TIER 2 MOTOR VEHICLE EMISSION STANDARDS

AND THE

IMPACT OF SULFUR IN GASOLINE

May 1998

Mobile Source Committee

Ozone Transport Commission

TABLE OF CONTENTS

Overview

This report provides technical support related to the OTC Mobile Source Committee analysis of the potential for emission reductions from advanced vehicle emission control technology and from reducing sulfur in gasoline in the context of the Tier 2 motor vehicle emission standard setting process. The document was developed based on review of existing information as well as other perspectives presented at two meetings of the OTC Mobile Source Committee (March 17 and April 23, 1998). EPA's Draft Study of Tier 2 Motor Vehicle Standards (Tier 2) became available on April 23, 1998 and EPA's Gasoline Sulfur White Paper became available on May 5, 1998. This technical report provides an examination of existing information related to the need for emission reductions that can be obtained through application of emission control technologies and fuel changes beyond the current vehicle emission standards and programs. In this context, subjects covered include the regional air quality need in the Northeast and Mid-Atlantic States and potential benefits of additional emission reductions beyond those already called for in EPA's proposed ozone transport SIP call (SIP call), including the implementation of Federal measures and State Section 177 Low Emission Vehicle (LEV) and National LEV (NLEV) programs.

This report concludes that reductions beyond these programs are needed to support the regions' and States' efforts to meet the National Ambient Air Quality Standards (NAAQS). The conclusions of the OTC Modeling and Mobile Source Committee's are presented as well as information from the Draft Tier 2 Study.

Secondly, significant advances have been made in vehicle emissions control technology, and are already being used to meet the existing LEV and NLEV program requirements. These advances are continuing, and it is believed that the advanced technologies becoming available in the market now are the result of the technology forcing nature of the LEV programs. Similar advances for the future through emerging technologies are being reported. Technologies for passenger vehicle emission control that are now becoming available in the marketplace as well as emerging technologies, can reasonably be expected to be applied to the growing light duty truck, minivan and sport utility vehicles (SUV) vehicle population.

Thirdly, as vehicle emissions technology has been rapidly improving, there has been a growing understanding and concern over the effect of sulfur in fuels on this technology and ultimately on increasing vehicle emissions. Based on all information available, it should be stated that sulfur's impact, particularly on NOx emissions, increases as the stringency of emission controls increases. Maximizing emission reductions from advanced vehicle technology is predicated on reducing sulfur levels in gasoline and potentially other fuels. Therefore, in addition to advances in emissions technology, reducing sulfur levels in gasoline would provide significant and cost-effective emission reductions on existing and future technologies.

Given the information available to date, the evidence of need, the availability of technology, and the overwhelming evidence that sulfur in fuel increases emissions and can hold back the introduction of cleaner technologies, EPA should act expeditiously through rulemaking on the implementation of new vehicle emission standards for gasoline and diesel fueled vehicles to be effective in model year 2004. Further, EPA should adopt new, stringent national sulfur limits also in time for model year 2004 to ensure maximum emission reductions from existing and emerging vehicle technologies.

Choices for Air Quality Improvements

The Clean Air Act places responsibility on the U.S. Environmental Protection Agency (EPA) to establish emission standards for new vehicles, including both light duty vehicles and light duty trucks. However, the Clean Air Act also recognizes that States can adopt regulations under Section 177 to adopt the more stringent emission standards pioneered in California. As a result, States have two options available to determine emission reductions from light-duty motor vehicles.

Currently within the Ozone Transport Region (OTR) seven States have rules allowing Section 177 to determine new passenger vehicle emissions (with one additional State in the proposal stage). Four of those States have chosen to apply the Section 177 programs to current new vehicle purchases, and three of the seven States are allowing the voluntary NLEV to apply as a compliance option. A total of eight States and the District of Columbia have agreed to allow NLEV to be their primary mechanism for ensuring lower emission standards. In general, States in the OTR have been recently faced with decisions on the right mechanism for determining vehicle emission reductions in the relatively near future. As programs change and as States and the region review these programs in the context of air quality goals, it is likely that additional choices will need to be made. In this context, the Tier 2 standards setting process, as well as changes adopted in the California LEV program, are likely to establish States' light duty vehicle control options for at least the next decade.

Air Quality Need

The Mobile Source Committee has concluded that the National Low Emission Vehicle program, in conjunction with the four State Section 177 programs, will provide significant emission reductions which will help to attain the NAAQS in the OTR. In addition, based on review of available information, the Committee has recommended that the OTC call upon EPA to finalize the Tier 2 study and adopt Tier 2 emission standards as soon as possible to be effective in the model year 2004, and to include rulemaking for expeditious phase-in of low gasoline sulfur levels (optimum use of caps and averages) to ensure that actual vehicle emissions reductions are maximized.

As the Region continues to address its ability to attain and maintain the NAAQS, there is likely to be increased pressure to identify and implement emission reductions from the passenger vehicle sector of mobile sources. Based on modeling and other technical analyses reviewed by the OTC Modeling Committee, current and planned ozone control programs (including the proposed ozone transport SIP call) will be helpful in reducing the emissions that cause ozone. However, these programs will not be sufficient to meet all of the requirements of the Clean Air Act (CAA) by the applicable deadlines. Based on this analyses and additional information compiled, the Committee concludes that further emission reductions from light and medium duty vehicles are needed and that technology and fuel changes by model year 2004 will be available to provide further needed emission reductions from the mobile source sector.

Among the specific provisions included in the NLEV program, EPA is required to complete its Tier 2 rulemaking by December 15, 2000 by adopting standards that are at least as stringent as NLEV. EPA has indicated it will follow a schedule for Tier 2 standards so that by the end of 1998 the agency would propose new standards and subsequent rules would be adopted in late 1999. Tier 2 standards can become effective as early as the 2004 model year. In addition, California has proposed its "LEV II" standards (November 7, 1997) and is expected to complete its rulemaking on proposed changes, including more stringent standards, in the near future. California LEV II as proposed includes a increasingly stringent fleet average requirements, and would promote innovation and catalyze market introduction of emission control technology. California's rule also proposes that new standards be phased in starting with the model year 2004. Testing of vehicles now available in California has led to a conclusion that many new vehicles with common emission technologies have certification test results meeting the proposed LEV and ULEV standards for NOx (0.05 g/mi.), though they are not currently being certified to these levels.

Despite historical improvements in emissions from new passenger vehicles, there are more recent and dramatic trends in sales and operations of light duty trucks, minivans and sport utility vehicles (SUVs). The result is that these vehicles, many being used primarily as passenger vehicles, are an ever increasing portion of the passenger vehicle market. These vehicles are also becoming a larger contributor to the persistent trend for increased vehicle miles of travel (VMT) that threatens to overwhelm emission improvements made to individual vehicles. These issues are compounded by the fact that many of these vehicles have higher emissions than their passenger vehicle counterparts. The recent accounting of this trend shows that sales of these vehicles are now nearly equal to sales of traditional passenger vehicles. In vehicle emission modeling for the Tier 2 Study, EPA predicts that by the year 2020 traditional passenger vehicles will represent less than 40% of driving that is attributable to light-duty vehicles and trucks. EPA expects that the greatest increase in VMT will be from small pick-up trucks, minivans and smaller SUVs. It is also reasonable to assume that emission control technologies used for passenger vehicles can and would be used on these light-duty trucks.

Passenger vehicle emission standards have gradually reflected technologies that result in lower emissions. However, light-duty trucks, which have higher emissions and often exceed the weight limits for vehicles included in LEV and NLEV programs, are dramatically growing in their use as passenger vehicles. The LEV programs adopted by individual States include emission standards for vehicles up to 5,750 lb. loaded vehicle weight (LVW – defined below). Similarly, the NLEV program also covers vehicles up to 5,750 lb. loaded vehicle weight. According to information analyzed by California, light-duty trucks often are in the range of 5,000 to 5,500 lb. "curb weight". California's proposed LEV II uses the "curb weight" which is the weight of the vehicle only – without being "loaded" (curb weight plus 300 lb. test weight) or as "gross vehicle weight" that also includes the added weight of a full payload. Use of the curb weight avoids adding any weight in the certification process that does not comport with the intended purpose of the vehicle (e.g. used as a passenger vehicle). To address these concerns, the proposed CA LEV-II standards apply to vehicles up to 7,000 lb. curb weight. The issue is whether these vehicles, used for the purpose of other passenger vehicles, should meet the same standards as their passenger vehicle counterparts. In essence, the available and emerging emission technologies applied to passenger vehicles can and should be applied to these vehicles.

Table 1 - Comparison of Tier 1, "Default" Tier 2, CA-LEV I and CA-LEV II

Category	**Durability Basis (Miles)**	**NMOG (gm/mi)**	**CO (gm/mi)**	**NOx (gm/mi)**	**PM * (gm/m**
Federal Tier 1	50k	0.25 NMHC		0.40	1.00
	100k	0.31 NMHC		0.60	
"Default" Tier 2	**100k**		**1.7**	**0.20**	

TLEV	50K	0.125 / 0.125	3.4 / 3.4	0.40 / 0.40	NA
	120k	NA / 0.156	NA / 4.2	NA / 0.6	
LEV	50k	0.075 / 0.075	3.4 / 3.4	0.20 / 0.05	NA
	120k	NA / 0.090	NA / 4.2	NA / 0.07	0.01
ULEV	50k	0.040 / 0.040	1.7 / 1.7	0.20 / 0.05	NA
	120k	NA / 0.055	NA / 2.1	NA / 0.07	0.01
SULEV	120k	NA / 0.010	NA / 1.0	NA / 0.02	0.01
ZEV		0.0 ** / 0.0 **	0.0 ** / 0.0 **	0.0 ** / 0.0 **	

Notes for Table 1:

* indicates for diesel only

** indicates that emissions from electric production is NOT included

NA indicates no CA-LEV I or II Standards

(current/proposed; x/y where x=current CA-LEV I and y=proposed CA-LEV II

120k is the proposed durability under CA-LEV II to replace existing 100k requirement

OTC Modeling Committee Conclusions

The OTC Modeling Committee has reviewed available information, including available States' Draft Phase II Attainment Demonstrations, to provide support to the OTC Mobile Source and Stationary/Area Source Committees. The OTC Modeling Committee has previously noted that as much as 70-75% reduction in regional NOx may be needed to ensure modeled attainment in the OTR. The full implementation of a finalized ozone transport SIP call as proposed and other measures are likely to achieve NOx reductions only in the range of 40-50%. From a modeling perspective, any shortfall in regional NOx reductions makes it more difficult for States to attain and maintain their air quality goals. The OTC Modeling Committee also reviewed and highlighted the work of Ozone Transport Assessment Group. The findings of the OTC Modeling Committee are summarized as follows:

- Additional regional NOx and VOC emission reductions provide for additional reductions in transported ozone. However, NOx emission reductions are more effective than VOC reductions in reducing ozone concentrations.
- The NOx emission reductions called for by the CAAA, the Federal measures endorsed by OTAG, and the proposed EPA ozone transport SIP call are needed to begin to address the regional transport problem.
- Emission reductions from both outside and inside of the OTR, including the CAAA controls and the transport SIP call, provide progress towards ozone reductions that support attainment demonstrations by States within the OTR.
- Additional emission reductions, both inside and outside of the OTR would provide additional benefits within the OTR to enable the region to meet and maintain the NAAQS.
- The additional regional emission reductions which could be provided by Phase III of the OTC NOx MOU (when more stringent than the proposed ozone transport SIP call) and Tier 2 emission standards (when more stringent than current LEV/NLEV programs), as well as other additional NOx emission reductions over the SIP call area, would be expected to provide such benefits.

<u>OTC Mobile Source Committee Conclusions</u>

There is significant evidence for the air quality need for more stringent motor vehicle emission control standards. Based on the feedback of the OTC Modeling Committee, the following general conclusions can be made:

- For attainment in the severe one-hour nonattainment areas of the OTR, Tier 2 standards could provide further emission reductions. These areas include the New York, Philadelphia, and Baltimore metropolitan areas, which involve six States in the OTR. Further reductions within the OTR, as well as areas outside of the severe nonattainment areas, can also be expected to help in addressing pollutant transport issues.
- With respect to the eight-hour standard, which appears to be exceeded over large portions of the OTR, Tier 2 standards could provide a significant needed step towards attainment. Even with implementation of the proposed transport SIP call, which includes reductions from LEV/NLEV programs, and other programs identified by the OTC, the geographic coverage of nonattainment areas for the eight-hour standard is likely to be greater than that of the one-hour severe nonattainment areas.
- Maintenance of both the one-hour and eight-hour standards will necessitate continuing efforts to reduce emissions while other factors increase emissions (such as increasing population). With respect to mobile sources, Tier 2 standards are important because the further emission reductions could serve to counteract the influence of increasing vehicle use and increased population, such as evident in trends of increased vehicle miles traveled (VMT).

It is important to note that new Tier II standards must be significantly more stringent than NLEV for the needed air quality benefits indicated above to occur. Standards should be implemented as soon as possible, and should take into account the trend in increased emissions due to a trend in increased sales and operation of light and medium duty trucks for use as personal passenger vehicles.

EPA Draft Tier 2 Study

Information and air quality assessments in the Draft Tier 2 Study provide evidence that supports the conclusions made above by the Committee. In addition, the study provides additional information on existing regional modeling evaluated as being representative of the ozone transport SIP call, and projected population exposure to high ozone levels. The Ozone Transport Assessment Group (OTAG) and related modeling and data analyses reviewed by the Committee all include emission reductions associated with an NLEV program as part of the base programs – Level 0 in OTAG – and were found to be part of an effective, although not a sufficient, strategy useful in reaching the NAAQS. EPA's analysis in its draft Tier 2 study is based on OTAG Run 5 as a surrogate for the proposed transport SIP call, indicating that even after applying the SIP call, which includes LEV/NLEV emission reductions, eight areas within the OTAG area still do not meet the 1-hour standard, and fifteen would not meet the 8-hour averaged ozone standard. Within the OTR, five metropolitan areas are not projected to meet the 8-hour ozone standard. Of the five areas in the OTR referenced by the study, EPA modeling projects that only one of these areas will meet the 1-hour ozone standard after implementation of the ozone transport SIP call. EPA projects that from the 1990 Census populations, ozone levels not meeting the 8-hour standard will affect nearly 32,000,000 persons in the OTR. In summary, the Draft Tier 2 Study concluded that in the timeframe contemplated for Tier 2 standards, there is an air quality need for emission reductions to support attainment and maintenance of the NAAQS. Air quality need is defined in the context of emission reductions beyond the implementation of the proposed ozone transport SIP call, including LEV/NLEV programs.

This analysis is consistent with OTC's conclusion that significant mobile source emission reductions beyond current LEV/NLEV programs are needed for the OTR. Based on evidence of existing and future air quality need and the potential effectiveness of additional emission reductions from light duty vehicles, EPA should establish standards that take full advantage, and create incentives for, advanced and emerging vehicle emission technologies.

Availability of Technology

The purpose of this section is to identify the current and near-term technologies available to support the establishment of emission standards for light duty vehicles and trucks at well below the "default" standards in Section 202 (i) of the Clean Air Act as Amended in 1990. In summary, the information presented below will support that these "default" standards are easily being attained with current technology, and therefore should not be used as a goal for consideration as a future Tier 2 standard. Much of the information discussed here is derived from the Draft Tier 2 Study, with its appendices, released by EPA on April 23, 1998. Based on a review of available information, the Mobile Source Committee believes that Tier 2 standards should be set at levels substantially more stringent than either the default standards or NLEV.

The technology for significant new emission reductions is now expected to be available by model year 2004 (the first year in which Tier 2 standards can be effective). The State of California has proposed a second stage of their LEV program, and is expected to complete any rulemaking later this calendar year. The NLEV program provides vehicles certified at 0.2 grams of NOx per mile standard, while the new standard proposed by California for similar vehicles is 0.05 grams of NOx per mile, or a 75% cut in the NOx certification level. In addition, the new proposed California standards will provide additional VOC emission reductions, in the form of increasingly stringent fleet averages, vehicle certifications beyond its current program (proposed 120,000-mile vehicle emissions certification), and provisions for zero-evaporative emissions. In particular, increased VOC emission reductions such as contained in California's proposed program can provide additional benefits, particularly in concentrated urban areas, that are consistent with the emission reduction needs of the Ozone Transport Region. California has developed these standards based on certification and other data indicating the potential extent of control technology in 2004. It is important to note that a natural gas fueled vehicle has already been certified with certification results about 90% below LEV category levels.

The Committee intends to revisit the issue of cost-effectiveness of more stringent standards in the context of information becoming available in the EPA's study and rulemaking on Tier 2 standards and as part of California's review. However, the Committee believes that few choices or opportunities as significant as the combination of Tier 2 standards and gasoline sulfur reductions exist from mobile sources.

Background

In section 202(i), Table 3, of the CAA, Congress provided specific numerical values for Tier 2 standards for EPA to consider in the establishment of the next generation of high technology vehicles. Congress also instructed EPA to consider standards that were different (either more or less stringent) than those specified in the CAA, as long as these standards were more stringent than the Tier 1 standards which completed phase-in with the model year 1996. Aside from the voluntary improvements beyond Tier 1 vehicles made by the auto industry, all light-duty vehicles and light-duty trucks up to 6,000 pounds GVW now meet these standards as a minimum.

Automotive emission control technology has made remarkable advances in the past several years and many of these technologies are "economically feasible". As a result, the emission reductions which can reasonably be expected from these technologies should be candidates for consideration in the setting of final Tier 2 standards. 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), Low Emission Vehicle (LEV), and Ultra Low Emission Vehicle (ULEV). Standards similar to these are included in the National LEV program that is now in effect, which will generally require the introduction of vehicles meeting the LEV standards by model year 1999 in the Ozone Transport Region and by model year 2001 in the balance of the nation. The exceptions are California and those states with Clean Air Act Section 177 programs.

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. As a result, it is quite clear, given current Federal and California certification information, that the technology exists for essentially all conventional vehicles (gasoline powered internal combustion engines) to achieve lower emissions than are required by current federal Tier 1 standards and the NLEV program. In light of the emission reductions needed in the Ozone Transport Region, EPA should use the proposed CA LEV-II standards as a starting point for their Tier 2 rulemaking analysis. These standards will be discussed in detail in this section.

California's experience in its LEV program has been very positive, and the capacity of emission control technology has exceeded the Air Resources Board's projections. As a result of these advances and in light of the demonstrated need for further emission reductions to reach attainment of the ozone standard, California has proposed a more stringent program that would begin to phase-in in 2004. This program will be enhanced with several emission reduction requirements including tighter NOx limits, lower PM standards for diesels, new super ULEV category (SULEV–that could be considered as "clean" as the ZEV when emissions from electric generation to power these electric vehicles is included), a 120,000 mile durability standard, an expanded light duty truck category which includes most pickups, vans and sport utility vehicles, and a zero emission evaporative emission standard.

A Primer on Emission Controls - "Engine-out" and Exhaust "Aftertreatment"

In general, emission controls on internal combustion engines fall into two categories. The first, called "engine-out" emission controls, are those which result from internal changes to the engine, which result in lower emissions exiting the engine. The primary causes for excessive "engine out" emissions are unburned fuel in the case of HC and high combustion temperatures in the case of NOx. The second category, called "aftertreatment" controls, are those commonly related to the various configurations of catalytic systems with any related exhaust system modifications.

Table 2 and Table 3, presented together for ease of reading on the next page, describe these two general control options and provide insight as to the value of each. It should not be expected that all of the options would necessarily result in the "cleanest" vehicle. The use of cleaner fuel, i.e. fuel with a "low" sulfur content, provides the widest choice of combinations. Generally clean fuel enables the maximum use of advanced technology to produce the best (cleanest) result.

Table 2- "Engine-Out" Emission Controls

Control	Effects
Combustion chamber modifications	More complete burn - eliminates crevices which store unburned f
Multiple intake/exhaust valves per cylinder with variable timing	Allows for more complete combustion and the positioning of the spark plug in the middle of the cylinder

	(one of the more effective HC controls)
Increased exhaust gas recirculation	Allows for more of the exhaust gasses to be re-burned thereby increasing overall combustion/destruction
Improved air/fuel mixture	Promotes the adjustment, by computer, of the air/fuel mixture to comply with the engine's "needs" at any time
Improved exhaust evaluation techniques to adjust for aggressive driving	Needs for fuel adjustments are most difficult under acceleration a deceleration. Better sensors improve the ability to adjust to these changes quickly and more accurately. **(one of the more effectiv NOx controls)**
Individual cylinder air/fuel controls	Eliminates the injection of fuel at the wrong times as with multi-po injection **(one of the more effective HC controls)**
Air assisted fuel injectors	Better atomization of the fuel creates a more homogeneous mixture.

Table 3- "Aftertreatment" Emission Controls

Control	**Effects**
Catalyst improvements	Changes in material and structure can account for great improvements
Retention traps	Stores emissions from start-up and high speed changes with a release of the emissions during steady state operation when catalytic converters are the most effective
Secondary air injection	Promotes more complete combustion in the hot exhaust manifold
Insulated and dual-wall exhaust systems	Promotes heat retention and quicker light-off of the catalytic converter.
Advanced catalyst design	Designs using multi-metals and multi-layers for improved efficien **(greatly improved HC <u>and</u> NOx control)**

<u>Impact of Sulfur Levels on Existing Technologies and Tier 2 Standards</u>

A complete discussion on fuel sulfur levels as it impacts the development of new technologies and the enhancement of existing technologies is discussed elsewhere in this report. The conclusion presented however is clear. Technology improvements and emission reductions are substantailly enabled by the reduction in fuel sulfur levels. Neither fuel quality nor vehicle technology should be considered to be a sufficient solution independently. The key is the synergism between fuel quality and vehicle technology.

Advanced Technologies - The Next Frontier

It is clear that technologies other than the 100+ year old internal combustion engine are becoming the hope of the future, both from the standpoint of emissions of ozone, carbon monoxide and greenhouse gases, and from the standpoint of optimizing use of natural resources (i.e. fuel consumption). These new technologies are emerging and anticipated to be available in the near future. Only the need for some refinement, coupled with the benefits of mass-production, stand between the present and this new future. Participants in the 18^{th} North American Motor Vehicle Emission Control Conference (NAMVECC) in Los Angeles in March 1998 were presented with a wide variety of new and emerging technologies for vehicle propulsion that have developed far beyond the conceptual stages. Commitments have been made by the manufacturers of fuel cell technology that 2004 would be the year of the commercially available fuel cell.

Given this background, the presentation made by EPA in its draft Tier 2 study the area of advanced technologies appears to be incomplete, with an overemphasis on improvements to the internal combustion engine. New technology, with the commensurate reduction in emissions, provides the hope for the future. An example of these emerging technologies includes the use of fuel cells, electrics, and hybrid electric and fossil-fuels. The levels of emission reductions which can be reasonably expected from these technologies should be a primary consideration in the establishment of new motor vehicle emission standards under the Tier 2 requirement placed upon EPA by the 1990 Clean Air Act as amended in 1990. The setting of the new Tier 2 standards provides an excellent and perhaps the only chance to establish new national standards at a level which will promote the most rapid introduction of technology already well underway.

A fuel cell is an electrochemical device that generates electricity from a chemical reaction between hydrogen and oxygen, in the part of the overall unit called the "reformer". The hydrogen may be from conventional fossil fuels which is combined electrically in the fuel cell (a series of plates with thin plastic film in between) with oxygen from the air to produce electrical energy. The byproducts of this process typically are heat and water vapor. The individual parts to produce the reformer are inexpensive, and as a result, when the engineering to mass-produce complete units can be readily accomplished, the cost of reformers can be expected to decrease. The necessary hydrogen can either be carried as a compressed gas or extracted from a fuel, such as gasoline or methanol, carried on the vehicle. 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, for all pollutants, including greenhouse gases. Another consideration regarding fuel cell technology is fuel quality; if gasoline is used in fuel cells, it must be low in sulfur.

Other emerging technologies include significant improvements in battery technology that has a wide variety of final applications other than just the electric vehicle. These include the hybrid propulsion system, which combines a small gasoline or diesel-powered engine to generate electricity, a bank of batteries and an electric motor, and is designed to operate at maximum efficiency over changing driving conditions. These designs can result in very high fuel efficiency and also very low emission levels.

Cost and Cost Effectiveness

The cost and cost effectiveness information presented in EPA's draft Tier 2 study can be expanded to address the newer and emerging technologies. Briefly, EPA indicates that the incremental costs for technology beyond that of NLEV are low enough to result in costs of less than $2500 per ton of NOx emissions removed. It should be noted that there is no limit on technology that can be used to satisfy LEV and NLEV programs. Therefore, incremental costs are better looked at in terms of a wide range of technologies that can be utilized to satisfy a fleet/corporate emissions average.

Cost effectiveness estimates in EPA's Tier 2 study compare favorably with other control measures as indicated below.

- Industrial boiler 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.

In addition, beyond State Implementation Plan programs already proposed, it is difficult to identify any measures to reduce NOx emissions at a cost of less than $2,500 per ton. (For example, in Pennsylvania's stakeholder process for ozone attainment planning in the southeastern portion of the State, aside from some stationary source reductions, there are few opportunities identified to reduce NOx emissions at less than $2,500 per ton.) Often even if relatively low cost per ton reductions can be identified, the magnitude of these reductions is relatively small. Other highway and non-highway NOx emission reduction opportunities often exceed $10,000 per ton of NOx reduction. In many instances, States have included measures that are projected to cost well in excess of the $2,500 per ton of NOx reduction asserted in the draft Tier 2 study.

It is believed that few choices or opportunities as significant as the combination of Tier 2 standards and gasoline sulfur reductions exist from mobile sources. It is strongly believed that the availability of this control option should be the primary consideration especially since Tier 2 emission standards offer probably the largest additional means of emission reductions. As discussed earlier in this report, emission reductions are required to accomplish attainment of many areas in the country. With the concept of transport firmly established by the Ozone Transport Assessment Group (OTAG), it is clear that emission reductions in only the northeast states will not be adequate for those states to reach attainment without some national strategies. It is imperative that the Ozone Transport Commission and the EPA look towards a strong Tier 2 standard as one more important strategy towards attainment.

Several important conclusions result from this review of EPA's draft Tier 2 Study:

- Technologies have developed far beyond those needed to satisfy LEV/NLEV requirements.
- Lower gasoline sulfur levels are integral to the full development of future gasoline-based technologies.
- Few choices or opportunities as significant as the combination of Tier 2 standards and gasoline sulfur reductions exist from mobile sources.
- The evaluation by EPA of the role of advanced technologies was not complete.
- EPA should use the proposed CA LEV-II standards as a starting point for their analysis of possible Tier 2 standards.

Fuel Sulfur

To the extent that gasoline remains a major fuel in the future, reducing sulfur levels in gasoline results in cleaner burning gasoline and enables the optimum emissions reductions available through newer, cleaner vehicle technologies. Existing information on the effect of sulfur in gasoline on emissions indicates that additional emission reductions can be achieved by decreasing sulfur levels. Studies completed individually and cooperatively by the auto manufacturers and the petroleum industry support this relationship. These studies also suggest that at emission levels being considered by California (second stage LEV), the effect of sulfur in gasoline can be more significant than have been demonstrated in the past. In general, the newer cleaner LEV category vehicles and associated emission technologies are more sensitive to high to low (e.g. 300-40 ppm by weight) sulfur levels in gasoline. These studies provide strong evidence by industry for the need to control sulfur levels in gasoline, particularly, to provide these reductions no later than the implementation with Tier 2 vehicle emission standards. There are also indications that some of the new hybrid technologies based in part on gasoline (e.g. gasoline fuel cell hybrids) also depend on gasoline sulfur reductions.

<u>Emissions Response to Sulfur</u>

Sulfur occurs naturally in crude oil. Through the refining process, some sulfur remains in gasoline. The amount of sulfur in gasoline is variable depending on the type of crude oil processed and refinery capabilities. As a result, sulfur levels in gasoline can be variable. Sulfur is a catalyst poison. No catalyst designs currently available are fully sulfur tolerant. Recent studies have shown that the sulfur effect on emissions, particularly NOx emissions, becomes more significant at lower levels of sulfur. While moderate reductions in sulfur content are helpful, even greater emission response and benefits occur by reducing sulfur content to low levels (greater emissions response from 150 to 40 ppm than from 330 ppm to 150 ppm). It should also be noted that new vehicles continue to be certified to the respective emission standards when fueled on a certification fuel that is inconsistent with in-use fuel sulfur levels. This certification has continued despite national sulfur content averages in the range of 300 to 350 ppm. As a result, vehicles in use while using commercial gasoline will have much higher emissions than when certified to a particular emission standard. The impact of sulfur from commercial grade gasoline on Tier 0 and Tier 1 vehicles have been less dramatic. It should be noted that vehicles certified as Tier 0 and Tier 1 are being nearly phased out as the result of existing LEV/NLEV programs. As newer emission technologies are being used to meet certification standards, the loss of emissions reductions is expected to increase due to sulfur and increased sensitivity of available and emerging technology to even small amounts of sulfur. In EPA's staff paper on gasoline sulfur, they conclude while there is a potential to vary the type and quantity of precious metal used in catalysts, it is unlikely that the sulfur effects can be eliminated and that no vehicle tested in industries' studies was completely insensitive to sulfur. Based on the data presented, the OTC Mobile Source Committee concurs with this assessment.

Various studies have demonstrated the adverse effect of sulfur on emissions. Recent studies prepared independently by both the automobile manufacturers and the petroleum industry show that increasing gasoline sulfur from 40 ppm to 600 ppm results in a VOC increase of nearly 50% and a NOx increase of approximately 150%. In general, sulfur has a more pronounced effect on NOx than on VOC emissions. These studies have also indicated that the increase in emissions is not linear with sulfur content, but rather that a greater percentage increase in emissions occurs at lower sulfur levels. Thus, as cleaner cars enter the fleet in the Northeast and Mid-Atlantic States through NLEV and individual State LEV programs, additional reductions could be obtained from operating those vehicles on low sulfur fuel. Recent studies have shown that LEV technology vehicles are more sensitive to a given sulfur differential than Tier 1 or Tier 0 vehicles. The impact of sulfur from commercial grade gasoline on Tier 0 and Tier 1 vehicles resulted in a loss of emission reduction between 5% and 15%. The estimated loss of emission reduction on LEV technology vehicles from sulfur levels at 330 ppm as opposed to 40 ppm is between approximately 60% and 250%. Although catalyst suppliers have indicated that catalysts can be manufactured that reduce emissions significantly even with moderate levels of sulfur. Even moderate sulfur levels would constrain the introduction of improved catalyst and emission performance that can be achieved with even lower levels of sulfur.

<u>Experience with Sulfur Control</u>

Recent national average sulfur levels in gasoline are at approximately 300-340 parts per million by weight (ppm). By contrast, sulfur levels in effect in California, and being considered in some other areas in the U.S., such as already reached in California (either capped at 80 ppm of sulfur per gallon of gasoline with a 30 ppm average or any gallon of gasoline with a flat limit of 40 ppm). As a result, gasoline sulfur levels in California currently average about 20 ppm. For areas where the Phase II of the Federal Reformulated Gasoline program applies, including areas where most of the gasoline is sold in the OTR, EPA expects that starting in 2000 gasoline sulfur content will average about 150-170 ppm with no cap per gallon (the American Petroleum Institute (API) has indicated that sulfur may be "capped" at approximately 200 ppm). In addition, Japan currently has sulfur levels similar to those in California, and

Canada and the European community is investigating similar levels. Japan has a maximum per gallon limit for sulfur of 100 ppm with 1996 premium gasoline levels averaging at 7 ppm and regular grade averaging at 27 ppm. The European Parliament has adopted fuel specification caps for both gasoline and diesel fuel of a 150 ppm cap starting in the year 2000 and a 30 ppm cap starting in the year 2005.

Ability to Reverse Effects of Sulfur

Although not yet studied directly by either EPA or industry, there is concern that once a vehicle (particularly a new, cleaner vehicle) has been temporarily exposed to high sulfur levels, the negative emission impact may not be reversed when subsequently operated on gasoline with lower sulfur levels. This lack of ability for vehicle emissions controls to rebound from temporary exposure to varying gasoline sulfur levels is becoming commonly referred to as the "reversibility" or "irreversibility" effect. Testing conditions used in combined and separate industry studies thus far subject vehicles to artificial and often extraordinary procedures to "purge" the vehicle engine and emissions system of sulfur effects. These extraordinary procedures used in testing often involve engine operating conditions (rich and hot) that would or could not be reproduced in real world driving conditions, particularly with more stringent emissions certification. The new Supplemental Federal Test Procedures (SFTP) will further constrain if not eliminate the conditions (e.g. dramatic changes in air-fuel ratio) that allow purging of the effects of sulfur on the emissions system. Additional petroleum and auto industry testing regarding the possible reversibility of this effect is underway and information is expected mid-1998. However, any new information should be looked at in terms of real world effect and include the new supplemental procedures.

While there is general agreement that sulfur adversely affects the operation of catalytic converters there is less conclusive evidence as to what extent that effect can be reversed through "normal" operation on lower sulfur fuel. While sulfur effects on Tier 0 and Tier 1 vehicles appear to be reversible, there is not a significant database to support a similar conclusion for cleaner technology vehicles such as LEVs and ULEVs. Testing reported thus far on such vehicles indicates that some recovery of emission controls is gained from operation on low sulfur fuel, but only after purging sulfur through an aggressive driving cycle resulting in a high engine-out VOC leading to increased catalyst temperature (referred to as a hot-rich condition).

The hot-rich condition needed to purge the effects of sulfur is problematic in that it is an operation that results in high emissions. The Supplemental Federal Test Procedure (SFTP) becomes part of the certification procedure starting with model year 2001 vehicles, and includes testing for even tighter emission standards while accounting for more aggressive driving cycles. Therefore, the hot-rich condition necessary for sulfur purge is unlikely to occur under actual driving conditions.

Given the disagreement between industry groups surrounding the use of technology and reductions of gasoline sulfur to provide for additional emission reductions, the Committee invited major stakeholders, including the auto and oil industry, to share their perspectives at the Committee meetings. The following is a summary of these perspectives.

Industry Perspective

The American Petroleum Institute (API), the National Petroleum Refiners Association (NPRA), the American Automobile Manufacturers Association (AAMA) and Association of International Automobile Manufacturers (AIAM) were invited to both Committee meetings to respond to initial presumptions developed by the Committee regarding the availability and need for new vehicle technology and fuel sulfur reductions. They were also invited to present their proposals and additional perspectives on how technologies and fuel changes can achieve additional emission reductions, and particularly as related to a Tier 2 standards setting by EPA. While both the auto and petroleum industries have concluded that reducing sulfur is needed, they disagree on the level of sulfur reduction needed, the relative cost-effectiveness of emphasizing vehicle or fuel controls, and the ability of catalyst technology to resist sulfur effects.

The differences between industries are most striking when comparing a recent API/NPRA proposal and a recent AAMA/AIAM petition to EPA (selected background materials are attached). The API/NPRA gasoline sulfur proposal starting in 2004 applies summer-time gasoline averages differentially across the U.S. (based primarily on OTAG geographic areas). This proposal does not cover the States of Maine, New Hampshire or Vermont. For the remainder of the States in the OTR, an average of 150 ppm would be met during the summer months. It is worth noting that in the context of what these States can expect through use of the Federal RFG II program (see above), the API/NPRA seasonal proposal offers minimal sulfur reduction benefit, as 70-80% of year-round gasoline throughput in the OTR will be Federal RFG II in 2000. Alternatively, the AAMA/AIAM petition to EPA calls for rulemaking at a minimum to cap per gallon gasoline sulfur content year round and nationally at 80 ppm with an average of 30/40 ppm. The combination of a cap and average is designed to provide flexibility to industry in meeting requirements.

It should be noted that even within the petroleum refining industry there appears to be broad differences in the sulfur levels that can be supported. For instance, in early 1998 the largest independent refiner in the U.S. endorsed an 80 ppm per gallon sulfur cap, touting its ability to apply refining technology that desulfurizes crude oil (hydotreating). In addition, testing to date has shown some variability between tested vehicles in their sensitivity to gasoline sulfur. However, it should be noted that sensitivity to gasoline sulfur is accelerated with increasingly advanced control technologies and lower emission levels.

Both the automobile manufacturers and the petroleum industry have recognized the need for sulfur control and made separate proposals to EPA for sulfur control. The AAMA/AIAM petition to EPA calls for a sulfur per gallon cap of 80 ppm by weight, similar to the sulfur limits in California reformulated gasoline.

The API/NPRA proposal includes a seasonal average sulfur requirement of 150 ppm in the OTAG region during the summer, and a 330 ppm average the rest of the year. Other states would receive higher sulfur fuel, on the order of 330 ppm. As a seasonal and regional program, the API/NPRA relies on the concept that sulfur impacts are fully reversible. API/NPRA is currently sponsoring research on this issue.

Some of the major differences, particularly as they relate to the OTR, between the API/NPRA proposal and the AAMA/AIAM petition are summarized as follows:

	API/NPRA Proposal	AAMA/AIAM Petition
Geographic area covered	Portion of OTR (not ME, NH, VT) and OTAG area (at 150 ppm); other areas outside of CA get 300 ppm average	Entire U.S.
Level of Reduction	150 ppm average in portion of OTR and OTAG area	30 ppm by weight annual average (or 40 ppm by weight per gallon) and per gallon cap of 80 ppm
Period	Seasonal (May-September)	Year-Round
Timing	2004	"as rapidly as possible"

The automobile manufacturers have also indicated that low sulfur fuel is necessary for successful introduction of other advanced technology engines such as gasoline direct injection and gasoline based fuel cells. Diesel engine manufacturers have also indicated that diesel engines will need reductions in diesel fuel sulfur levels to make emission control devices more effective.

Certification

New vehicles are currently certified to vehicle emission standards while operating on a certification fuel. This fuel is much cleaner than fuels available in-use in the U.S. with the exception of California's Phase II fuel, particularly with respect to sulfur levels. Certification fuel typically averages sulfur levels below 100 ppm with levels often in the range of California's fuels (below 40 ppm). Under the NLEV program, certification fuels are harmonized with California fuel requirements.

Caps Versus Averages

Caps on sulfur levels require that refiners not exceed some specified level in any batch. As a result a maximum per gallon gasoline sulfur limit is established with a cap. EPA has noted that caps would force individual refiners to control individual high sulfur level batches more so than with an averaging system in place. Currently gasoline sulfur is voluntarily "capped" at approximately 1000 ppm. However recent averages have been between 300 and 350 ppm, with Federal RFG expected to average between 150 and 170 ppm with no cap. In California, sulfur can be no greater than 40 ppm per gallon by weight as a "flat limit", or at the refiner's option, no greater than 30 ppm annual average by weight with a per gallon cap of 80 ppm.

Costs

API/NPRA, while agreeing that lower sulfur levels in gasoline result in lower emissions, have expressed major concern about increased costs to their industry. They also predict costs to increase dramatically with reductions in average sulfur levels. Generally, there are at least two major options available for reducing sulfur in gasoline; either switching to a lower sulfur crude oil or by applying control processes at the refinery. Refinery options vary with hydrotreating the fluidized catalytic cracker (FCC) gasoline blendstock as a common option. Hydrotreating is a process that uses hydrogen gas under high pressure and temperature to force out sulfur. If hydrotreating is applied to the feedstream rather than the blendstock, many of the disadvantages often associated with blendstock hydrotreatment (e.g. a decrease in octane and reduced volume of gasoline produced) can be avoided. In addition hydrotreatment of the feedstream can also reduce sulfur levels in diesel fuel. Because this process treats a larger portion of the crude feed stock, it tends to be more expensive and has been used less in the U.S.

The cost estimates of sulfur control as an emission reduction strategy vary. API/NPRA estimates the cost of 150 ppm average fuel to be 1.5 cents per gallon (cpg) increase. The API cost estimate for reducing sulfur to 40 ppm from approximately 300 ppm is 5.1 cents per gallon. The cost range developed for EPA/DOE estimates for the same reduction are between 5.1 and 8.0 cents per gallon. Given these two estimates, the cost to reduce sulfur levels from the current average of 330 ppm down to 40 ppm would be in the range of 5 to 8 cents per gallon of gasoline for the eastern half of the U.S. However, EPA has indicated in their staff paper on gasoline issues that due to "promising new technology" (i.e. catalytic distillation) this cost may be reduced to between 1 and 2 cents a gallon. EPA is currently investigating the reasonableness of these technologies as well as looking at any efficiencies or economies of scale from including desulfurization of diesel fuel in conjunction with gasoline.

As mentioned previously, the costs of fuel sulfur reduction are associated with two types of emission reduction benefits. First, additional hardware advances in emissions reductions are facilitated only through the use of clean fuels. Second, reductions in fuel sulfur would result in a reduction in emissions from current in-use technology with no additional hardware and therefore no additional cost to the motorist.

Conclusions

In conclusion, there is evidence to support the need, in terms of timing and stringency, for mobile source emission reductions within the OTR substantially more than provided for by the Clean Air Act and the implementation of LEV and NLEV programs. Given a persistent trend for increasing VMT, the amount of time it takes for any new vehicle standards to become fully effective, and the need to attain and maintain both the 1-hour and 8-hour ozone standards the need for stringent and timely Tier 2 emission standards is clear. Through its analyses, EPA's general conclusions on the need for immediate and stringent new vehicle emission standards are consistent with those expressed by the OTC.

Information on current and emerging emissions technology indicates that these substantial emission reductions would be available in model year 2004. Information in the draft Tier 2 Study shows that vehicles already available are achieving at least 75% less NOx emissions than required by the LEV certification levels. These emission reduction technologies also should be applied to a broader range of vehicles, including SUVs, minivans, and pickup trucks that are increasingly becoming a larger portion of the passenger vehicle fleet. In addition, given the emerging technologies and additional technology initiatives such as increasing fuel efficiency, EPA needs to consider gasoline and diesel fuels, as well as alternative fuels and technologies (e.g. fuel cells, hybrid technologies, and electric), when setting new standards.

The ability to cut emissions and comply with more stringent vehicle emission standards through the use of new technologies is integrally linked with sulfur levels in fuels. The substantial effect of sulfur levels in gasoline on existing fleets, including the current phase-in of LEV technologies, is ample reason for EPA to establish stringent sulfur limits. In addition, given the emission reduction opportunities from introducing new technologies and the increasing sensitivity of these technologies to even low levels of sulfur, EPA should ensure that the maximum emission reductions are achieved through sulfur limits and emerging technology. Therefore, EPA should, in conjunction with stringent new vehicle standards, establish stringent sulfur limits nationally no later than model year 2004.