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MOTOR VEHICLE POLLUTION CONTROL

GLOBAL PROGRESS and REMAINING PROBLEMS

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1. BACKGROUND AND INTRODUCTION

At the present time, as the world's vehicle population inches over 700 million, countries around the world are continuing to struggle with their motor vehicle pollution problems. Areas of rapid industrialization are now starting to experience similar air pollution problems to those of the industrialized world. Cities such as Mexico, Delhi, Seoul, Singapore, Hong Kong, Sao Paulo, Manila, Santiago, Bangkok, Taipei and Beijing to cite just a few already experience unacceptable air quality; in some cases, pollution levels are several times higher than healthy levels.

Some countries have made great progress in reducing CO and HC emissions from vehicles, and to a lesser extent NOX, in spite of substantial growth in their vehicle populations. Ambient levels of Ozone and CO are declining in many areas as a result of these emissions reductions. Particulate matter from vehicles and other sources is quickly becoming the pollutant of greatest health concern in cities. While light duty gasoline fueled vehicle standards continue to be tightened, the motor vehicle focus is gradually shifting to diesel fueled cars and heavy duty trucks and buses and off road vehicles and engines. Fuels improvements are also playing an increasingly important role. Finally, concerns with CO2 and other greenhouse gases are getting increased attention. The purpose of this paper will be to provide a broad overview of these developments.

2. CONCERNS WITH PARTICULATE

Ambient particulate levels appear to be the most serious urban air pollution problem. Motor vehicle particle emissions and the particles formed by the transformation of motor vehicle gaseous emissions tend to be in the fine particle range. Fine particles (those less than 2.5 micrometers in diameter) are of health concern because they easily reach the deepest recesses of the lungs. Scientific studies have linked fine particles (alone or in combination with other air pollutants), with a series of significant health problems, including premature death; respiratory related hospital admissions and emergency room visits; aggravated asthma; acute respiratory symptoms, including aggravated coughing and difficult or painful breathing; chronic bronchitis; and decreased lung function that can be experienced as shortness of breath. The World Health Organization (WHO) estimates that approximately 460,000 people die prematurely each year as a result of exposure to PM in the air.

a. Threshold For Adverse Effects

The Air Quality Guidelines for Europe were first published by the WHO Regional Office for Europe, in 1987. Since 1992 they have been in the process of being reviewed and updated[1] with the new

1/WHO, 1987. Air Quality Guidelines for Europe, Regional Office for Europe.
WHO, 1992. Air quality guidelines in the European region, EUR/ICP/CEH 079/A
WHO, 1994. Updating and Revision of the Air Quality Guidelines for Europe - Inorganic air pollutants, EUR/ICP/EHAZ 94 05/MT04
WHO 1995a. Updating and Revision of the Air Quality Guidelines for Europe - "Classical" air pollutants, EUR/ICP/EHAZ 94 05/PB01
WHO, 1995b. Updating and Revision of the Air Quality Guidelines for Europe -PCBs, PCDDs, PCDFs, EUR/ICP/EHAZ 94 05/MT10

guidelines intended to be globalized, that is to apply to populations everywhere.

WHO has adopted the following guidelines.

Compound	Guideline [μg m-3]	Averaging time
Carbon monoxide	100 000	15 min
	60 000	30 min
	30 000	1 h
	10 000	8 h
Nitrogen dioxide	200	1 h
	40 - 50	1 a
Ozone	120	8 h
Sulphur dioxide	500	10 min
	125	24 h
	50	1 a

The above table does not include guidelines for suspended particulate matter since a threshold for adverse effects from this material including the size-dependent fractions PM10 and PM 2.5 could not be established. Based on the available data, the World Health Organization estimates that every 50 $\mu g/m^3$ increase in PM10 leads to a 5% increase in mortality; a 25 $\mu g/m^3$ increase causes a 5% increase in hospital admissions for respiratory conditions; a 7 $\mu g/m^3$ increase causes a 5% increase in bronchodilator use among asthmatics, etc.[2] In conclusion, the WHO decided that "No specific guidelines are recommended for PM because there was no obvious exposure concentration and duration that could be judged a threshold and decreased by uncertainty factors to avoid risk. Rather, the data base on PM suggests a continuum of effects with increasing exposure".

b. Toxicity

Some particles have been found to be more hazardous than others. For example, the California Air Resources Board (ARB) evaluated diesel exhaust as a candidate toxic air contaminant under the State's air toxics identification program and concluded that a reasonable and likely explanation for the increased rates of lung cancer observed in the epidemiological studies is a causal association between diesel exhaust exposure and lung cancer.

It is important to note that a comprehensive assessment of the available health information on **diesel** particulate was carried out by the International Agency For Research on Cancer (IARC) in June 1988 and concluded at that time, over a decade ago, that diesel particulate is probably

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WHO, 1995c. Updating and Revision of the Air Quality Guidelines for Europe - Ecotoxic effects, EUR/ICP/CEH230/B
WHO,1996. Updating and Revision of the Air Quality Guidelines for Europe - Volatile organic compounds, EUR/ICP/EHAZ 94 05/MT12

2/"Update and Revision of the Air Quality Guidelines For Europe", World Health Organization, 1995.

carcinogenic to humans.[3]

c. Ultrafine Particles

While all regulation of diesel particulate from vehicles is based on the mass of particulate, several studies in recent years in the United Kingdom, Switzerland and the US have increased the interest in and concern with the number of very small ultrafine particles.[4] Observations that modern engines with reduced particle mass concentrations may actually emit larger number concentrations than older designs raises concerns that the form of future regulations should focus more on the number of particles in addition to or as an alternative to the mass. Additional studies indicate that large numbers of ultrafine particles may also be emitted by gasoline and CNG fueled vehicles, at least at high speeds and loads, and especially from the more fuel efficient direct injection technology.[5]

Studies are underway to characterize the size distribution of particles in ambient air as well as to understand the health consequences of these particles. Depending on the results of these studies, future vehicle regulation may focus more on these compounds. This could be mooted, however, to the extent that mass based standards result in the use of particulate filters or traps as studies consistently show that these devices successfully reduce both the mass and the number of particles.

3. OTHER TOXINS

Another area of growing concern is toxic emissions. The 1990 Clean Air Act (CAA) directed the US EPA to complete a study of emissions of toxic air pollutants associated with motor vehicles and motor vehicle fuels; the study found that in 1990, the aggregate risk was 720 cancer cases as a result of exposure to vehicle emissions across the US. Within the last several months, two new reports have become available that characterize the actual and projected exposures for a large number of chemicals found in ambient air and compare these ambient air levels with health-derived guidance levels. Toxic air pollutants typically associated with mobile sources were found at elevated levels exceeding a one-in-ten-thousand cancer risk. These new monitoring studies indicate that EPA's earlier study may understate the problem.

In February, 1998 the Vermont Agency of Natural Resources issued a report which included a

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3/ The term `carcinogen' is used by the IARC to denote an agent that is capable of increasing the incidence of malignant tumors.

4/"First International ETH Workshop On Nanoparticle Measurement", ETH Zurich, A. Mayer, 7 August 1997., "Characterization of Fuel and Aftertreatment Device Effects on Diesel Emissions", Bagley, Baumgard, Gratz, Johnson and Leddy, HEI Research Report Number 76, September 1996., "UK Research Programme on the Characterization of Vehicle Particulate Emissions (ETSU, September 1997)

5/"Characterization of Exhaust Particulate Emissions from a Spark Ignition Engine", Graskow, Kittleson, Abdul-Khalek, Ahmadi and Morris, SAE#980528., "A study of the number, size and mass of exhaust particles emitted from european diesel and gasoline vehicles under steady state and european driving conditions" CONCAWE report No. 98/51, February 1998.

comparison of the state's health-based ambient air standards with findings from state monitoring sites measured from 1993-1998. The comparison showed that monitored levels of some contaminants greatly exceeded health based air standards. Contaminants from mobile sources were significantly higher in urban sites than in rural areas.

In April and May 1998, EPA scientists published two peer reviewed articles based on EPA's Cumulative Exposure Project, which found that in 1990, twenty (20) million people in the United States were exposed to concentrations of air toxics in excess of a one in ten thousand cancer risk level. These findings were based on modeled emissions data of hazardous air pollutants which were then verified by ambient air quality monitoring data. The EPA study showed findings similar to those in Vermont.

The table below provides a comparison of the Vermont and EPA findings for six contaminants associated with mobile sources. In most cases, actual measured ambient air levels in Vermont, a state with relatively few sources, are within an order of magnitude of the highest modeled census tracts nationally. Further, the health based standards determined by the Vermont Department of Health and peer reviewed by public health scientists are virtually the same as the health standards estimated by EPA scientists.

Comparison of Ambient Toxics & Public Health Standards
(micrograms/cubic meter)

Air Toxic	**Air Levels Monitored or Modeled**		**Health Standards**	
	Vermont (Max. Annual Avg.)	EPA (Modeled Max. Census tract)	Vermont Health Standard	EPA Bench Mark Estimate
Benzene	4.05	79	0.12	0.12
1,3 butadiene	0.95	6.7	0.0019	0.0036
Formaldehyde	10.2	52	0.078	0.077
Acetaldehyde	4.65	21	0.45	0.45
Xylene	8.09	72	1033	300
Toluene	11.87	89	400	400

The Vermont study and EPA's Cumulative Exposure Project suggest two general conclusions.

- Health risks from mobile source related ambient air toxics are in the range of public health concern.
- Even small urban centers are at risk from mobile source air toxics.

4. CLIMATE CHANGE

Beyond direct adverse health effects from urban air pollutants, 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.

Over the past few centuries, however, human activities have increased atmospheric concentrations of naturally occurring greenhouse gases and added new and very powerful infrared absorbing gases to the mixture. Even more disturbing, in recent decades the atmosphere has begun to change through human activities at dramatically accelerated rates. According to a growing scientific consensus, if current emissions trends continue, the atmospheric build up of greenhouse gases released by fossil fuel burning, as well as industrial, agricultural, and forestry activities, is likely to turn our benign atmospheric "greenhouse" into a progressively warmer "heat trap," as Norway's former Prime Minister and current head of the WHO, Ms. Gro Harlem Brundtland, has termed this overheating.

In late November 1995, the IPCC Working Group 1 concluded that “the balance of evidence suggests that there is a discernible human influence on global climate.”

5. THE IMPORTANCE OF MOTOR VEHICLES AS A SOURCE OF AIR POLLUTION

Many sources contribute to air pollution but worldwide, cars, trucks, buses, and other motor vehicles continue to play a dominant role. They are a major source 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).

a. European Union

Throughout the European Union as a whole, for example, both on and off road vehicles are the largest source of CO, NOx and non-methane hydrocarbons.[6]

In densely populated urban areas, vehicles can be a major source of particulate as well. For example, "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."[7]

b. United States & Japan

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, EPA

6/"The Estimation of the Emissions of Other Mobile Sources and Machinery Subparts Off-Road Road Vehicles and Machines, Railways and Inland Waterways In The European Union”, Andrias, Samaras and Zierock, September 1994.

7/"Diesel Vehicle Emissions and Urban Air Quality", Second Report of the Quality of Urban Air Review Group, prepared at the request of the Department of the Environment, December 1993.

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.[8]

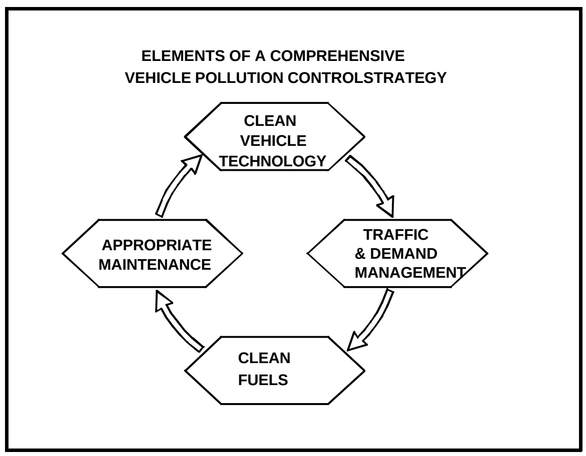
Further, when focusing on emissions in congested city centers, the importance of vehicle emissions is even greater. One study, for example, used a chemical mass balance technique to determine the source of the particulate in a midtown Manhattan street; in this instance, diesel buses were the primary source.

c. Cities in Developing Countries

Vehicle emissions problems are not limited to the cities in highly industrialized countries. Numerous studies have found vehicles to be the major source of emissions in many of the world's megacities.[9]

6. STRATEGIES TO REDUCE MOTOR VEHICLE POLLUTION

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. Achievement of this goal generally requires a comprehensive strategy encompassing emissions standards for new vehicles, clean fuels, strategies designed to assure that vehicles are maintained in a manner which minimizes their emissions and traffic and demand management and constraints. These emission reduction goals should be achieved in the least costly manner.



Standards for permissible levels of exhaust and evaporative emissions from motor vehicles should be based on a realistic assessment of costs and benefits keeping in view the technical and administrative feasibility of proposed countermeasures. Technological approaches to achieve the desired emission standards may include fitting new vehicles with emission control devices such as catalytic converters or particulate traps or requiring such devices to be retrofitted to existing vehicles, modifying fuels or requiring the use of alternative fuels in certain vehicles, and traffic and demand management and policy instruments. However, many of the potential benefits of these countermeasures will be squandered if they are not buttressed by regulatory and economic instruments which assure that

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8/ These emissions estimates are based on the most accurate data currently available. The Agency continues to analyze emissions data and modeling assumptions. Consequently, these estimates could be subject to change.

9/"Clean Fuels for Asia", World Bank Technical Paper No. 377, Walsh & Shah, 1997
"Air Pollution From Motor Vehicles", The World Bank, Faiz, Weaver & Walsh, 1996.

vehicle owners, manufacturers and fuel suppliers have sufficient incentives to achieve the desired goals. A key element of the overall strategy, therefore, must be effective enforcement to ensure maximum compliance with standards.

a. Fuel Modifications and Alternative Fuels

Conventional vehicle fuels have undergone substantial modification in recent decades and will likely be improved even more in the future; in parallel, alternative fuels such as ethanol, methanol, natural gas and LPG continue to receive attention.

The major trend underway worldwide is the gradual replacement of lead in petrol, both to reduce lead emissions and to facilitate the use of pollution control technologies such as the catalytic converter. In 1997, over 80% of all gasoline sold worldwide was unleaded. Additional petrol improvements include reduced volatility, increased oxygen content, reduced aromatics, lower sulfur levels and more widespread use of detergent additives. Such fuel modifications can substantially improve the environmental impacts of gasoline fueled vehicles.

Conventional diesel fuel can also be improved by the reduction of sulfur and aromatic content and the use of detergent additives.

The principal alternative fuels presently under consideration are ethanol, natural gas and methanol made from natural gas, and in limited applications, LPG. Environmental assessment of alternative fuels should not be based solely on vehicle end-use emission characteristics but should account for pollutant emissions associated with the production, storage, and distribution of these fuels.

Alternative fuels can make significant contribution to improved air quality and are increasingly playing a role in urban areas. Most often, these fuels are used with special groups of vehicles which can have a large impact on the environment (e.g., transit buses or taxicabs) and can be fueled at central location, thus minimizing the need for a widespread fueling infrastructure.

b. Vehicle Emission Control Technology Measures

Technology has been developed and introduced on millions of gasoline fueled vehicles worldwide which has demonstrated the ability to lower CO, HC and NOx emissions by approximately an order of magnitude compared to vehicles without controls. The backbone of these systems is the catalytic converter and similar approaches are now being gradually phased into the two wheeled vehicle market. In 1998, almost 90% of all new cars produced in the world required the exclusive use of unleaded gasoline to protect their catalytic emissions control systems.

As the world community increasingly embraces today's state of the art controls on these vehicles, advanced controls are emerging which will likely become increasingly widespread throughout the next decade.

Development of diesel control technologies beyond crude smoke controls has started later but is now advancing rapidly. At the present time, exhaust aftertreatment systems are becoming increasingly available. Buses throughout Sweden’s major cities and in London have been fitted with oxidation catalysts and diesel particulate filters and this number will likely increase substantially in the next few years. A critical requirement for the use of these systems is the availability of low sulfur fuel.

7. TRANSPORTATION and GLOBAL WARMING

As noted earlier, increased concern is being focused on potential climate change as a result of emissions of greenhouse gases from many sources including motor vehicles.

a. Kyoto Agreement

In December, 1997 countries around the world approved the Kyoto Protocol to the 1992 Climate Change Treaty. Key aspects of the agreement include:

REDUCTIONS: Thirty-eight industrialized nations are 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. 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.

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

`OFFSHORE' REDUCTIONS: Countries that do not meet their own emission targets can strike deals with nations that do better than required, to buy the excess ``quota.'' This may encourage reductions to be made where most cost-effective.

ENFORCEMENT: A later meeting of the treaty parties will decide on ``appropriate and effective'' ways to deal with non-compliance.

THIRD WORLD: Developing countries, including major greenhouse gas emitters such as China and India, are asked to set voluntary reduction targets.

NEXT STEP: The accord approved by the Kyoto conference takes effect once it is ratified by 55 nations, representing 55 percent of 1990 carbon dioxide emissions. It is binding on individual countries only after their governments' complete ratification.

Implementing this agreement will require significant improvements in fuel economy and carbon dioxide emissions from vehicles.

b. US Efforts

In the US, transportation is responsible for approximately one quarter of greenhouse gases. The Big Three automakers[10] and the U.S. government have been sharing high-tech information and manufacturing know-how since 1993 in an effort to serve mutually beneficial purposes. The

10/At least prior to the merger of Chrysler and Mercedes Benx.

program is called the Partnership for a New Generation of Vehicles (PNGV) and matches engineers from the auto industry with government researchers from national laboratories, renowned in the past for their work on military technologies.

The goal is to create technology that will lead to a working model of a super-car by the year 2004 -- a car capable of getting 80 miles to the gallon while meeting Tier 2 emissions levels or better. This effort does not yet include a commitment to produce vehicles meeting these fuel efficiency targets although the Administration is considering a number of tax incentive schemes to stimulate a market..

c. European Efforts

CO_2 from passenger cars accounts for about half of CO_2 emissions from Transport, and about 12 percent of total CO_2 emissions in the European Union.[11] Under a "business as usual" scenario, CO_2 emissions from cars are expected to increase by about 20 percent by the year 2000 and by about 36 percent by the year 2010 from 1990 levels. In one year, an average medium size car in the European Union emits some 3 tons of CO_2.[12] The road transport sector has stood out in recent years as one of the few sectors in the Union experiencing CO_2 emissions growth.

In the UK, a government report noted that "fuel consumption is rising fastest in the road transport sector, and there has been no improvement in fuel efficiency over the last 20 years. Fuel use for road transport has increased by 90 percent since 1970, accounting for a quarter of total energy consumption. Gasoline prices rose by just 2 percent during that period, compared with an 11 percent rise in household fuel.

European Union environment ministers have accepted an offer from EU car makers to voluntarily cut the amount of carbon dioxide emitted from car exhausts by twenty-five percent over the next 10 years. The offer -- made by the European automobile manufacturers' association ACEA in July in a bid to avoid binding legislation -- will help the 15-nation bloc reduce output of the greenhouse gases blamed for global warming. ACEA's pledge means manufacturers will have to cut average car fuel consumption to 5.8 liters per 100 kilometers by 2008, which in turn should reduce CO_2 emissions from new cars to 140 grams per kilometer from today's average of 186 g/km.

d. Japan Close to Fuel Economy Agreement

MITI and MOT jointly drafted energy saving standards for automobiles and electric appliances on 13 October in compliance with the energy saving law. The draft standards are to be discussed at the joint advisory committee and then finalized within this year at the earliest.

11/Derived from "A Community strategy to reduce CO2 emissions from passenger cars and improve fuel economy", COM (95) 689, Communication from the Commission to the Council and the European Parliament, Adopted by the Commission on December 20, 1995.

12/Assuming 12,600 km per year and an average on road fuel consumption of 9.6 liters per 100 kilometers.

The standards were drafted based on the "top runner method" or best-in-class method and are as follows.

- For gasoline passenger cars: average improvement of 23%, set by weight class, and for gasoline trucks: average 13%; resulting in a 21% improvement for all gasoline vehicles.

- For diesel passenger cars: average 15%, and for diesel trucks: average 7%; resulting in a 13% improvement for all diesel vehicles.

8. GLOBAL PROGRESS DURING 1998

In view of the above concerns, great progress occurred during 1998. Among the major developments during this past year have been the following:

- The European Union has adopted Directives regarding light duty vehicle emissions and fuel quality which tighten standards significantly (2000 and 2005), broaden the scope of coverage (e.g., cold temperature), added several important features previously missing (OBD, in use durability) and imposed low sulfur requirements for diesel fuel and gasoline;
- The US EPA and the automobile industry, working in close cooperation with the states, reached agreement to voluntarily introduce California's Low Emissions Vehicle Standards across the country;
- 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 sport 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 unleaded gasoline across the entire country by 2000;
- Japan tightened the gasoline fueled automobile standards for the first time in twenty years and introduced the next phase of diesel fueled vehicle requirements;
- The India Supreme Court banned the sale of leaded gasoline in Delhi as of September as well as mandating that all new cars meet Euro 1 auto standards (similar requirements will likely be phased in across the entire country by 2000);
- The US EPA in conjunction with the California Air Resources Board 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% by about 2008;
- Taiwan adopted step 4 of its motorcycle control program, effectively banning two stroke motorcycles by 2003; and
- The CARB formally decided that diesel PM is a toxic air contaminant, triggering a process which will likely lead to an effort to further reduce PM emissions from urban vehicles.

9. CONCLUSIONS

Continuing air pollution problems from vehicle related pollution have been stimulating innovative pollution control approaches around the world. As these approaches are implemented, steady progress in reducing certain air pollution problems is occurring. An example is the experience in

Southern California's Los Angeles Basin, which has had the most aggressive motor vehicle pollution control program in the world over the past forty years.[13] From 1955 to 1993, peak ozone concentrations were cut in half. The number of days on which Federal ozone standards were exceeded fell by 50 percent from the 1976-78 time frame to the 1991-1993 interval. Further, the average annual number of days above the Federal carbon monoxide standard fell from 30 to 4.3 during this same period and lead levels are now 98 percent lower than in the early 1970's. Most remarkably, this achievement occurred while the regional economy out-paced the national economy in total job growth, manufacturing job growth, wage levels and average household income. In short, a strong focus on environmental protection is not only not incompatible with strong economic development, they seem to be mutually reenforcing.

On a US national level, emissions of almost all pollutants are down significantly over a similar time frame in spite of a more than doubling in vehicle miles traveled and gross domestic product (GDP). Similar reductions are beginning to occur in Germany. Globally, the use of advanced pollution control technology, especially catalysts has been spreading as has the use of unleaded gasoline leading to improvements elsewhere as well.

However, spurred by continued growth in the vehicle population and lingering air quality problems, in conjunction with newly emerging problems such as toxic emissions and climate modification, it is clear that the US, Europe and Japan and other countries are continuing to push for even tighter controls in coming years, including more focus on other "pollutants" such as carbon dioxide, nitrous oxide and toxic materials. In this regard, the year 1998 has been a watershed year in the history of motor vehicle pollution control.

As much as been accomplished, several additional steps are underway:

- The US EPA will shortly propose Tier 2 standards as well as tighten the sulfur requirements in gasoline;
- the European Union is well along in deciding the next phase (or phases) of heavy duty standards;
- The Japanese MITI and industry are close to agreement regarding lower CO_2 emissions from vehicles;
- Increased attention is being focused on ultrafine PM from vehicles, both diesel as well as gasoline DI technology, increasing the likelihood that this will be a subject of control efforts in the future;
- On a global basis, pressure continues to build for lower emissions of greenhouse gases (especially CO_2, CH_4 and N_2O from the transportation sector;
- the US EPA will conduct a review of heavy duty engine emissions during 1999 with special focus on OBD, tighter PM standards and the need for low sulfur diesel fuel; and
- Urban toxic emissions are receiving increased focus in the United States with diesel PM standing out as a major contributor.

To respond to these challenges, a number of technological challenges and opportunities stand out, including:

13/"The Automobile, Air Pollution Regulation and the Economy of Southern California, 1965-1990", Jane Hall et al, Institute for Economic and Environmental Studies, California State University, April 1995.

- advanced low NOx technology which can operate on lean burn engines with high efficiency without increasing N_2O emissions;
- technologies which can not only reduce the mass of PM but also lower the number of ultrafine particles from future diesel and (DI) gasoline engines;
- adaptation of low emissions technologies to off road vehicles and engines;
- more durable emissions control systems which can routinely last for the actual life of vehicles, which continues to increase in many parts of the world; and
- engine, fuel and control technologies which substantially lower greenhouse gases without exacerbating urban air pollution problems.