone precursors reduced. Alternatively, API suggested that NOx be weighed more heavily than VOC, since NOx appears to be the more important pollutant to control for mobile source impacts on ozone. Marathon Oil went further, suggesting that VOC benefits be ignored altogether in calculating the cost-effectiveness of Tier 2 vehicles.

Response: The relative effects of NOx and VOC on the formation of ozone can vary substantially from region to region and even from hour to hour within a given region. As a result, it is very difficult to establish a single ratio of NOx to VOC that is representative of the impact of these two pollutants on ozone in all areas at all times. Calculating the cost effectiveness of the Tier 2 standards in terms of ozone impact would require photochemical grid modeling, which is beyond the scope of the study. The study calculates separate $/ton values for

NOx, VOC, and NOx+VOC to allow the most appropriate comparison to other programs, some of which evaluated the cost effectiveness of only one ozone precursor, while others evaluated the cost-effectiveness of both NOx and VOC.

Comment: There was disagreement concerning the study's allocation of costs to the separate $/ton values for NOx and VOC. AIAM agreed with the study's approach of splitting costs, but suggested that the separate costs for NOx control and VOC control be made proportional to the mass of NOx and VOC benefits produced. API, on the other hand, disagreed with any allocation of costs between NOx and VOC.

Response: EPA generally assigns costs to either NOx or VOC control depending on the purpose of that particular emission control technique. When both VOC and NOx emissions are controlled substantially and simultaneously, then the costs are split between the two pollutants evenly. In the study, when calculating separate cost effectiveness estimates for NOx and VOC control, the Agency deemed it inappropriate to include all costs in each case, since the total costs would have been lower had only one of the two pollutants been controlled. AIAM's suggested approach of allocating costs to NOx and VOC in a proportional manner to the mass of each pollutant reduced would have the effect of producing identical $/ton values for NOx, VOC, and NOx+VOC. Thus, the value of applying this technique is unclear given that the cost effectiveness of VOC+NOx control has already been calculated.

Appendix F

SUMMARY OF COMMENTS ON REGULATORY ISSUES

In Chapter VI, EPA raises a number of important issues that the Agency will need to resolve in developing Tier 2 standards for LDVs and LDTs, ranging from the relative stringency of the Tier 2 LDV and LDT standards to test fuel specifications and the appropriate level of sulfur in commercial gasoline. These issues were also outlined in the Draft Study, and EPA received a number of comments on these issues. This Appendix summarizes the comments received, grouped by topic. Since the Agency raised these issues only to gather information for future rulemaking, and since these issues do not directly impact the analysis and conclusions of the Study, EPA is not responding directly to these comments at this time. Rather, these comments will be considered fully during the development of the proposed Tier 2 standards and gasoline sulfur requirements. A complete list of commenters is provided at the end of this Appendix for the reader's information.

I. Relative Stringency of the Tier 2 LDV and LDT Standards

EPA outlined three possible options for setting LDV and LDT standards. The three possible options were:

1) Require LDTs to meet the same numerical emission standards as LDVs;
2) Set the LDT standards to require use of the same emission control technology as the LDV standards; or
3) Set different standards based on vehicle use.

EPA received comments supporting all three options. However, the majority of the comments supported option 1, requiring LDTs to meet the same numerical emission standards as LDVs. Those supporting option 1 were individual states, regional state affiliations, environmental groups, health organizations, and several oil companies.

Auto manufacturers suggested a combination of options 2 & 3. AAMA suggested that the current truck classification system should retained, while AIAM felt that EPA should explore new definitions for LDT classes that recognize vehicles that are designed and used for similar purposes and set standards appropriate for each class. Both groups felt that equivalent emission control technologies should be required on trucks as on cars, but the truck standards should be numerically higher.

API stated that LDT standards should be based on a cost effectiveness level equal to the cost effectiveness for LDV standards. EMA noted that EPA must take into account the functional requirements of trucks and felt that diesel powered LDTs should have separate and numerically higher emission standards than LDVs.

Several states, state organizations, and environmental groups felt that in addition to LDVs and LDTs having the same numerical emission standards, EPA should also adopt California's proposed LEV II emission program, while AIAM argued that EPA should refrain from adopting standards as stringent as California's.

Finally, several oil industry groups suggested that Tier 2 emission standards should include trucks over 6,000 lb GVWR, and several state and environmental commenters felt EPA should include trucks up to and over 8,500 lb GVWR.

II. Uniform Application of Emission Standards

In the Tier 2 Study, EPA referred to uniform standards as the application of the same emission standards to similar vehicles regardless of what fuel is utilized. The primary fuel options for conventional engines are gasoline and diesel fuel.

EPA received comments from a wide spectrum of groups, including states, environmental groups, the oil industry, and auto manufacturers. All but one of the commenters agreed that future Tier 2 emission standards should be the same for gasoline and diesel fuel. Only one commenter, EMA, felt that there should be separate standards. EMA felt EPA did not justify the need for additional regulation for LDTs, and in particular, for LDTs powered by diesel engines. Therefore, EMA did not see any reason to have fuel neutral emission standards.

The American Lung Association (ALA) encouraged EPA to require diesel LDVs and LDTs to meet the same SFTP emission standards as those required for gasoline LDVs and LDTs.

III. Evaporative VOC Emission Standards

EPA suggested that it may be appropriate to consider tightening the current evaporative VOC emission standards in the process of considering tighter Tier 2 exhaust emission standards. It also mentioned that CARB has recently proposed a "zero evaporative emission" which would essentially require that evaporative VOC emissions be below measurable levels.

Several commenters, including states, oil industry commenters, and auto manufacturers, agreed that EPA should consider tighter evaporative VOC emission standards. Several even suggested that EPA should consider "inherently zero evaporative emission" requirements, similar to California. There was also the suggestion that EPA should determine the stringency of evaporative VOC standards based on cost effectiveness.

Toyota argued that before EPA considers tightening evaporative standards, further discussion needs to take place on how to appropriately incorporate the evaporative emission effects into EPA's in-use emission modeling to determine whether there is any need to tighten evaporative VOC emission standards.

IV. Corporate Average Tier 2 Standards

The Study stated that EPA is considering establishing corporate average emissions standards for Tier 2, similar to the fleet average standards that will be used by the voluntary National LEV program and currently exist for California's LEV program.

There were no comments opposed to the concept of corporate averaging for Tier 2 emission standards. Several commenters from states and the auto industry stated that EPA should consider corporate averaging of Tier 2 emission standards. New York and AIAM suggested that EPA should give consideration to a corporate averaging program that includes both hydrogen and nitrogen oxide emissions. AIAM also felt that EPA should consider other concepts for vehicle manufacturers to gain emission credits against any average standard, such as 1) voluntarily certifying to longer useful life, 2) voluntarily electing to conduct in-use enforcement without screening vehicles for proper maintenance and use, and 3) voluntarily electing to certify to the same standard for useful life as for 50,000 miles.

V. Extended Useful Life and Other Options to Improve In-Use Performance

Section 202(i) of the CAA directed EPA to consider in the Tier 2 Study extending the useful lives of the LDV and LDT emission standards. Therefore, the Study stated that EPA was considering extending the useful lives for LDVs and LDTs to 120,000 miles from their current 100,000 miles, similar to what California had recently proposed in their Phase 2 LEV emission program (i.e., LEV II).

EPA received several comments from states, health organizations, and the oil industry suggesting that useful life requirements be increased from the current 100,000 mile requirement. All of the comments suggested that useful life should, at a minimum, be raised to 120,000 miles, while the International Center for Technology Assessment (CTA) stated that it should be raised to as high as 160,000 miles.

AIAM disagreed with the other commenters and argued that the useful life requirement should not change. They stated that changes to useful life should not be considered until data is available on the effectiveness of the current useful life requirements.

VI. Test Fuel Specifications

In the Study, EPA stated that in an attempt to further develop test procedures that are representative of real world conditions, the Agency is considering requiring test fuel to be the same as, or "representative " of commercial in-use fuel. In the study, EPA only commented on gasoline, not diesel fuel.

EPA received comments from several states and several members of the oil industry. All agreed that Tier 2 emission standards should require certification and in-use fuel to be the same. The commenters from the oil industry felt that this should only apply to sulfur content, while the various state commenters suggested that all fuel specifications should be the same. CTA commented that EPA should use the "worst" commercial fuel for testing. Toyota stated that a changes in the test fuel should result in a change in standards to compensate.

VII. Gasoline Sulfur

Among the regulatory issues raised in the Draft Study was the question of the need to control commercial gasoline sulfur levels to reduce the negative emissions impact that sulfur has on the performance of automotive catalysts. In response to the various issues raised in that discussion (Section G of Chapter VI), a number of comments were received. These comments are summarized in the following sections, grouped by topic.

In addition to the short discussion in the Draft Study, EPA has released a more detailed analysis of the issues surrounding control of gasoline sulfur in a Staff Paper released in May 1998.[1] EPA is in the process of receiving comments on the Staff Paper and thus is not responding to comments on the Staff Paper in this document. However, the Agency will consider the comments received on the Staff Paper during the development of the rulemaking.

A. Appropriate Sulfur Level for Commercial Gasoline

In the Draft Study, EPA indicated that the level of sulfur control would be determined on the basis of cost and emissions reductions, as well as technology enablement. A number of parties commented that sulfur should be reduced to California gasoline sulfur levels - nominally 30 ppm on average, with a maximum of 80 ppm. Nissan noted that it is doubtful that Tier 2 standards could be feasible without reducing gasoline sulfur levels to at least 40 ppm. The automotive industry was joined by the Manufacturers of Emission Controls Association (MECA) in calling for this level. In addition, STAPPA/ALAPCO, the OTC, the ALA, and various individual states also supported this level. Massachusetts supported even lower levels to enable more advanced technologies, such as fuel cells. Generally, maximized emissions reductions and enablement of even cleaner technologies in the future were cited as arguments for reducing

[1]Office of Mobile Sources, EPA, "Staff Paper on Gasoline Sulfur Issues," EPA 420-R-98-005, May 1998.

gasoline sulfur to these levels. AAMA also cited the need to have consistent fuel standards worldwide given the move to harmonize emissions standards worldwide.

Other parties argued for more limited sulfur control. In most cases, the sulfur level suggested by the API/NPRA proposal - 150 ppm on average - was cited as an acceptable level for the region defined to get low sulfur fuel, with an average level of 300 ppm for the rest of the country. API argued that some vehicles available today can meet Tier 2-type emissions standards with gasoline sulfur levels of 150 ppm, and thus lower levels were not needed. In addition to representatives of the oil industry, several states supported this level. Florida indicated that 150 ppm would be an acceptable temporary level of sulfur control, although the state clearly indicated the need to go even lower in the long term. Oklahoma expressed the opinion that states should have the right to determine what level of sulfur they want (or how quickly they want lower sulfur fuel) to meet their own needs.

B. Geographic Extent of Sulfur Control Program

As noted in Chapter VI, the geographic extent of a sulfur control program - whether it applies nationally or to a more limited region - has implications for the costs and the emissions benefits to be gained from sulfur control. Comments were received in support of both options.

The oil industry, represented by the American Petroleum Institute (API) and the National Petrochemical & Refiners Association (NPRA), as well as individual oil companies, supported a regional sulfur program in lieu of a national program. API and NPRA have jointly proposed a regional program that would provide lower sulfur fuel to the 22 states covered by the NOx SIP call. Specific arguments in favor of a regional program included the belief that other areas had limited air quality needs for control or would benefit little from additional mobile source controls, citing the work of the Ozone Transport Assessment Group. Others stated that a regional fuel program could help to restrict the growth of individual state "designer" or "boutique" fuels designed to address air quality problems in a limited area. Several individual states also expressed interest in a regional program. For example, Florida, not included among the 22 states, expressed interest in a regional program provided they would be included in the region. Other states supported a regional program due to the belief that not all areas need or want sulfur control. Idaho specifically suggested that states outside of the control region be given the opportunity to opt-in to the more stringent sulfur level if they want more control. API stated that the impact of sulfur on catalysts was reversible, negating the need for a national program.

Other parties gave strong support to a national sulfur control program. Automakers, represented by the American Automobile Manufacturers Association (AAMA) and the Association of International Automotive Manufacturers (AIAM), expressed support for a national sulfur program and even petitioned the Agency to implement a national, low sulfur gasoline program in the near future. STAPPA/ALAPCO and the Ozone Transport Commission (OTC) have made similar resolutions, and many individual states commented in support of a national program. Environmental organizations, such as the American Lung Association and the

American Council for an Energy Efficient Economy, also favor a national sulfur control program. Arguments supporting the need for a national program, beyond the general emissions benefits and vehicle technology enabling explanations, included the fact that most of the international community, including Europe, Japan, Canada, and other countries are moving towards low gasoline sulfur requirements for the early 2000s, as well as concerns regarding reversibility and illumination of onboard diagnostics lights.

C. Sulfur's Impact on Catalysts and the Reversibility of this Impact

EPA has estimated the impact of sulfur on emissions based on test data demonstrating the effect sulfur has on catalysts. EPA also raised the question about whether future automotive catalysts could be designed to be less sensitive to sulfur than those available today. In response, API suggested that there were various technical solutions to reducing the impact of sulfur on emissions and designing cleaner vehicles, such as reducing engine-out emissions, improving control of air-fuel ratios, and others, that indicated very low sulfur levels were not needed. Sinclair noted that LEVs and ULEVs are cleaner than Tier 1 vehicles regardless of sulfur level. In contrast, the auto industry commenters and MECA all commented that sulfur control is critical to enable emission control hardware to perform at the levels necessary to meet likely Tier 2 standards. These commenters noted that not only does sulfur impact current vehicle emissions, but as vehicles are required to be cleaner (and thus their emission control systems more efficient), sulfur inhibits their performance.

EPA also noted that a key question was how reversible the sulfur effect is an issue that would help to determine both the maximum acceptable sulfur level and the geographic extent of a sulfur control program. Several parties, including the auto industry, STAPPA/ALAPCO, MECA, and a group of 22 environmental organizations, commented that reversibility is a concern and the variability in data on reversibility argues for sulfur control. Individual commenters referenced work done by a catalyst manufacturer, Johnson Matthey, which suggests that long term exposure to high sulfur fuel leads to less reversible catalyst damage than short term exposure. Many comments also argued that some of the techniques needed to reduce the sulfur impact on catalysts, such as high temperatures and/or rich (low oxygen) operation, would not be possible in the future as catalysts were required to be increasingly durable and new standards controlling "off-cycle" emissions under the supplemental federal test procedure (SFTP). Commenters from the oil industry presented data which they interpret to demonstrate that the catalyst degradation due to sulfur levels up to 300 ppm can be completely reversed. The oil industry comments also presented data which was cited to demonstrate that vehicles exist today which can meet SFTP emissions standards when operated on sulfur levels up to 300 ppm.

D. Sulfur Control Costs and Refinery Considerations

Although EPA provided no estimates of sulfur control costs or other refining industry impacts of sulfur control in the Draft Study, there was a discussion of the need to consider costs and other issues when developing a sulfur control program. (EPA presented a more detailed evaluation of costs and related issues in the Staff Paper.) Several comments submitted on the Draft Study addressed these types of issues.

Many comments addressed what refining technologies should be considered in evaluating the feasibility and cost of sulfur control. Several states, as well as STAPPA/ALAPCO, encouraged that emerging sulfur removal technologies, such as a new process being developed by CDTECH, be considered. These commenters further suggested that standards should be set to push improvements in refining technology. In contrast, Sunoco specified that only commercially proven technologies be considered as the basis for justifying sulfur reductions. Ford suggested that the Agency investigate current and future refining technologies in the U.S. to understand why 10% of refineries are already making low sulfur gasoline with no apparent marketplace disadvantages.

Other comments addressed the factors that should be considered when evaluating sulfur control. Cost was mentioned by many commenters as a key consideration. Sinclair suggested that costs be evaluated for different parts of the country, and that the Agency consider that the costs to consumers will vary as rural consumers tend to use more gasoline than urban dwellers. Sunoco noted the cost of enforcement for refiners. Other oil industry representatives suggested that in addition to cost per gallon of gasoline, the Agency should consider overall costs, lead time, and energy impacts in deciding the appropriate level of sulfur control. Specific attention was called to the anticipated growth in demand for refined products, and the commenters suggested that the ability of the industry to meet this demand as well as additional environmental requirements be considered in the Agency's evaluation. MECA encouraged EPA to give adequate lead time to refiners, as well as to provide implementation flexibility. Nissan, however, stated that API's own cost estimates indicated that the cost of controlling fuel sulfur to AAMA/AIAM recommended levels was cost-effective. Ford indicated that EPA's cost estimates (presented in the Staff Paper on gasoline sulfur) were too high.

E. Other Comments

Many comments were received on technical issues related to gasoline sulfur that were not explicitly raised in the Draft Tier 2 Study. Some of these issues were discussed in the Staff Paper on Gasoline Sulfur Issues, and several parties appeared to be addressing both documents when submitting their comments. For completeness, the comments received on other sulfur-related issues are summarized here.

1. Sulfur's Effect on Advanced Technologies

Several commenters addressed the effect that sulfur is likely to have on more advanced technologies, such as gasoline direct injection engines using lean-NOx catalysts, or gasoline-powered fuel cells. STAPPA/ALAPCO expressed the opinion that the enabling of such technologies is of even greater concern than the resolution of the reversibility of the sulfur effect on today's catalysts. API expressed the opinion that lean-NOx catalysts will not require low sulfur gasoline, citing test data from a Mitsubishi vehicle. Furthermore, oil industry commenters argued that the needs of advanced technologies should not enter into the current debate over gasoline sulfur levels since such vehicles will not be introduced into the U.S. market any time soon.

Automotive industry commenters and catalyst manufacturers suggested that sulfur control is necessary to enable future technologies, because advanced technology catalysts would be permanently damaged (irreversibly) by sulfur. One comment encouraged the Agency to consider going to even lower sulfur levels (below 40 ppm) for the benefit of these technologies. The CO_2 reductions to be achieved through the use of these advanced technologies was cited as justification for reducing sulfur to enable these technologies.

The National Conference of State Legislatures took the arguments for advanced technologies a step further. They encouraged EPA (and Congress) to fund increased research and development of alternative fuels (alternatives to gasoline) and alternative-fueled vehicles.

2. Air Quality Concerns and Benefits of Sulfur Control

Many commenters, in supporting their positions on the need for sulfur control, made recommendations about what air quality concerns should be considered in evaluating the need for sulfur reductions. The National Conference of State Legislatures (NCSL) and AIAM both suggested that toxics should be factored into the evaluation; the NCSL encouraged EPA to focus specifically on toxics. AIAM also encouraged consideration of other benefits of sulfur control, including reductions in the formation of secondary particulate matter (PM) in the form of sulfates and nitrates, reduced acid deposition due to SO_2 reductions, and improved visibility. Commenters from the oil industry, by contrast, suggested that the Agency only consider what is needed to achieve the NAAQS for ozone, PM, and carbon monoxide (CO).

The environmental community encouraged a broader consideration of the benefits of sulfur control. Twenty-two environmental groups joined together to encourage year-round control of sulfur based on the belief that the public health benefits to be achieved occur year-round. Other environmental groups suggested that the public health benefits outweigh the costs, and thus argued for national, year-round control to the lowest levels.

3. Need to Control Other Gasoline Properties

A number of comments addressed the need to control gasoline properties in addition to sulfur to enable vehicles to meet expected Tier 2 standards. The automotive industry suggested that the Agency control the distillation properties of gasoline by restricting the "driveability index" (DI) of the fuel. They claimed that fuels with driveability indices too high have an impact on their ability to control the ratio of air to fuel in the engine, and thus impact emissions. One commenter also suggested that, since high DI fuels are expected to cause performance problems in addition to higher emissions, high DI fuels could sour customers on some of the newer, cleaner technologies if DI were not controlled. Comments from Exxon argued against the need to control gasoline distillation properties, arguing that technological improvements such as using air assisted injection to improve fuel vaporization before combustion would be preferred.

At least one automotive industry comment also suggested that the Agency control combustion chamber deposits (CCD), arguing that control of CCD was needed to permit vehicles to meet the very clean emissions levels expected for Tier 2.

4. Need to Control Diesel Fuel Properties

Since diesel vehicles (both cars and light trucks) may be required to meet the same Tier 2 standards as gasoline vehicles, a number of comments addressed the question of whether diesel fuel changes were necessary to enable these vehicles to meet the standards. Sunoco encouraged EPA to consider diesel fuel changes only upon review of the needs of heavy-duty engines in addition to the needs of light duty diesel cars and trucks. The automotive industry representatives and most of the commenters from the environmental community suggested that diesel fuel sulfur levels must be controlled to no more than 50 ppm if diesel engines will be able to meet Tier 2 standards. Some of these commenters stated that low sulfur diesel would enable certain catalysts and/or the use of exhaust gas recirculation to control emissions. The benefits of reducing diesel sulfur levels were noted to include reductions in particulate formation via a reduction in sulfates, and reductions in SO_2 emissions. The Engine Manufacturers Association suggested that, in addition to sulfur levels, cetane, aromatics, and density of diesel fuel also needed to be controlled to enable the cleanest diesel engine technologies.

Some commenters, such as MECA, suggested that diesel sulfur control be pursued concurrently with gasoline sulfur controls to enable refiners to make appropriate capital investments. Sunoco commented that, contrary to expectations, control of diesel sulfur levels concurrent with gasoline sulfur control would not necessarily result in economies of scale due to the number of variables that must be considered, including the sulfur levels required in the two fuels, the location of the refinery, the technologies available to desulfurize these fuels, etc. Even if the feed to the fluidized catalytic cracker unit (FCC) were desulfurized (the expectation if both diesel and gasoline sulfur levels are controlled), Sunoco argued that additional desulfurization may be required if one or both fuels are pushed to the lowest sulfur levels.

VIII. Miscellaneous

EPA received several comments on regulatory issues that were not raised in the Draft Study. These comments are summarized below.

AIAM and Nissan suggested that EPA adopt a phase-in of the Tier 2 standards over a three to four year period to allow vehicle manufacturers to incorporate emission control system revisions along with model changeover. AIAM stated that a similar strategy was followed by

EPA in the Tier 1 standards and by CARB in its LEV standards and in most other regulatory actions that have been promulgated in the past decade. Nissan also favored streamlining of certification.

AIAM and COSVAM both argued that EPA should provide for the needs of small volume manufacturers (SVMs). AIAM stated that if a phase-in approach were adopted, then SVMs should not have to comply with the new Tier 2 requirements until the final year of the phase-in, i.e., when all other manufacturers achieve 100 percent compliance. COSVAM commented that the air quality impact of vehicles sold by SVMs is small, and the proportionally higher burden emission requirements place on SVMs necessitates additional flexibility.

The Northeast Alternative Vehicle Consortium (NAVC) wanted EPA to recognize the fact that advanced transportation technologies (i.e., hybrid electric vehicles and fuel cells) are advancing at an extremely rapid pace and that it is important for the Tier 2 regulations to recognize the rapid technology advancements and their co-benefits of reducing criteria pollutants and greenhouse gas emissions. They therefore suggested that EPA incorporate two year technology reviews with the regulations so that goals are not set in stone for too long.

A commenter from environmental groups recommended labeling of emission levels on new vehicles and setting a PM standard for the supplemental federal test procedure (SFTP) and eliminating diesel testing waivers.

LIST OF COMMENTERS

Docket ID #	Commenting Party
* II-D-01 to - 36	These documents received before draft Tier 2 study issued for public comment
II-D-37	David T. Saunders (private citizen)
II-D-38	Shawn R. Cowls (private citizen)
II-D-39	Robert Brooks (private citizen)
II-D-40	H.M. Gilbreath (private citizen)
II-D-41	Nancy Kerby (private citizen)
II-D-42	Christopher Jesse Imbach (private citizen)
II-D-43	Coalition Of Small Volume Automobile Manufacturers, Inc. (COSVAM)
II-D-44	Manufacturers of Emission Controls Association (MECA)
II-D-45	Wisconsin Department Of Transportation (DOT)
II-D-46	Oklahoma Department of Environmental Quality (DEQ)
II-D-47	Northeast Alternative Vehicle Consortium (NAVC)
II-D-48	Misc. Environmental Organizations (Amer. Council for Energy Efficient Economy, etc.)
II-D-49	State and Territorial Air Pollution Program Administrators/Association of Local Air Pollution Control Officials (STAPPA/ALAPCO)
II-D-50	Alaska Department of Environmental Conservation (DEC)
II-D-51	American Petroleum Institute (API)
II-D-52	Ozone Transport Commission (OTC)
II-D-53	New York State - Department of Environmental Conservation (DEC)
II-D-54	National Association of Automotive Dealers (NADA)
II-D-55	Nissan North America Inc
II-D-56	National Petroleum Refiners Association (NPRA)
II-D-57	22 Environmental Groups, Including: Alaska Center for the Environment, ...
II-D-58	National Park Service/US Dept of Interior
II-D-59	American Lung Assn (Blake Early)
II-D-60	Exxon
II-D-61	The International Center for Technology Assessment/The Campaign on Auto Pollution (Blake Ethridge)

II-D-62	Association of International Automobile Manufacturers (AIAM)
II-D-63	Massachusetts (Executive Office of Environmental Affairs)
II-D-64	Washington - Dept of Ecology
II-D-66	Environmental Advocates
II-D-67	Idaho - Governor
II-D-68	National Conference of State Legislatures
II-D-70	Sinclair
II-D-71	American Automobile Manufacturers Association (AAMA)
II-G-01 to -03	moved to II-D category
II-G-04	Toyota
II-G-05	Engine Manufacturers Association (EMA)
II-G-06	Sunoco
II-G-07	Duplicate of II-G-05
II-G-08	M. Thomas, American Council for Energy Efficient Economy (ACEEE); J. Hathaway, Natural Resources Defense Council (NRDC); R. Hwang, Union of Concerned Scientists (UCS)
II-G-09	J. Colucci, Automotive Fuels Consulting, Inc.
II-G-10 to -64	Internet mail from private citizens in support of more stringent Tier 2 standards and sulfur controls
II-G-65	Florida Department of Environmental Protection (DEP)
II-G-68	Ford - Kelly Brown (comments on sulfur paper)
II-G-66	Marathon Ashland Petroleum
II-G-67	Virginia (Governor)