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Vehicle Emissions Trends and Forecasts
The Lessons of The Past 50 Years

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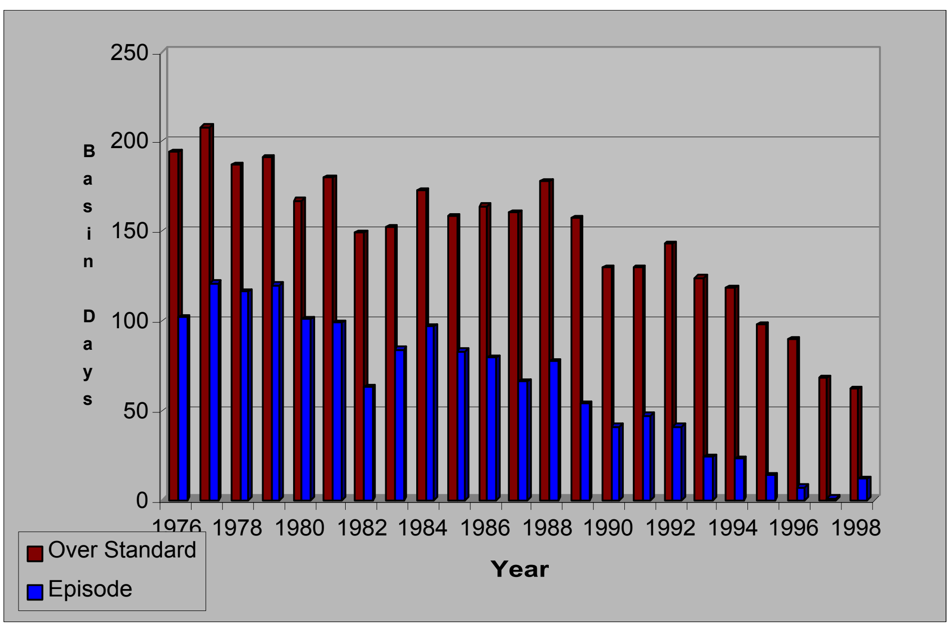
1.**Background and Introduction**

Over the past fifty years, countries around the world have gradually imposed increasingly stringent emissions regulations on the motor vehicle and fuels industries with the result that new cars today emit but a small fraction per mile driven of what they did when the process began. While increasing numbers of vehicles have offset some of these gains, air pollution levels are decidedly down in most industrialized countries. Further, the clean vehicle technologies and fuels originally developed for the US or Europe or Japan in response to their standards are increasingly finding there way onto the roads of developing countries as well with the result that some air quality improvements also are occurring there. About 80% of all gasoline to be sold this year will be unleaded and almost 90% of all newly produced cars will contain a catalytic converter.

As we turned the corner into the new century, global vehicle emissions of non-methane hydrocarbons were about 67% lower than they would otherwise have been, carbon monoxide 56% lower and nitrogen oxides 18% lower. Focusing on Los Angeles, one of the most polluted cities in the world when this process began, the figure below illustrates that there has been continuous improvement in Air Quality over the past twenty-five years.

However, in spite of this progress, it is premature to declare victory. Most major industrialized countries continue to experience serious air pollution problems and even worse problems exist in the major cities in developing countries. Further, vehicle growth continues, maintaining the pressure to bring all vehicle emissions down to lower and lower levels, if not to zero, just to maintain the status quo.



Further new problems such as toxic emissions from diesel and other vehicles are emerging which will clearly require significant additional vehicle technology advances in coming years.

Worldwide, cars, trucks, buses, and other motor vehicles continue to play a dominant role in causing air pollution. They are major sources of volatile organic compounds (VOCs) and nitrogen oxides, the precursors to both tropospheric ozone and acid rain; carbon monoxide (CO); toxic air pollutants such as diesel particulate; and chlorofluorocarbons (CFCs).

In the European Union as a whole, for example, on and off road vehicles are the largest source of CO, NOx and non-methane hydrocarbons. Prior to the adoption of the Euro 3/4 requirements, forecasts indicated that vehicles would remain a major emissions source out to 2010. In densely populated urban areas, vehicles can be a major source of exposure to particulates as well. Currently, road vehicles account for 74% of nitrogen oxides and 94% of black smoke emissions in London. On their own, diesels account for 32% and 87% of total emissions (43% and 92% of vehicle emissions) for these two pollutants respectively. The European Commission recently issued a Communication summarizing the results of the 4-year Auto-Oil II program, aimed at finding the most cost-effective ways to reduce emissions from road transport. It states that emissions from road transport of the traditional, regulated pollutants are expected to have fallen to 20% of their 1995 levels by 2020, leading to a marked improvement in air quality. However, it notes that some air quality problems such as particulate matter and ozone are a long way from being solved, so the report identifies particulate matter from diesel engines, dangerously high levels of localized nitrogen oxides and ozone as the major challenges for future policy.

Motor vehicles are also major emissions sources in the United States and Japan. In the densely populated Northeastern United States where the air pollution problem is especially severe, the Environment Protection Agency (EPA) has projected that highway vehicles will account for approximately 38% of the total NOx inventory and 22% of the total VOC inventory in 2005, in spite of the introduction of tighter motor vehicle standards in the 1990 Clean Air Act. Further, when focusing on emissions in congested city centers, the importance of vehicle emissions is even greater. One recent study used a chemical mass balance technique to determine the source of the particulate in a midtown Manhattan street and concluded that diesel buses emitted more than 50%.

Japan has found that in spite of their strenuous efforts, particulate and NO_2 air quality levels have been stable over the past 20 years and remain significantly higher in the vicinity of roadways than overall.

While not as well documented, it is increasingly clear that motor vehicles are also the major source of pollution problems in the developing world. Many citizens of Delhi, Bangkok, Jakarta, Manila, Sao Paulo, Seoul, Mexico City etc. are literally choking to death on air pollution.

At the same time, the world is increasingly coming to grips with the realization that oil is a finite resource and its consumption at current much less increasing rates is jeopardizing energy security, distorting balances of payments and altering the chemistry of the atmosphere in ways that are already heating the planet.

The purpose of this paper is to review the progress made in reducing vehicle emissions, the trends in regulations to address these concerns and to highlight some areas of ongoing concern. Finally, an attempt will be made to draw some fundamental policy conclusions, which could serve as guideposts for future efforts.

2. **Recent Steps To Reduce Vehicle Emissions**

Most regions of the world have been significantly tightening their motor vehicle regulations. Major developments during the past few years have included the following:

< The EU has adopted Directives regarding light duty vehicle emissions and fuel quality that tighten standards significantly (2000 and 2005), broaden the scope of coverage (for example, cold temperature), added several important features previously missing (Onboard Diagnostics, in-use durability) and impose low sulfur requirements for diesel fuel and gasoline.

< The California Air Resources Board (CARB) then took emissions standards to the next level, not only tightening CO, HC, NOx and PM requirements but also establishing the principles of fuel neutrality (diesel vehicles meet the same standards as gasoline fueled vehicles) and usage neutrality (light trucks and sports utility vehicles, used primarily as passenger cars, must meet the same standards as cars)

< China formally adopted the Euro 1 auto emissions standards and decided to phase out the use of leaded gasoline across the entire country by 2000.

< Japan tightened the gasoline fueled automobile standards for the first time in twenty years and introduced very stringent diesel fueled vehicle requirements. It is expected that all new diesel fueled vehicles will be fitted with particulate filters by 2005.

< The Supreme Court of India banned the sale of leaded gasoline in Delhi as of September 1999 as well as mandating that all new cars meet Euro 1 auto standards; similar requirements were then phased in across the entire country in 2000. Delhi then adopted Euro 2 standards as of April 2000.

< The U.S. EPA in conjunction with the CARB imposed the largest enforcement action in history on the heavy engine industry.

< The EU and the auto industry reached agreement on a voluntary commitment to reduce CO_2 emissions per kilometer driven by 25 per cent by about 2008.

< Taiwan adopted step 4 of its motorcycle control program, effectively banning two stroke motorcycles by 2003.

< The CARB formally decided that diesel PM is a toxic air contaminant, triggering a process which will lead to an effort to further reduce PM emissions from urban vehicles, including PM retrofit where feasible.

< The Ministry of International Trade and Industry (MITI) in Japan and Japanese industry reached agreement regarding lower CO_2 emissions from vehicles.

< The U.S. EPA adopted a further tightening of light duty vehicle standards closely modeled after the California LEV 2 standards (so called Tier 2) as well as tighter sulfur requirements in gasoline.

< The EU adopted the next phases of heavy duty standards – Euro 3, 4 and 5 - which will likely result in particulate and NOx aftertreatment systems and

< The U.S. EPA then tightened its heavy-duty engine emissions requirements with special focus on tighter PM and NOx standards as well as low sulfur diesel fuel. Most recently, EPA has proposed similar requirements for off road diesels and fuels.

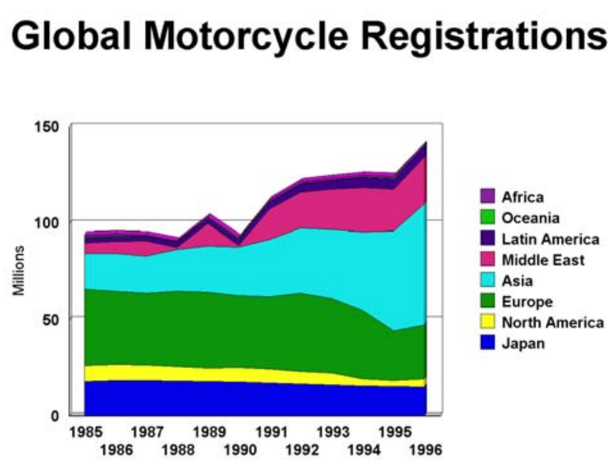
3. **Remaining Challenges**

While substantial progress has occurred in reducing vehicle emissions and further improvements in air quality are expected in coming years in most major industrialized countries, significant problems remain which require additional action beyond that noted above. Some of the more serious challenges will be summarized below.

A. **Vehicle Growth**

Overall growth in the production of motor vehicles, especially since the end of World War II, has been quite dramatic, rising from about 5 million motor vehicles per year to almost 55 million. Between 1950 and now approximately 1 million additional vehicles has been produced each year compared to the year before.

Over the past several decades, motor vehicle production has gradually expanded from one region of the world to another. Initially and through the 1950's, it was dominated by North America. The first wave of competition came from Europe, and by the late 1960s European production had surpassed that of the United States. Over the past two decades the car industry in Asia, led by Japan, has grown rapidly and now rivals both those in the United States and Europe. Both Latin America and Eastern Europe appear poised to grow substantially in future decades. For example, driven in large part by Brazil, motor vehicle production in South America now exceeds 2 million units per year.



Beyond cars and trucks, motorcycle production has also grown rapidly, especially in Asia. China has now become the world’s largest producer by far, building over 10 million motorcycles per year more than half the world’s annual total.

Since motor vehicle production is increasing at a more rapid rate than vehicle scrappage, worldwide vehicle registrations are sharply upward and are actually accelerating. Europe (including Eastern Europe and the USSR) and North America each have about 35 percent of the world's motor vehicle population with the remainder is divided among Asia, South America, Africa, and Oceania (Australia, New Zealand, and Guam), in that order.

With regard to motorcycles, the figure above illustrates that Asia already contains the dominant share and the population of this category is growing rapidly.

As the millennium came to a close the world’s roads were supporting about 800 million vehicles, almost 500 million of which are cars and the remainder commercial trucks and buses or motorcycles and scooters. The United States, Japan, and Europe account for the lion's share of the ownership and use of motor vehicles (except for motorcycles) but the future growth is expected to be most rapid in Asia and Latin America where most of the world’s 6 billion people reside.

Looking to the future, population growth, and increased urbanization of that population and economic improvements tend to be closely linked with vehicle growth and all three are projected to increase. Therefore one can expect a continued trend toward more and more vehicles especially in the rapidly industrializing regions of Asia.

According to the United Nations, the global population is projected to increase by an additional 50% to 9 billion by 2050. As illustrated in the table below, this growth will not be evenly distributed but will be concentrated outside of the OECD, in Asia, Africa and Latin America.

	1950	**1998**	**2050**
World	2,521	5,901	8,909
More developed regions	813	1,182	1,155
Less developed regions	1,709	4,719	7,754
Africa	221	749	1,766
Asia	1,402	3,585	5,268
Europe	547	729	628
Latin America and the Caribbean	167	504	809
North America	172	305	392
Oceania	13	30	46

Simultaneously, all regions of the world continue to urbanize with the greatest increases expected in Asia. This is significant since per capita vehicle populations are greater in urban than in rural areas.

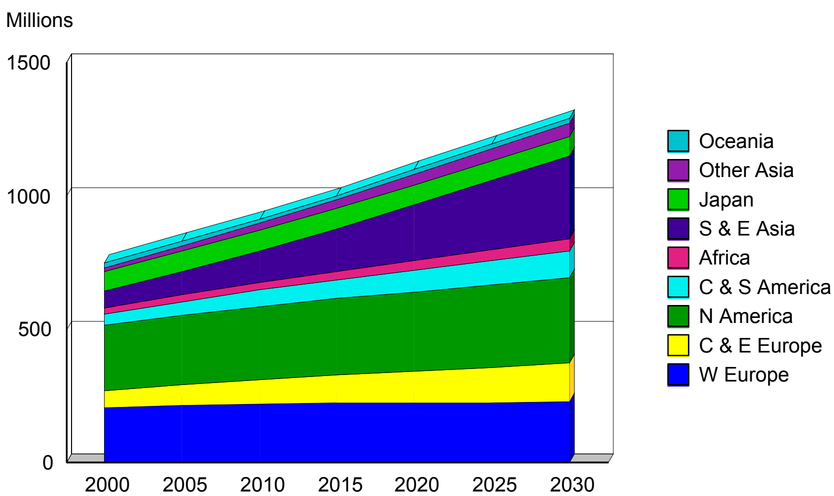
	% Urban 1999	**Annual Growth Rate %**
EAST AND NORTH-EAST ASIA	40	2.7
SOUTH-EAST ASIA	38	3.4
SOUTH AND SOUTH-WEST ASIA	31	3.1
NORTH AND CENTRAL ASIA	68	0.4
PACIFIC	70	1.3

According to the OECD, annual GDP growth rates over the next two decades will be highest in China, East Asia, Central and Eastern Europe and the former Soviet Union which will further stimulate the increase in vehicle populations.

	Annual GDP growth rates (%)				
Region	1995-2000	2000-2005	2005-2010	2010-2015	2015-2020
Canada, Mexico and United States	2.9	2.5	2	1.6	1.6
Western Europe	2.4	2.6	1.5	1.2	1.2
Central and Eastern Europe	3.6	4.5	4.1	3.6	3.6

	Annual GDP growth rates (%)				
Japan and Korea	0.75	2.25	1.5	1	1
Australia and New Zealand	3	3.1	2.2	1.75	1.75
Former Soviet Union	-2.5	3.5	4.5	4	4
China	7.6	5.6	5	4.8	4.8
East Asia	2.4	4.8	4.8	4.5	4.2
Latin America	1.75	3.1	2.9	2.8	2.8
Rest of the World	2.75	3.2	3	3	3

Global Trends in the Total Vehicle Population (Excluding Motorcycles)



As a result of these expected trends, as illustrated in the Figure to the left, the vehicle population is expected to grow significantly, especially in the rapidly industrializing countries of Southeast Asia; as a result, vehicles will continue to apply pressure to the environment.

B. Toxic Emissions (Including Diesel Particulate)

In addition to contributing to the health and welfare problems associated with exceedances of air quality standards for such pollutants as ozone and PM_{10}, emissions from diesel and gasoline vehicles include a number of air pollutants that increase the risk of cancer or have other negative health effects. These air pollutants include benzene, formaldehyde, acetaldehyde, 1,3-butadiene, and diesel particulate matter. All of these compounds are products of combustion; benzene is also found in non-exhaust emissions from gasoline-fueled vehicles.

Based on currently available data, diesel emissions tend to be the dominant source of mobile source cancer risk. The concern for the carcinogenic health hazard resulting from diesel exhaust exposures is widespread and several national and international agencies have designated diesel exhaust or diesel particulate matter as a 'potential' or 'probable' human carcinogen.[1 2] The International Agency for Research on Cancer (IARC) in the late 1980s concluded that diesel exhaust is a 'probable' human carcinogen.[3] Based on IARC findings, the State of California identified diesel exhaust in 1990 as a chemical known to the State to cause cancer and after an extensive review in 1998 has listed diesel exhaust as a toxic air contaminant.[4] The National Institutes for Occupational Safety and Health has classified diesel exhaust a "potential occupational carcinogen." The World Health Organization recommends that "urgent efforts should be made to reduce [diesel engine] emissions, specifically of particulates, by changing exhaust train techniques, engine design and fuel composition." The Department of Health and Human Services (DHHS) will decide in 2000 whether to list diesel particulate matter in its Report on Carcinogens (ROC) in terms of its lung cancer hazard.

Early in 2000, the National Institute For Environmental Health Sciences (NIEHS) added diesel particulate to its list of substances which are reasonably anticipated to be human carcinogens in its 9th National Toxicology Report on Carcinogens. More recently, the US EPA has concluded that diesel particulate is a probable human carcinogen.

The most compelling information to suggest a carcinogenic hazard is the consistent association that has been observed between increased lung cancer and diesel exhaust exposure in certain occupationally exposed workers working in the presence of diesel engines.

Approximately 30 individual epidemiological studies show increased lung cancer risks of 20 to 89 percent within the study populations depending on the study. Analytical results of pooling the positive study results show that on average the lung cancer risks were increased by 33 to 47 percent. The magnitude of the pooled risk increases is not precise owing to uncertainties in the individual studies, the most important of which is a continuing concern about whether smoking effects have been accounted for adequately. While not all studies have demonstrated an increased risk (six of 34 epidemiological studies summarized by the Health Effects Institute[5] reported relative risks less than 1.0), the fact that an increased risk has been consistently noted in the majority of epidemiological studies strongly supports the determination that exposure to diesel exhaust is likely to pose a carcinogenic hazard to humans.

To put the above into perspective, it is useful to consider actual real world exposures. The Multiple Air Toxics Exposure Study (MATES-II) is a landmark urban toxics monitoring and evaluation study conducted for the South Coast Air Basin (Basin) in Los Angeles. It represents one of the most comprehensive air toxics programs ever conducted in an urban environment. It consists of several elements - a comprehensive monitoring program, an updated emissions

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1() National Institute for Occupational Safety and Health (1988) Carcinogenic effects of exposure to diesel exhaust. NIOSH Current Intelligence Bulletin 50. DHHS (NIOSH) Publication No. 88-116. Centers for Disease Control, Atlanta, GA.

2() World Health Organization (1996) Diesel fuel and exhaust emissions: International program on chemical safety. World Health Organization, Geneva, Switzerland.

3() International Agency for Research on Cancer (1989) Diesel and gasoline engine exhausts and some nitroarenes, Vol. 46. Monographs on the evaluation of carcinogenic risks to humans. World Heath Organization, International Agency for Research on Cancer, Lyon, France.

4() California EPA (1998) Proposed Identification of Diesel Exhaust as a Toxic Air Contaminant Appendix III Part A: Exposure Assessment. California Environmental Protection Agency. California Air Resources Board April 22, 1998.

5() Health Effects Institute (1995) Diesel Exhaust: A Critical Analysis of Emissions, Exposure, and Health Effects pp. 253-292. April 1995.

inventory of toxic air contaminants, and a modeling effort to fully characterize Basin risk.

The key result of the MATES-II study was that the average carcinogenic risk in the Basin is about 1,400 per million people. Mobile sources (e.g., cars, trucks, trains, ships, aircraft, etc.) represent the greatest contributor. About 70% of all risk is attributed to diesel particulate emissions; about 20% to other toxics associated with mobile sources (including benzene, butadiene, and formaldehyde); about 10% of all risk is attributed to stationary sources (which include industries and other certain businesses such as dry cleaners and chrome plating operations.)

Another aspect of diesel particulate which continues to be a cause for concern is its size. Approximately 80-95 percent of diesel particle mass is in the size range from 0.05-1.0 micron with a mean particle diameter of about 0.2 microns. These fine particles have a very large surface area per gram of mass, which make them excellent carriers for adsorbed inorganic and organic compounds that can effectively reach the lowest airways of the lung. Approximately 50-90 percent of the number of particles in diesel exhaust are in the ultrafine size range from 0.005-0.05 microns, averaging about 0.02 microns. While accounting for the majority of the number of particles, ultrafine diesel particulate matter only accounts for 1-20 percent of the mass of diesel particulate matter. To the extent that particle filters are used to comply with PM mass standards, the concern with ultrafines will likely diminish since these systems have been shown to dramatically reduce ultrafines as well. However, to the extent that new vehicles can comply with standards without the use of the filtering systems it is likely that pressure will continue to adopt additional standards to assure that they are introduced.

The issue of ultrafine particles appears to have influenced the EU Council of Environment Ministers when they indicated following their December 2000 meeting that they are interested in lowering sulfur levels, reducing the number of nanoparticles and tightening diesel vehicle NOx standards to levels equivalent to those of gasoline fueled vehicles.

C. Conventional Fuels

Improvements in fuel quality can have immediate, far ranging and diverse benefits. In addition to reducing directly emitted pollutants, certain fuel parameters such as lead and sulfur sharply limit options for dealing with other pollutants. Platinum, palladium and other precious metal catalysts, for example, will very effectively destroy engine-out emissions of oxides of nitrogen, carbon monoxide and hydrocarbons. But lead "poisons" catalytic converters, so leaded gasoline effectively precludes their use.

The oxygen sensor measures the concentration of oxygen in the engine's exhaust and feeds this information to an on-board computer, which then adjusts the fuel mixture to optimize not only the reduction in pollution, but to increase fuel economy and driveability as well. Like the catalytic converter, the oxygen sensor utilizes precious metal catalysts that are poisoned by lead. Leaded gasoline thus also precludes the use of such "closed loop" engine management systems that not only reduce emissions but also save fuel.

Sulfur has a comparable effect, especially in the context of advanced engines that hold the promise of substantially increased fuel economy and, hence, lowered emissions of carbon dioxide.. New engine designs such as gasoline direct injection or GDI, can raise the fuel economy of gasoline engines substantially. Similarly, advanced diesel engines can achieve comparable increases in fuel economy compared to current versions. But in doing this, both the gasoline and diesel advanced engines increase emissions of oxides of nitrogen. Catalytic converters or NOx adsorbers can eliminate much of this NO_x, but sulfur disables them in much the same way that lead poisons the three-way catalyst. Thus, the presence of sulfur in gasoline and diesel fuels effectively bars the path to fuel savings and climate protection as well as low emissions of conventional pollutants.

The global move toward low sulfur fuels is now underway. The reasons for such a move are elaborated below.

a. Diesel Fuel

Sulfate particulate and SOx emissions, both of which are harmful pollutants, are emitted in direct proportion to the amount of sulfur in diesel fuel. Therefore, lowering the sulfur content of diesel fuel from an average of 340 ppm[6] to 30 ppm would reduce these pollutants by approximately 90%. Lowering sulfur to under 10ppm would, of course, have an even greater impact.

Sulfate PM contributes to PM10, and PM2.5 emissions directly with their associated adverse health and environmental effects. SO2, one fraction of the SOx, is a criteria pollutant with associated adverse effects. The health and welfare effects of SO_2 emissions from diesel vehicles are probably much greater than those of an equivalent quantity emitted from a utility stack or industrial boiler, since diesel exhaust is emitted close to the ground level in the vicinity of roads, buildings, and concentrations of people. Further some of the SOx is also transformed in the atmosphere to sulfate PM with the associated adverse effects noted for PM.

Diesel PM which, as is noted above, has been found to be a human carcinogen by the California Air Resources Board consists of three primary constituents - a carbonaceous core, a soluble organic fraction (SOF) which sits on the surface of this core and a mixture of SOx and water which also sits on the surface of the core. Lowering the sulfur in the fuel lowers the SOx fraction of PM thus lowering the overall mass of PM emitted

Perhaps even more importantly, most of the most successful or promising systems to reduce NOx, PM and toxics from diesel engines would benefit from low sulfur or even zero sulfur fuel. Use of these technologies could likely enable manufacturers of light duty vehicles to achieve the US EPA's recently adopted Tier 2 standards. Heavy Duty engine manufacturers could likely go well beyond the 2004 requirements and achieve levels in the range of 1.0 grams/bhp-hour for NOx and 0.01 for PM while simultaneously reducing toxic emissions and ultrafine particles. Comparable reductions would seem

6() Outside of California, Alaska, American Samoa and Guam.

feasible for off road vehicles and engines.

Some promising technologies such as selective catalytic reduction (SCR) appear to be tolerant of today's on highway sulfur levels but these systems address only one portion of the diesel problem, NOx emissions, while doing nothing to lower PM, toxics or ultrafines. Further it remains to be seen whether such systems would be practical in moving vehicles. A urea distribution network and infrastructure is just one of the hurdles to be overcome. Even if overcome, associated oxidation catalysts will be sensitive to sulfur.

Achieving the very low levels of NOx, PM, toxics and ultrafines which all categories of diesels will need to do in the future presents a very strong challenge to the vehicle industry. In meeting this challenge they deserve to be provided with the quality of fuel which maximizes their opportunities for success in all vehicle applications. This means 30-ppm maximum sulfur in the 2004 time frame and near zero sulfur shortly thereafter. As stated by the German government in a recent petition to the European Commission in support of low sulfur fuel, "A sulphur content of 10 ppm compared to 50 ppm increases the performance and durability of oxidizing catalytic converters, DeNox catalytic converters and particulate filters and therefore decreases fuel consumption. There are also lower particulate emissions (due to lower sulphate emissions) with oxidizing catalytic converters. For certain continuously regenerating particulate filters, a sulphur content of 10 ppm is required for the simple reason that otherwise the sulphate particles alone (without any soot) would overstep the future [European] particulate value of 0.02 g/kWh."

b. Gasoline

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.

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 emerging low emissions vehicles (on average) by 40 percent and 150 percent, respectively, relative to their emissions with fuel containing roughly 30-ppm sulfur.

Sulfur sensitivity is temperature dependent. Sulfur adheres to the catalyst surface more thoroughly at lower catalyst temperatures (approximately 450EC to 500EC) than higher temperatures. 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 450EC, thus not allowing complete adsorption of sulfur to the catalyst surface, whereas real-world vehicle operation in metropolitan non-attainment areas quite frequently result in catalyst temperatures at or below 450EC.

D. **Global Warming**

Beyond direct adverse health effects, there are other concerns with vehicle emissions. Among these is global warming or the greenhouse effect. Greenhouse warming occurs when certain gases allow sunlight to penetrate to the earth but partially trap the planet's radiated infrared heat in the atmosphere. Some such warming is natural and necessary. If there were no water vapor, carbon dioxide, methane, and other infrared absorbing (greenhouse) gases in the atmosphere trapping the earth's radiant heat, our planet would be about 60 F (33 C) colder, and life as we know it would not be possible. Naturally occurring greenhouse gases include water vapor, carbon dioxide (CO_2), methane (CH4), nitrous oxide (N_2O), and ozone (O_3).

Several classes of halogenated substances that contain fluorine, chlorine, or bromine are also greenhouse gases, but they are, for the most part, solely a product of industrial activities. Chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs) are halocarbons that contain chlorine, while halocarbons that contain bromine are referred to as halons. Other fluorine containing halogenated substances include hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulphur hexafluoride (SF6).

There are also several gases that, although they do not have a direct global warming effect, do influence the formation and destruction of ozone, which does have such a terrestrial radiation absorbing effect. These gases include carbon monoxide (CO), oxides of nitrogen (NOX), and nonmethane volatile organic compounds (NMVOCs).

Aerosols, extremely small particles or liquid droplets often produced by emissions of sulphur dioxide (SO_2), can also affect the absorptive characteristics of the atmosphere.

Although CO_2, CH_4, and N_2O occur naturally in the atmosphere, the atmospheric concentration of each of them has risen, largely as a result of human activities. Since 1800, atmospheric concentrations of these greenhouse gases have increased by 30, 145, and 15 percent, respectively (IPCC 1996). This build-up has altered the composition of the earth's atmosphere, and may affect the global climate system.

Beginning in the 1950s, the use of CFCs and other ozone depleting substances (ODSs) increased by nearly 10 percent a year, until the mid-1980s when international concern about ozone depletion led to the signing of the Montreal Protocol. Since then, the consumption of ODSs has rapidly declined, as they are phased-out. In contrast, use of ODS substitutes such as HFCs, PFCs, and SF6 has grown significantly and all have strong greenhouse forcing effects.

In late November 1995, the IPCC Working Group 1 concluded, “the balance of evidence suggests that there is a discernible human influence on global climate.”[7] In December 1997, acting on this consensus, countries around the world approved the Kyoto Protocol to the 1992 Climate Change Treaty. When and if ratified by 55 nations, representing 55 percent of 1990 carbon dioxide emissions, thirty-eight industrialized nations will be required to reduce their “greenhouse” gas emissions from 1990 levels between 2008 and 2012. The European Union would reduce them by 8 percent, the United States by 7 percent and Japan by 6 percent.[8] Some would face smaller reductions, and a few would not face any now. As a group, the industrialized nations would cut back on the emissions of such gases by just more than 5 percent.

Emissions of six gases would be affected: carbon dioxide, methane, nitrous oxide, and three halocarbons used as substitutes for ozone-damaging chlorofluorocarbons.

The greenhouse gases most closely identified with the transportation sector include carbon dioxide (CO2), nitrous oxide (N2O) and methane (CH4). Relative to CO2, N2O and CH4 have the following global warming potentials relative to carbon dioxide.

IPCC GWP	Methane (CH4)	Nitrous Oxide (N2O)
20 Year Horizon	56	280
100 Year Horizon	21	310
500 Year Horizon	6.5	170

However, it is important to note that other vehicle related pollutants contribute to global warming although their quantification has been more difficult. These include CO, NMHC and NO2. According to the original (1990) IPCC report, the following global warming potentials were attributed to these gases. Because of difficulty reaching agreement on the appropriate quantification, specific GWPs for these gases were not contained in the most recent IPCC report.

GWP	CO	NMHC	NO2
20 Year Horizon	7	31	30
100 Year Horizon	3	11	7
500 Year Horizon	2	6	2

In most countries, over 90% of the global warming potential of the direct acting greenhouse gases from the transportation sector comes from carbon dioxide. The

7() In its most recent draft report, the IPCC has changed the wording to “there is a discernable human influence on global climate.”

8() The US Government has recently repudiated the Kyoto Protocol but most other countries appear to be proceeding anyway in the hopes of eventually bringing the US along.

transportation sector is responsible for approximately 17% of global carbon dioxide emissions and these emissions are increasing in virtually every part of the world.

Even the potential global warming benefits of diesel vehicles, due to their substantial fuel economy benefits relative to gasoline fueled vehicles, have been undercut by recent studies, which indicate that diesel particles may by reducing cloud cover and rainfall, more than offset any CO_2 advantage. As noted by NASA's Dr. James Hansen, "Black carbon reduces aerosol albedo, causes a semi-direct reduction of cloud cover, and reduces cloud particle albedo."[9]

The landmark Indian Ocean Experiment for example, "…revealed that dark particles such as soot can have a warming effect by absorbing solar energy".[10] The Indian Ocean Experiment results suggest that the pervasive presence of dark hazes contributed to the scarcity of clouds. It is likely that the lack of clouds was largely due to the dryness of air flowing off the Indian subcontinent, and the soot-effect served to diminish cloud cover even further.

Based on these results, other researchers have concluded "The magnitude of the direct radiative forcing from black carbon itself exceeds that due to CH_4, suggesting that black carbon may be the second most important component of global warming after CO_2 in terms of direct forcing."[11]

4. **Conclusions**

A great deal of progress has been made in reducing vehicle emissions in many countries with the result that many cities have experienced actual air quality improvements. However certain problems remain and with continued growth in vehicle populations are likely to continue to be significant problems in the future without focused actions. These problems include toxic emissions, especially diesel particulate and climate change. Further, continued high growth will offset many of the gains achieved to date unless continued improvements are made per vehicle.

As we look to the future efforts, it is useful to do so in the context of the experience to date. Based on this experience, several policy fundamentals or principles have emerged which are summarized below:

A. **Principles Regarding New Vehicle Standards**

< Standards should be based on the most stringent levels technologically feasible by the technological leader.

< Standards for new vehicles should require that pollution controls function as designed for the **full actual life** of the vehicles on which they are installed when the vehicles are

9() "Global Warming in the 21st Century: An Alternative Scenario", James Hansen, NASA Goddard Institute for Space Studies Research at www.giss.nasa.gov/research/impacts/altscenario/

10() "Reduction of Tropical Cloudiness by Soot", A. S. Ackerman, O. B. Toon, D. E. Stevens, A. J. Heymsfield, V. Ramanathan, E. J. Welton, Science, Volume 288, Number 5468, Issue of 12 May 2000, pp. 1042-1047.

11() "Strong radiative heating due to the mixing state of black carbon in atmospheric aerosols", Mark Z. Jacobson, Department of Civil & Environmental Engineering, Stanford University, Stanford,

normally maintained and used.

< New vehicle standards should be **fuel neutral** (e.g., diesel standards = gasoline standards).

< PM standards should be designed to reduce the **mass** of PM as well as the absolute **number** of particles.

< Vehicles which perform the **same function** should be required to meet the **same standards**, based upon the capability of the leader rather than the laggard (e.g. SUV standards = car standards)

< Since carbon is an air pollutant in all forms, CO, HC, CO_2, etc., standards should be adopted for all forms for all vehicles; **CO_2 standards** should be adopted for all vehicle categories.

B. Principles Regarding Clean Conventional Fuels

< The sale and use of toxic **lead** in gasoline should be **banned** worldwide.

< **Sulfur** levels in gasoline and diesel fuel should be reduced to **near zero** levels as soon as possible.

< **Benzene** levels in gasoline should be capped at no more than 1% everywhere in the world.

C. Overriding Policies

< Clean Vehicle Strategies Should Consider Both Air Quality Needs and Energy Needs in Parallel

< Clean Vehicle Strategies Should Pursue Inherently Clean Vehicles & Fuels

< New Vehicle Strategies Directed At One or Two Dozen Manufacturers are inherently easier to implement and enforce than strategies dealing with millions of vehicle owners

< It is Much Harder Technologically As Well as Managerially to Maintain Vehicles Clean if they inevitably tend toward being dirty.

< Clearly Defined Roles For the National, Provincial and Municipal Governments Benefit Everyone

< Manufacturers Can Build Clean Vehicles More Efficiently if they have clearly defined targets

< The limited government resources are used more efficiently if each branch focused on the role assigned to it.

< A Newly Developed Vehicle Industry Should Be Based On New Technology & Not Be a Dumping Ground For Old Technology

< It is not necessary to follow the same sequence in control measures in rapidly industrializing countries as has been followed in the OECD countries; leapfrogging is possible

< Vehicles and Fuels Should Be treated as a package rather than as independent entities

< Policies Adopted to Facilitate Clean and Efficient Vehicles and Fuels Should Be Mutually Reinforcing Not Conflicting