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# CLEAN FUELS IN THE UNITED STATES

# THE KEY TO LOW EMISSIONS

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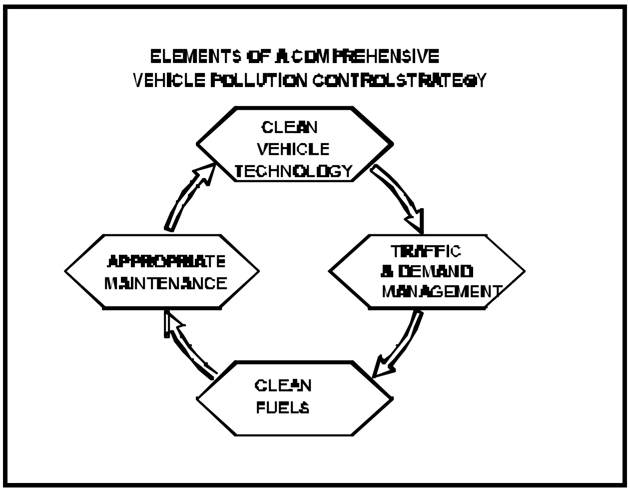
## 1. Background and Introduction

Over the past 50 years, the world's vehicle population has grown fifteenfold. As a result, the global motor vehicle population today -- including passenger cars, trucks, buses, motorcycles and three wheeled vehicles (Tuk Tuks) – exceeds 800 million units and is projected to reach 1 billion within a few years. Most of these vehicles were originally concentrated in the highly industrialized countries of the OECD, but that is now changing. As a result, an increasing number of urbanized areas in developing countries are experiencing accelerated growth in vehicle population and vehicle miles traveled. While these vehicles have brought many advantages -- increased mobility, economic flexibility, efficiency improvements, more jobs, and other quality of life enhancements as well as increased traffic congestion and traffic accidents. -- the benefits have been at least partially offset by excess pollution and the adverse effects which result.

Motor vehicles emit large quantities of carbon monoxide, hydrocarbons, nitrogen oxides, and such toxic substances as fine particles and lead. Each of these, along with secondary by-products such as ozone, can cause adverse effects on health and the environment. Because of the growing vehicle population and the high emission rates from many of these vehicles, serious air pollution and health effect problems have been an increasingly common phenomena in modern life.

## 2. Elements of a Successful Mobile Source Control Program




Reducing the pollution that comes from vehicles will usually require a comprehensive strategy. Generally, the goal of a motor vehicle pollution control program is to reduce emissions from motor vehicles in-use to the degree reasonably necessary to achieve healthy air quality as rapidly as possible or, failing that for reasons of impracticality, to the practical limits of effective technological, economic, and social feasibility. A comprehensive strategy to achieve this goal includes four key components: increasingly stringent emissions standards for new vehicles, specifications for clean fuels, programs to assure proper maintenance of in-use vehicles, and traffic and demand management. These emission reduction goals should be achieved in the most cost effective manner available.

Following passage of the 1970 Clean Air Act Amendments, the US EPA realized that cleaner fuels would be a critical component of its clean air strategy. Over the course of the past 30 years this understanding has grown and deepened. Fuel quality is now seen as not only necessary to reduce or eliminate certain pollutants (e.g., lead, benzene) directly but also a precondition for the introduction of many important pollution control technologies. Further, one critical advantage of cleaner fuels has emerged - its rapid impact on both new and existing vehicles.

The remainder of this report will focus on three stages of the US clean fuel effort - the initial period with the primary attention directed toward phasing out leaded gasoline, the second stage where other gasoline reformulations received the most effort, and the latest stage where the move toward almost zero sulfur in both diesel and gasoline is underway.

## 3. Phase 1 - Eliminating Lead From Gasoline

The toxic properties of lead at high concentrations have been known since ancient times as lead has been mined and smelted for more than 40 centuries. Precautions in its use have been widespread for centuries but only within the past few decades have its adverse impacts at very low levels have been fully appreciated. As recently noted, "Lead poisoning is currently thought to be one of the most serious diseases of environmental and occupational origin because of its high prevalence, environmental pervasiveness, and persistence of toxicity in affected populations."[1]

### a. Effects On Children

Children are considered particularly susceptible to the adverse effects of lead because of smaller body size, higher rates of absorption through ingestion and sensitivity of target organs, particularly the brain. Low level exposure in children has adverse effects on the development and function of the central nervous system leading to various behavioral disorders, including distraction, inability to follow simple directions, and lower scores on intelligence tests. The seminal work in this area was the 1979 report by Dr. Herbert Needleman and his colleagues which showed that children with high levels of lead accumulated in their baby teeth experienced more behavioral problems, lower IQ*s, and decreased ability to concentrate.[2] More recent evidence indicates that it is not only the length and severity of exposure to lead which results in the health damage but the age at which exposure occurs. This is especially important because "Of all the persons in the community, the newborn child is the most prone to injury from overexposure to lead for several reasons, and the damage that may be caused then will have the greatest long-term social and economic consequences."[3] Needleman has shown that exposure to lead in childhood is associated with deficits in central nervous system functioning that persist into young adulthood. Children whose teeth had lead levels greater than 20 ppm at ages 6 and 7 were found to have a markedly higher risk of dropping out of high school and of having a reading disability as compared to those with dentin lead levels below 10 ppm.[4] A study, in which 249 children were monitored from birth to two years of age, found that those with prenatal umbilical-cord blood lead levels at or above 10 micrograms per deciliter consistently scored lower on standard intelligence tests than those at lower levels.[5] More recently, British researchers reviewed every epidemiologic study on lead and IQ published since 1979 that had

1/"Lead In The Americas, A Call For Action", Howson, Hernandez-Avila, and Rall, 1996.

2/ "Deficits In Psychological And Classroom Performance Of Children With Elevated Dentine Lead Levels", Needleman, et al, The New England Journal Of Medicine, Vol. 300, Number 13, March 29, 1979.

3/ "Exposure to Lead In Childhood: The Persisting Effects", Moore, Nature Vol. 283, 24 January 1980

4/"The Long Term Effects of Exposure To Low Doses of Lead In Childhood, An 11 Year Follow Up Report", Needleman, Schell, Bellinger, Leviton and Allred, The New England Journal of Medicine, January 11, 1990.

5/"Longitudinal Analyses of Prenatal and Postnatal Lead Exposure and Early Cognitive Development", Bellinger, Leviton, Waternaux, Needleman, and Rabinowitz, The New England Journal of Medicine, April 23, 1987.

over 100 children and measured IQ as a function of blood or tooth lead levels. Based on a meta-analysis of all the data, they concluded that a doubling of body lead burden from 10 to 20 µg/dl in blood levels was associated with a mean fall of about 1 to 2 IQ points.[6]

**b. Effects on Adults**

As part of its overall review of lead in gasoline during the mid 1980's, the U.S. Environmental Protection Agency (U.S. EPA) uncovered evidence linking lead in the blood and high blood pressure in adults and these findings have subsequently been verified in several other studies.[7] Lead-induced hypertension has been observed in three types of studies: population-based studies in which lead exposure and blood pressure are measured; prospective studies, in which blood pressure is monitored in persons as their lead exposures increase (usually in occupational settings, including employment in traffic police and transport), and case: control studies, in which lead exposure is measured and compared in persons with and without diagnosed hypertension. While the effects of lead on blood pressure are relatively small, they are statistically significant and discernible after careful control of other risk factors. Given the clear relationship between blood pressure and risk of stroke and hypertensive heart disease, a population shift in blood pressure increases the predictable incidence of these diseases substantially.

Other studies show that exposure to lead may impair renal function in the general population.[8] "Continuous, prolonged high lead exposure results in chronic and nonreversible effects associated with progressive interstitial fibrosis, which may lead to renal damage characterized by interstitial fibrosis, sclerosis of vessels, glomerular atrophy, reduced glomerular filtration, and azotemia."[9]

**c. Overall Conclusions Regarding Health Effects**

Several comprehensive studies of the health issue have been conducted over the past two decades with the result that health concerns are increasingly emerging at lower and lower levels. Lead is now recognized to have no physiologic role in biological systems, including human biology. Over the past century, a range of clinical, epidemiological and toxicological studies have continued to define the nature of lead toxicity and to identify young children as a critically susceptible population. At low doses, lead is particularly toxic to the brain, the kidney, the reproductive system, and the cardiovascular system. Its manifestations include impairments in intellectual function, including problems in learning among children, kidney damage, infertility, miscarriage, and hypertension. At relatively high exposures, lead is lethal to humans, usually causing death by inducing convulsions and irreversible hemorrhage in the brain. Long term

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6/Pocock S.J., et al, "Environmental Lead and Children's Intelligence: A Systematic Review of the Epidemiological Evidence", BMJ 1994, November 5; 309: 1189-97.

7/Schwartz, J., H. Pitcher, R. Levin, B. Ostro, and A.L. Nichols. 1985. Costs and Benefits of Reducing Lead in Gasoline: Final Regulatory Impact Analysis , Report No. EPA-230-05-85-006, U.S. EPA, Washington, D.C.

8/"Impairment of Renal Function With Increasing Blood Lead Concentrations in the General Population", Staessen, Lauwerys, Buchet, Bulpitt, Rondia, Vanrenterghem, Amery and the Cadmibel Study Group, The New England Journal of Medicine, July 16, 1992.

9/"Effects of Lead On Adult Health", Julieta Rodriguez de Villamil in "Lead In The Americas, A Call For Action", Howson, Hernandez-Avila, and Rall, 1996.

exposures may be associated with increased risks of kidney cancer.

A study by Schwartz estimated that in economic terms, the total benefit of a 1 microgram per deciliter reduction in blood lead levels for one year's cohort of children in the United States is $6.937 billion, with $5.060 billion due to earnings losses as a result of loss of cognitive ability and lower educational achievement and the remainder due to increased infant mortality.[10] With a reduction in median blood lead levels in the U.S. from 1980 to 1990 of 6.4 micrograms/deciliter, this reflects a savings of $44.4 billion over this time frame alone.

### d. The Linkage Between Lead in Gasoline and Lead in Blood

Gasoline lead affects human health through several media. First, of course, is air and it is generally recognized that over 90 percent of atmospheric lead concentrations in most urban areas which use leaded gasoline are associated with gasoline lead emissions. Beyond this, however, gasoline lead increases the amount of lead ingested through the digestive system. This is especially true with children who not only receive this lead through the normal food chain, but through their playing in streets and yards which are contaminated with lead. When viewed in this context it is not surprising that "both average blood lead levels and cases of lead poising in children correlate more strongly to gasoline lead than to lead in the air alone."[11] Because of this close relationship, reducing the lead content of gasoline has been demonstrated to significantly reduce the health risks in urban areas. For example, as total lead in gasoline was reduced by 96% in the United States during the 1980's, ambient lead levels were reduced by 87% and the median blood lead levels by 70%.[12]

### e. The US Program To Phase Out The Use of Lead Was Too Slow

While one motivation for phasing out the use of lead in gasoline was the direct health effects, another reason was the need for lead free fuel to enable the use of catalytic converters to reduce other vehicle pollutants. While unleaded gasoline was made widely available, therefore, prior to the introduction of catalysts, some leaded gasoline continued to be marketed until the mid 1990's. Since leaded gasoline cost less art the pump than unleaded gasoline, some individuals were motivated to use leaded gasoline in catalyst equipped cars. The impact of leaded petrol on catalyst performance was studied by the US Environmental Protection Agency in 1984.[13] Twenty-nine in use automobiles with three-way catalyst emission control systems were misfueled with leaded gasoline in order to quantify the emissions effects. The vehicles used between four and twelve tanks of leaded gasoline with an average lead content of 1.0 grams Pb per gallon. Four different test programs were conducted with different misfueling intensities (rates) and mileage accumulation schedules. The US Federal Test Procedure (FTP) and several short tests were conducted at various stages. The results of the program indicated that vehicle

10/"Societal Benefits of Reducing Lead Exposure", Schwartz, Environmental Research 68, 105-124, 1994.

11/"Health Effects of Gasoline Lead Emissions", Joel Schwartz, U.S. EPA, April 6,1983

12/US EPA, "The International Dimensions of Lead Exposure", Silbergeld, The International Journal of Occupational and Environmental Health, Volume 1, Number 4, Oct/Dec 1995.

13"Misfueling Emissions of Three-Way Catalyst Vehicles", R. Bruce Michael, U.S. Environmental Protection Agency, presented at the Society of Automotive Engineers, Fuels and Lubricants Meeting, October 8-11, 1984, SAE Paper #841354.

emissions are mainly affected by the amount of lead passing through the engine and secondarily by the rate of misfueling.

Based on the data collected, it was possible to develop quantitative relationships between lead consumption and HC, CO and NOx emissions. Emission levels for each of the 29 vehicles involved in the EPA program were normalized to the levels which existed prior to any lead contamination[14] and then plotted as a function of the total amount of lead consumed. Normalization made it possible to eliminate the influence of different emissions standards. Regression equations were then derived relating HC, CO and NOx emissions respectively to the grams of lead consumed by each vehicle.

FTP emissions of HC, CO and NOx generally increase steadily with continuous misfueling. HC emissions increase the most rapidly on a percentage basis, followed by CO and, to a lesser extent, NOx. Reasonably good correlations exist for the relationship between total lead consumed and emissions increases of each pollutant, especially for HC the pollutant most affected. In the case of this latter pollutant, approximately 90% of the variability in emissions can be explained by the lead exposure. More recent data tends to verify these results.

With the benefit of hindsight, it is now generally agreed that the EPA lead phase out was much too slow. A more rapid elimination of leaded gasoline would have reduced human exposure much more quickly as well as substantially reduced the accidental or deliberate misfueling of catalyst equipped cars with the associated increases in CO, HC and NOx emissions. Fortunately China learned from this mistake and once it decided to phase out the use of lead in gasoline, it did so quickly.

## 4. Phase 2 - Other Gasoline Improvements

The potential for "reformulating" gasoline to reduce pollutant emissions attracted considerable attention in the U.S. as pressure to shift to alternative fuels increased during the mid to late 1980's. One result was a major cooperative research program between the oil and auto industries. During the early 1990's, this was followed by a similar effort in Europe. The result is that a great deal has been learned about the potential for modifying gasolines in a manner which can significantly improve air quality. An additional advantage of fuel reformulation is that it can reduce emissions from all vehicles on the road in much the same way that reducing lead in gasoline can reduce lead emissions from all vehicles.

The most significant potential emission reductions that have been identified for gasoline "reformulation" have been through reducing volatility (to reduce evaporative emissions), reducing sulfur (to improve catalyst efficiency), and adding oxygenated blend stocks (with a corresponding reduction in the high-octane aromatic hydrocarbons which might otherwise be required). The potential benefits of improving certain fuel parameters are summarized below.

### a. Lowering Volatility

Fuel volatility, as measured by Reid vapor pressure (RVP) has a marked effect on evaporative emissions from gasoline vehicles both with and without evaporative emission controls. Tests

[14](Emissions)/(Emissions with no lead)

on vehicles without evaporative emission controls showed that increasing the fuel RVP from 9 pounds per square inch (psi) (62 kilipascals) to approximately 12 psi (82 kPa) roughly doubled evaporative emissions. The percentage effect is even greater in controlled vehicles. In going from 9 psi (62 kPa) to 12 (81 kPa) RVP fuel, the U.S. EPA found that average diurnal emissions in vehicles with evaporative controls increased by more than 5 times, and average hot-soak emissions by 25-100%. The large increase in diurnal emissions from controlled vehicles is due to saturation of the charcoal canister, which allows subsequent vapors to escape to the air.

Vehicle refueling emissions are also strongly affected by fuel volatility. In a comparative test on the same vehicle, fuel with 11.5 psi (79 KPA) RVP produced 30% greater refueling emissions than gasoline with 10 psi (64 KPA) RVP (1.45 vs. 1.89 g/liter dispensed). In response to data such as these, the U.S. EPA has established nationwide summertime RVP limits for gasoline.

An important advantage of gasoline volatility controls is that they can affect emissions from vehicles already produced and in-use and from the gasoline distribution system. RVP control should be complemented by Stage I vapor control in the loading and unloading of gasoline.

#### b. Oxygenates

Blending small percentages of oxygenated compounds such as ethanol, methanol, tertiary butyl alcohol (TBA) and methyl tertiary-butyl ether (MTBE) with gasoline has the effect of reducing volumetric energy content of the fuel, while improving the antiknock performance and thus making possible a potential reduction in lead and/or potentially harmful aromatic compounds. Assuming no change in the settings of the fuel metering system, lowering the volumetric energy content will result in a leaner air-fuel mixture, thus helping to reduce exhaust CO and HC emissions.

#### c. Sulfur

Lowering sulfur in gasoline lowers emissions of CO, HC and NOX from catalyst equipped cars. As noted by the Auto-Oil study, "The regression analysis showed that the sulfur effect (lowered emissions) was significant for HC on all ten cars, for CO on five cars, and for NOX on 8 cars. There were no instances of a statistically significant increase in emissions." To the extent that oxygenates are sulfur free, their addition would tend to traditionally lower gasoline sulfur levels. Based on the Auto/Oil study, it appears that NOX would go down about 3% per 100 PPM sulfur reduction.

#### d. Other

According to the Auto/Oil study, "NOX emissions were lowered by reducing olefins, raised when $T_{90}$ was reduced, and only marginally increased when aromatics were lowered." In general, reducing aromatics and $T_{90}$ caused statistically significant reductions in exhaust mass NMHC and CO emissions. Reducing olefins does increase exhaust mass NMHC emissions; however, "the ozone forming potential" of the total vehicle emissions was reduced overall.

With regard to toxics, the reduction of aromatics from 45% to 20% caused a 42% reduction in benzene but a 23% increase in formaldehyde, a 20% increase in acetaldehyde and about a 10% increase in 1,3-Butadiene. Reducing olefins from 20% to 5% brought about a 31% reduction in 1,3-Butadiene but had insignificant impacts on other toxics. Lowering the $T_{90}$ from 360 to 280F resulted in statistically significant reductions in benzene, 1,3-Butadiene (37%), formaldehyde

(27%) and acetaldehyde (23%).

### e. The Law of Unintended Consequences

As noted above, one of the key aspects of fuel reformulation during the 1990's was the addition of oxygenates, especially MTBE. Considering the air quality impact alone, this addition was a huge success reducing both the ozone forming potential of the fuel as well as its overall toxicity. However, over time it became apparent that MTBE has certain properties which facilitate its rapid migration into drinking water. As a result, a move is underway today to eliminate the use of this particular oxygenate in gasoline across the US. California has already announced a complete ban.

The lesson which has been painfully learned is that great care must be exercised when adding anything new to fuels because that additive will quickly become ubiquitous. Therefore there must be a high degree of vigilance and confidence that it will not have "unintended" consequences.

## 5. The Next Phase - Dramatically Lowering Sulfur Content in Gasoline and Diesel Fuel

As noted above, the Auto Oil study established that lowering the sulfur content of gasoline had significant beneficial impacts on catalyst performance. However, as further work continued throughout the 1990's, an even greater appreciation emerged regarding the benefits of reduced sulfur, not only for existing vehicles but also to maximize the benefits of emerging pollution control systems. Further, this conclusion was true for both gasoline and diesel fuel.

### a. Gasoline Sulfur Control Requirements

As part of its rulemaking to mandate the next generation of low polluting passenger cars, the so-called Tier 2 program, EPA adopted a very aggressive restriction on sulfur in gasoline. EPA's low-sulfur gasoline program:

- Establishes uniform, national, year-round standards to sharply reduce sulfur in gasoline;
- Sets a gasoline sulfur standard of 30 parts per million on average, to take effect in 2004, and includes a sulfur cap of 80 parts per million;
- Includes flexibilities to minimize the cost to and compliance burden on affected parties; and
- Provides incentives for refiners to reduce sulfur levels prior to the 2004 effective date.

In deciding to proceed with this mandate, EPA relied on a growing body of evidence that fuel sulfur impacts vehicle emissions in two basic ways. One is an immediate impact, which occurs within a few miles of driving. The other is a more lasting impact, ranging from 20 or more miles to potentially permanent. This lasting effect of sulfur on emissions is termed irreversibility, referring to the fact that the emission impact of high sulfur fuel does not reverse when low sulfur fuel is used.

The immediate impact of sulfur on emissions is substantial. Operation on typical conventional gasoline containing 330 ppm sulfur will increase exhaust VOC and NOx emissions from LEV and Tier 2 vehicles (on average) by 40 percent and 150 percent, respectively, relative to their emissions with certification fuel containing roughly 30 ppm sulfur.

Some have argued that these effects are reversible and would not be a problem if low sulfur fuel were available in ozone nonattainment areas and higher sulfur fuel were used elsewhere. First of all, it was concluded that there is no area of the country where these excess CO, HC and NOx emissions as well as the SO2, PM and PM precursor emissions directly related to sulfur in gasoline would not be a problem. Virtually all parts of the country - areas with high ozone or PM, pristine areas, or even areas with concerns over individual toxic exposures would benefit from lower vehicle emissions. Further, the available evidence indicates that catalysts do not fully recover from sulfur exposure.

Sulfur sensitivity is temperature dependent. Sulfur adheres to the catalyst surface more thoroughly at lower catalyst temperatures (approximately 450°C to 500°C) than higher temperatures. In fact, the sulfur sensitivity results from the numerous fleet studies appear to actually underestimate the sensitivity of sulfur on exhaust emissions, because the test cycles (FTP or LA4 cycles) used to saturate the catalyst with sulfur result in catalyst temperatures that are too high. Specifically, most vehicles achieve catalyst temperatures over the FTP that exceed 450°C, thus not allowing complete adsorption of sulfur to the catalyst surface, whereas real-world vehicle operation in metropolitan non-attainment areas quite frequently result in catalyst temperatures at or below 450°C.

A second concern about the current estimates of sulfur sensitivity is that all of the vehicles in the test programs used to develop projections of sulfur sensitivities were only exposed to high sulfur fuel for a few miles of driving prior to emission testing. In addition to adsorbing onto the surface of the catalyst, sulfur can also penetrate into the precious metal layer, especially into palladium, and into the oxygen storage material. This penetration may not have fully occurred during the very few miles of operation prior to emission testing on high sulfur fuel. In an API sulfur reversibility test program, vehicles' sulfur sensitivity were measured after both short-term exposure to high sulfur fuel and after 1,000-2,000 miles of driving with high sulfur fuel. For the five vehicles tested, NMHC emission sensitivity was the same with both short-term and longer-term exposure to high sulfur fuel. However, NOx emission sensitivity was 25-50% higher after longer-term exposure to high sulfur fuel when compared to short-term exposure. Thus, the above sulfur sensitivities could significantly underestimate the impact of sulfur on NOx emissions for LEVs, ULEVs and Tier 2 vehicles.

Further, as noted by EPA, if sulfur reversibility was the only criteria involved in catalyst design, auto manufacturers could place their catalysts right up against the engine and design the onboard computer to vary the air fuel ratio from rich to lean sufficiently to regenerate the catalyst after any temporary exposure to high sulfur fuel. Engine exhaust temperatures are generally high enough at the exhaust manifold during typical driving to facilitate sulfur removal. The onboard computer is certainly capable of varying the air-fuel ratio significantly. However, other critical catalyst design criteria prevent such the use of such simple measures. First, excessive temperatures can thermally damage the catalyst and reduce its efficiency. Second, simultaneously high conversion efficiencies of HC, CO and NOx require very tight air fuel ratio control (minimal swings to either rich or lean conditions).

Regarding catalyst temperature, auto manufacturers must balance a number of conflicting criteria. One important criterion for catalyst design is that it light-off quickly. Most of the HC and

CO emissions from LEV vehicles, and significant amounts of NOx emissions, occur prior to catalyst light-off. Achieving this has affected the type and amount of materials used in the catalyst and resulted in moving the catalyst closer to the engine. Many manufacturers have switched to catalysts containing palladium, which generally can withstand higher temperatures than platinum and rhodium catalysts. At the same time, catalyst manufacturers have improved the design of their platinum and rhodium catalysts so that they can withstand higher temperatures, as well. Moving the catalyst closer to the engine also increases catalyst temperature during warmed-up operation, other factors being equal. Despite improvements in the thermal durability of catalysts, sufficiently high temperatures can still cause a significant loss of catalyst efficiency.

Engine load also affects exhaust and catalyst temperature. The engine load for a given vehicle is a function of vehicle speed, rate of acceleration, vehicle weight and road grade, with higher levels of all of these factors leading to higher engine loads and catalyst temperatures. Vehicles which carry the most widely varying loads and which are driven the most aggressively will generally experience the most variation in their catalyst temperature. Manufacturers must design their catalysts to both light-off quickly and stay warm under light loads while not sustaining thermal damage under heavy loads. Light trucks and sporty vehicles probably present the most difficult challenges in this regard. For example, light trucks are most often driven with one person and minimal cargo. However, they also are used to carry numerous passengers or carry or pull heavy cargo up steep hills. The catalyst must be designed to withstand the higher temperatures of these heavier loads.

One additional factor affecting catalyst temperature is the upcoming implementation of EPA and California Supplemental Federal Test Procedure (SFTP) standards. The SFTP standards address emissions generated while the vehicle is driving aggressively (high speeds and high rates of acceleration) and while the air conditioning is turned on, both of which generate higher engine loads than exist during EPA's FTP test cycle. Manufacturers have historically designed their engines to run rich under high loads. The excess fuel decreases exhaust and catalyst temperature relative to an engine running at stoichiometry (just the right amount of air to burn the fuel). The SFTP standards will require that manufacturers reduce much of this high-load enrichment in order to reduce HC and CO emissions during these high loads. Therefore, all other factors being equal, exhaust and catalyst temperatures under extreme conditions will increase after implementation of the SFTP standards, which begin their phase-in in the 2001 model year. Thus, the SFTP standards incrementally increase the difficulty of quickly lighting-off the catalyst while still protecting it from thermal damage during extreme driving conditions. While these extreme conditions must be considered in the catalyst design process, their frequency in-use is not sufficient to rely upon for sulfur removal. For example, some vehicle owners own and tow trailers up steep hills, while others do not. Therefore, while the SFTP standards may increase temperatures under some conditions, they will not necessarily increase sulfur removal capability for the general vehicle population.

Requiring manufacturers to increase the temperature of their catalysts under light loads to improve sulfur reversibility would therefore increase temperatures under heavy loads even further, thereby potentially jeopardizing the durability of the catalyst system. Regular operation at such temperatures places the catalyst at risk of thermal damage from even occasional excursions above this level, which can regularly occur from the types of high load operation described above, as well as occasional spark plug misfire. Since the vast majority of the HC, CO and NOx emission control occurring under both the current standards and the proposed Tier 2 standards relies on the proper operation of the catalyst over the life of the vehicle, increasing catalyst temperatures to enhance sulfur reversibility risks essentially all of the benefits of EPA's exhaust emission control program (both current and proposed),. Therefore, it would be imprudent to require vehicle manufacturers to design catalysts that operate at temperatures high enough to improve the reversibility of sulfur effects and also meet the proposed Tier 2 standards in-use.

Moving to the variation in air-fuel ratio, manufacturers have significantly enhanced their engines' and computers' abilities over the past few years specifically to avoid large swings in rich and lean operations. This ability to maintain tight control of the air-fuel ratio has increased catalyst efficiency significantly in the process. Designing the vehicle to have alternating rich-lean operation may improve the reversibility of sulfur effects, but would reduce catalyst efficiency and potentially prevent the achievement of both current and proposed Tier 2 exhaust emissions standards. As was the case with increasing catalyst temperature, it would be counter-productive to reverse this progress in overall emission control just to enhance the sulfur reversibility of catalyst systems.

Thus, the two changes in emission control design which some suggest should be used to reverse the detrimental impacts of sulfur on catalyst performance, hotter catalyst temperatures and variable air-fuel ratios both run counter to other design criteria aimed at achieving stringent emission standards in-use over the full useful life of the vehicle. Therefore, the American Lung Association believes that the full lifetime control should not be placed in jeopardy in an effort to accommodate high levels of sulfur which will in addition cause other unnecessary emissions problems.

### b. The Diesel Fuel Sulfur Cap

EPA has concluded that it is necessary to substantially reduce the emissions of NOx and particulate from diesel vehicles. Inextricably linked to tight diesel engine standards is the issue of low-sulfur diesel fuel. The ability of heavy-duty diesels to comply with stringent engine standards is directly dependent on the timely, nationwide availability of diesel fuel with ultra-low levels of sulfur. Without such fuel, the technologies capable of achieving such low emission standards will be rendered inoperable. For this reason, EPA recently adopted a 15-parts-per-million (ppm) cap on sulfur in diesel fuel, to take full effect across the country in mid-2006, with no phase in.

#### i. Feasibility and Cost

Low sulfur diesel fuel is already available in Europe and in some locations across the United States. Some oil producers testified at the EPA hearings in support of the proposal.[15] The issue is not whether the fuel can be produced but whether it is worth the cost. The engine manufacturers are willing to require their products to use a slightly more expensive fuel because they know that this fuel is necessary for them to be able to provide their customers with the high performance, efficient and clean engines that they want. In the Los Angeles hearing on the proposal, for example, the California Trucking Association strongly supported low sulfur fuel. The trucking industry supports low sulfur fuel for both on and off road vehicles and engines because they know that the public is opposed to smoke belching trucks on our highways. Further, they know that their drivers are as much if not more at risk from dirty diesels than anyone else.

15/For example, TOSCO.

Finally, the public expressed its view in a nationwide public opinion survey in which 85 percent of survey respondents believe that up to 4 cents a gallon is a reasonable price to pay for cleaner diesel fuel that would significantly reduce pollution.

### ii. Maintenance Savings Will Result And Offset Increased Costs

In addition to its role as a technology enabler, low sulfur diesel fuel gives benefits in the form of reduced sulfur induced corrosion and slower acidification of engine lubricating oil, leading to longer maintenance intervals and lower maintenance costs. These benefits would apply to new vehicles and to the existing heavy-duty vehicle fleet beginning in 2006 when the fuel will be introduced. These benefits can offer significant cost savings to the vehicle owner without the need for purchasing any new technologies.

The individual components of the engine system which might be expected to realize benefits from the use of low sulfur diesel fuel are summarized in the Table below.

**Components Potentially Affected by Lower Sulfur Levels in Diesel Fuel**

| *Affected Components* | *Affect of Lower Sulfur* | *Potential Impact on Engine System* |
|---|---|---|
| Piston Rings | Reduce corrosion wear | Extended engine life and less frequent rebuilds |
| Cylinder Liners | Reduce corrosion wear | Extended engine life and less frequent rebuilds |
| Oil Quality | Reduce deposits and less need for alkaline additives | Reduce wear on piston ring and cylinder liner and less frequent oil changes |
| Exhaust System (tailpipe) | Reduces corrosion wear | Less frequent part replacement |
| EGR | Reduces corrosion wear | Less frequent part replacement |

The actual value of these benefits over the life of the vehicle will depend upon the length of time that the vehicle operates on low-sulfur diesel fuel. For a vehicle near the end of its life in 2007 the benefits would be quite small. However for vehicles produced in the years immediately preceding the introduction of low-sulfur fuel the savings would be substantial.

These savings, due to the use of low sulfur diesel fuel, can be expressed in terms of a savings in cents per gallon of low sulfur diesel fuel. The average savings were estimated by EPA to be approximately 1.4 cents/gallon for light heavy-duty diesels, 1 cent/gallon for medium heavy-duty diesel engines and 0.7 cents/gallon for heavy heavy-duty diesel engines. The average savings estimated across all weight classes is therefore approximately one cent per gallon. While there may be uncertainty regarding the magnitude of this effect, this estimate may in fact be a conservative estimate of the savings as there are likely to be other benefits not accounted for in this analysis.

These benefits result in an estimated savings of $153 for light heavy-duty vehicles, $249 for medium heavy-duty vehicles, and $610 for heavy heavy-duty vehicles and urban buses.

### iii. Benefits of Low Sulfur Fuel Have Been Demonstrated

The benefits of low sulfur fuel were demonstrated in California where BP Amoco [now BP] released the results from its fleet demonstration project. According to the report, "Overall emission reductions in the test vehicles averaged between 90 and 99 percent for particulate matter (PM), hydrocarbons (HC) and carbon monoxide (CO)." These outstanding test results are being attributed primarily to the low sulfur content of BP Amoco's new fuel that has a maximum sulfur content of 15 parts per million (ppm), and its use with catalytic exhaust filters. The ultra-low sulfur content of the fuel is important in that it enables the catalytic exhaust particulate traps on diesel engines to function.

## 6. Conclusions

It is now well established that cleaner fuels must be an integral part of a comprehensive and effective motor vehicle pollution control effort. The elimination of lead in gasoline as well as the dramatic reduction if not virtual elimination of sulfur from both gasoline and diesel fuel are now well established elements of a clean fuels program. The major lesson of the past twenty five years with regard to these components is to move quickly.

It is also well established that certain additives can be beneficial in reducing the emissions of certain pollutants from vehicles. However, the experience in the US with MTBE indicates that great care is needed to assure that the use of such additives does not produce unintended consequences which can be more harmful than the benefits achieved.