Older Gasoline Vehicles

In Developing Countries and Economies in Transition : Their Importance and the Policy Options for Addressing Them

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Older Gasoline Vehicles Preface

"A healthy population and a healthy environment are a social good and an economic good. We cannot think of a healthy population without a healthy environment and ecosystems."

Klaus Töpfer, Executive Director, United Nations Environment Programme

The world's 700 million cars are a major source of air pollution. The emissions from these vehicles include hydrocarbons, nitrous oxide, carbon monoxide, and toxic fine particles called particulate matter. In countries where leaded gasoline is used, vehicle emissions are also a major source of airborne lead.

Vehicle emissions are linked to a number of health effects, including respiratory and cardiovascular diseases such as asthma and lung cancer. The World Health Organization estimates that approximately 460,000 people die prematurely each year as a result of exposure to particulate matter. The US Environmental Protection Agency has estimated that 60 percent of the annual US cancer cases related to air pollution are due to automotive emissions.

New technologies, such as catalytic converters, have significantly lowered automotive emissions and improved the environmental performance of the modern automobile. Consequently, vehicles less than ten years old generally pollute less than older vehicles. Used, older vehicles are also generally less expensive than newer vehicles and thus more affordable - particularly in developing countries where new vehicles are often prohibitively expensive.

Globally, there is a tendency for older, polluting vehicles to be exported to developing countries and countries with economies in transition, where their use poses a particular challenge for policy makers. In Mexico City, for example, older vehicles account for approximately 60 percent of the total vehicle kilometers traveled but are responsible for 90 percent of hydrocarbon and carbon monoxide emissions and 80 percent of nitrous oxide emissions. In Bangkok, where the fleet is younger, older vehicles travel half of the total vehicle kilometres, but account for over 60 percent of the hydrocarbon and carbon monoxide emissions.

In the countries of Central and Eastern Europe, the rapid growth of the automobile fleet has come mainly from used vehicles imported from western Europe. As these vehicles age, they have the potential to create long-term air-quality problems similar to those that currently exist in some developing countries.

Helping policy makers select the best option and programme is the basis for this publication. *Older Gasoline Vehicles (Developing Countries and Economies in Transition: Importance and the Policy Options for Addressing Them)* offers policy makers the opportunity to compare the strategies and experiences of other countries in their efforts to reduce automotive emissions.

Older Gasoline Vehicles also complements information from the UNEP/OECD publication, *Phasing Lead out of Gasoline: An Examination of Policy Approuches in Different Countries.*

Please read this report carefully, consider the recommendations and act to reduce automotive emissions, It is not just a play on words to say that we will all breathe a little easier.

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Acknowledgements

In December 1996 UNEP and the Organisation for Economic Co-operation and Development (OECD) convened in Paris a consultative meeting on lead in gasoline. One result was a decision to commission two issue papers - the first concerning problems arising from the use of older vehicles in developing countries and the second on policy options for phasing out the use of lead in gasoline. In late 1997, the International Lead Management Center (ILMC) generously offered to provide funding for the preparation of the studies. A Steering Committee was created to oversee the process.

Draft copies of the papers were distributed to the Steering Committee for their review in mid-1998. Extensive and very helpful comments were received from several members, especially from the Ford Motor Company, Octel, the Natural Resources Defense Council, OECD and ILMC. Comments were also solicited from other organisations, including the Danish Environmental Protection Agency, Hampshire Research, UNICEF, CONCAWE, the Manufacturers of Emissions Controls Association, the US Environmental Protection Agency, and the International Petroleum Industry Environmental Conservation Association (IPIECA).

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Executive Summary

1. Background and Introduction

Over the past 50 years the world's vehicle population has grown fifteen-fold: it now exceeds 700 million units and will soon reach 1 billion. Most vehicles were originally concentrated in the highly industrialized countries of the OECD, but an increasing number of urbanized areas in developing countries and Central and Eastern Europe are now also heavily congested. While vehicles have brought many advantages — increased mobility and flexibility for millions of people, more jobs, and enhanced quality of life — the benefits heve been at least partially offset by pollution and its adverse effects on human health and the environment.

Motor vehicles emit large quantities of carbon monoxide, hydrocarbons, nitrogen oxides, and toxic substance such as fine particles and lead. Each of these, along with their 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 vehicles, serious air pollution problems heve been an increasingly common phenomena in modern life.

Reducing the pollution that comes from vehicles requires a comprehensive strategy. Generally, this requires emissions standards for new vehicles, clean fuels, programmes designed to ensure that vehicles are maintained in a manner that minimizes their emissions, and traffic and demand management measures. Society's goal shouid be to achieve these emission reduction goals in the lesst costly manner.

Many countries around the world have made progress in introducing advanced technologies for new vehicles. Vehicles introduced before tight standards went into effect, however, or which have had their pollution controls damaged or destroyed as they aged remain a serious concern in many countries. The issue of exactly how to reduce emissions from these older, higher polluting vehicles is a challenge to policy makers, particularly where they constitute a large percentage of the vehicle fleet.

2. Emissions from Older Vehicles antiquated

Older vehicles or those with antiquated or malfunctioning pollution controls are a major source of emissions in many countries for a variety of reasons:

- climates that allow vehicle chassis to last for many years without rusting,
- economic or political conditions that encourage the import and sale of used vehicles or engines rather than new, relatively low pollution vehicles, and
- economic conditions that increase the value of substandard vehicles sufficiently that they remain on the road well beyond the time they would in wealthier countries.

The situation and circumstances regarding older vehicles differ significantly among different countries. Several general conclusions appear warranted:

- Many developing countries have large populations of older uncontrolled vehicles that make a disproportionate contribution to their air pollution problems. For these countries, control efforts will need to focus on older vehicles if rapid progress in reducing emissions is to be achieved.
- Older vehicles tend not to be a serious problem at present in many rapidly industrializing developing countries such as China; because vehicles are relatively valuable, however, one can foresee problems as these vehicles age.
- In some countries, especially those Central and Eastern Europe, the large and rapid influx of used vehicles in recent years appears to have created a special problem. As these vehicles age it is likely that they will create long term problems if no actions are taken.

3. Strategies To Reduce Emissions From Existing Older Vehicles

Several strategies have emerged to address the problem of older vehicles. These fall into the following major categories:
- Inspection and Maintenance (I/M)
- Retrofit
- Accelerated Retirement (Scrappage)
- Import Restrictions
- Alternative Fuel Conversions

Conclusion Regarding I/M

- I/M programmes have the potential to significantly reduce emissions of CO, HC, NO_x and particulate emissions from vehicles.
- As evidenced by the British Columbia experience (to cite one well studied example) these reductions are significant in a well run programme.
- Centralized I/M programmes are more likely to achieve substantial reductions because they tend to have better quality control, are easier to

enforce, and can use more sophisticated test procedures in a cost effective manner. In Mexico City, where both centralized and decentralized programmes were run in parallel, the latter were more subject to corruption and were less effective.

Conclusions Regarding Retrofit Programmes

- Real world experience indicates that retrofit programmes can be very successful, especially if they are focused on specific vehicle categories. A combination of tax incentives coupled with restrictions on the use of non-retrofitted vehicles has worked well in stimulating successtul retrofit programmes.
- Catalytic converter retrofit programmes require careful planning, dependable unleaded fuel supplies, and effective oversight of equipment suppliers, installation facilities, and vehicle operators. Programmes should include retrofit of closed-loop engine management systems for best catalyst durability and emission benefit.
- If the decision is made to proceed with a retrofit programme, public education and effective enforcement are essential.
- Finally, an incentive must be established to bring about a significant number of actual retrofits. The incentive can be either in the form of mandatory requirements or economic incentives such as tax credits. It is extremely difficult to institute a successful retrofit programme unless a good I/M programme is also in place.

Conclusions Regarding Accelerated Retirement Programmes

- Analysis indicates that early retirement programmes for older vehicles can exhibit a wide range of outcomes, depending on both the structure of the programmes and the values of a number of key variables that are very uncertain.
- It is quite likely that a carefully designed early retirement programme, targeted at areas that exceed air quality standards, can achieve environmental benefits at costs equal to or lower than those of other emissions-reduction options. These programmes can also achieve significant gasoline savings and an improvement in fleet safety, primarily because of the improved safety design of newer cars and the likelihood that the brakes and other safety systems on the vehicles retired are in worse condition than those on the replacement vehicles.
- An important side effect of a very large early retirement programme is to increase the demand for, and raise the prices of, the remaining cars in the fleet, because many of the former owners of the retired vehicles seek to purchase replacement vehicles. This will adversely affect lower income vehicle buyers just entering the car market. Money used to purchase vehicles, however, goes directly to former owners of retired vehicles, many of whom may be expected to have lower income levels.
- The actual benefits of a scrappage programme depend critically on a number of variables that are hard to predict with any confidence. For example, one cannot be sure what types of vehicles will be attracted to a large-scale scrappage programme, particularly their emissions levels and the extent to which they would have soon been retired anyway, or else would have been kept operative but used much less than average vehicles. If the assumed values for the emissions and remaining lifetimes of the vehicles in the programme are too high (or too low), then the benefits will be overstated (or understated).
- Estimated net benefits depend on assumptions about the nature of replacement vehicles, and the nature of resulting changes in the existing fleet in the area affected by the scrappage programme. It is unclear whether the "vehicle miles lost" by scrapping cars before their normal retirement dates will be made up by increased driving of the remaining fleet or by increased sales and use of new vehicles. Another uncertainty arises with scrappage programmes confined to limited areas, where the issue is whether owners of scrapped cars replace them primarily with cars of more recent vintage, (having better fuel economy and lower emissions) or "import" older cars from outside the programme area, thereby sharply reducing emission benefits and fuel savings.
- Past emissions testing programmes have demonstratod wide variations in emissions performance among older vehicles of the same model type and vintage, probably because of different maintenance regimes as well as the random nature of failures of emission control systems. Policymakers concerned about obtaining a better cost benefit ratio from a scrappage programme might wish to examine options that tie participation in such programme to emissions performance. For example, scrappage bonuses might be offered only to vehicles that have failed scheduled emissions tests in an I/M programme, or that are identified as high polluters by remote sensing. Although some vehicle owners might deliberately sabotage their vehicles to cause them to fail an emissions test, the effectiveness of a selective programme in the face such tampering would be no worse than that obtained by a programme offering scrappage bonuses to all willing participants, and most likely would be considerably better. If a vehicle retirement programme can selectively retire vehicles with emissions double the national average for their age group, high programme benefits are much more likely.

- Another option for removing polluting vehicles from the fleet is to insist that vehicles failing I/M emission tests be removed from service if they cannot be repaired. More effective I/M programmes will reduce the incremental emissions benefits of a vehicle retirement programme by removing the highest emission (and highest net benefit) vehicles from the fleet.

- Still another option is to vary the size of the bonus (or the magnitude of the corporate incentive, e.g., emission credit) according to some measure of the potential emissions benefits. The measure can be based on previous emissions experience with different engine classes, data on average remaining lifetime and average emissions of different vintages, etc. Given an accurate basis for estimating emissions and lifetimes, this approach improves the cost-effectiveness of the programme. There may, however, be important concerns about the availability of adequate data, especially about remaining vehicle lifetime.

Conclusion Regarding Alternative Fuels

- Some alternative fuels do offer the potential for large, cost-effective reductions in emissions in specific cases. Care is necessary in evaluating the air-quality claims for alternative fuels, however - in many cases, the same or even greater emission reduction could be obtained with a conventional fuel, through the use of a more advanced emission control system. Which approach is more cost-effective depends on the relative costs of the conventional and alternative fuels compared to other measures.

Conclusions Regarding Used Imports

- Imported used vehicles or engines remain a serious problem in many countries. Three primary approaches have been demonstrated to stop or drastically reduce the problem:

  - Ban imports of certain types of used vehicles or engines,
  - Place a high tax on imported used vehicles or engines, or
  - Require imports to pass a stringent emissions requirement as a condition of registration.

Each of these approaches can be successful.

What is striking is the lack of restrictions by exporting countries on older vehicles or engines. In general the prevailing attitude is that it is up to each importing country to determine its own environmental priorities and to decide whether the social benefits of used vehicles outweigh the environmental risks.

Conclusions Regarding Mechanical Impact of Unleaded Gasoline on Engines

- The potentially detrimental effects of eliminating leaded gasoline have been greatly exaggerated in the public mind, while the potentially beneficial effects heve been understated or ignored. Public concern over the effects of removing lead from gasoline has little foundation in fact.

Conclusions Regarding Environmental Impact of Unleaded Gasoline

- Gasoline is inherently toxic. Some of the lead substitutes can increase this toxicity. For example, the increased use of benzene and other aromatics (which tend to increase benzene emissions in the exhaust) has led to concern over human exposure to benzene. In order to maximize the health benefits of unleaded petrol use in vehicles without catalytic converters, it is prudent to ensure that acceptable alternatives are used.

- Research suggests that oxygenates, at levels that exist in reformulated gasoline, pose no greater health risk than the gasoline they replace. As part of the cleaner gasoline formulation oxygenates help decrease vehicle emissions.

Contents

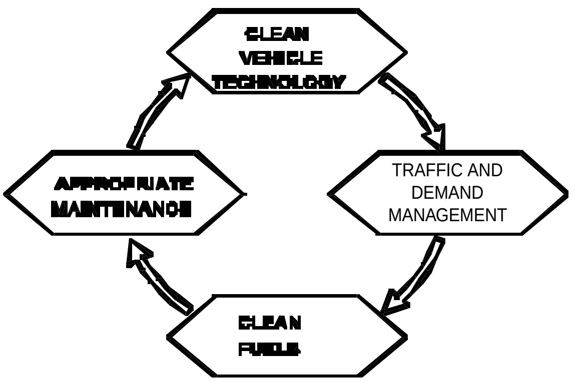
1. Background and Introduction

Over the past 50 years, the world's vehicle population has grown fifteen-fold; it now exceeds 700 million units and will soon reach 1 billion. Most vehicles were originally concentrated in the highly industrialized countries of the OECD, but an increasing number of urbanized areas in developing countries and in Central and Eastern Europe are now also heavily congested. While these vehicles have brought many advantages — increased mobility and flexibility for millions of people, more jobs, and enhanced quality of life — 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 their secondary by-products (such as ozone), can cause adverse effects on health and the environment[1]. Because of the growing vehicle population and the high emission rates from many of these vehicles, serious air pollution problems have been an increasingly common phenomena in modern life.

Reducing the pollution that comes from vehicles usually requires 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 limits of effective technological, economic, and social feasibility. Achievement of this goal generally requires emissions standards for new vehicles, clean fuels, programmes designed to assure that vehicles are maintained in a manner that minimizes their emissions, and traffic and demand management and constraints. These emission reduction goals should be achieved in the least costly manner.

ELEMENTS OF A COMPREHENSIVE VEHICLE POLLUTION CONTROL STRATEGY



Many countries around the world have made progress in introducing advanced technologies on new vehicles. Vehicles introduced before tight standards went into affect, however, or which have had pollution controls damaged or destroyed as they aged, remain a serious concern in many countries.

The purpose of this paper is to address the issue of how to reduce emissions from older, higher polluting vehicles. The next section illustrates the importance of older vehicles as a source of emissions. It begins with a hypothetical example, and then illustrates the different role of older vehicles through a number of case studies. Following chapters focus on the emissions reduction potential of different strategies. Finally conclusions and recommendations are presented.

1/See Appendix A for a detailed review of the adverse health affects associated with vehicular related air pollution.

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2. Emissions from Older Vehicles

Older vehicles or vehicles with little or no functioning pollution controls are a major source of emissions in many countries for a variety of reasons including:

- climates that allow vehicle chassis to last for many years without rusting,
- economic or political conditions that encourage the importation and purchase of used vehicles or engines rather than new, relatively low pollution vehicles, and
- economic conditions that increase the value of substandard vehicles sufficiently that they remain on the road well beyond the time they would in wealthier countries.

2.1 - Hypothetical Example

To illustrate the relative significance of these factors a hypothetical experiment was designed, based upon the actual situation in Taiwan. In the first scenario, emissions were calculated based on the assumption that twenty five model years worth of vehicles were evenly distributed (i.e., each model year accounts for 4% of the vehicles on the road), and none of the vehicles were equipped with any pollution controls. In the second scenario, the same age distribution was assumed but new car standards adopted by Taiwan were included. In the third scenario, the actual age and emissions control situation in Taiwan was modeled. The results for CO, HC and NO_x, respectively, are illustrated in Figure 1. This figure illustrates that overall emissions of all three pollutants are reduced as one progresses from Scenario 1 to Scenario 2 (more pollution controls) to Scenario 3 (more pollution controls, younger age distribution).

A second question, however, and the major focus of this paper is how do these different scenarios impact on the relative importance of older vehicles [1] to the emissions problem. These impacts are illustrated in Figures 2, 3 and 4. In comparing scenario 2 to scenario 1, it is clear that for countries which have adopted emissions controls on new vehicles, while absolute emissions are lower, the proportion of the remaining emissions contributed by older vehicles is greater. In the actual

Figure 1: Impact of Vehicle Age Distribution On Emissions

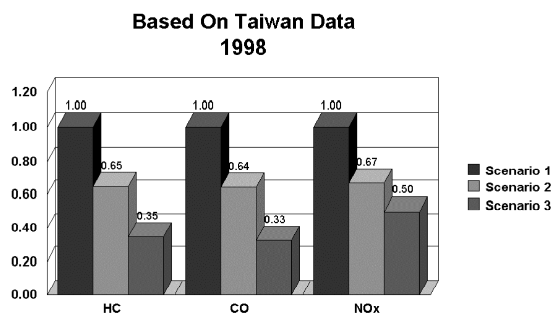


Figure 2: Impact of Vehicle Age Distribution On Emissions - CO

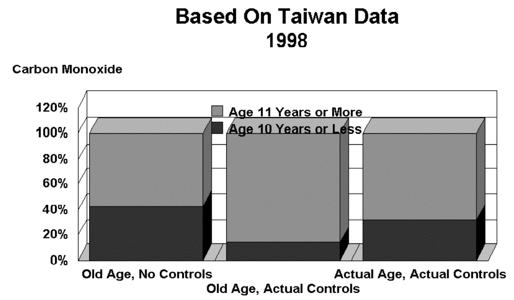


Figure 3: Impact of Vehicle Age Distribution On Emissions - HC

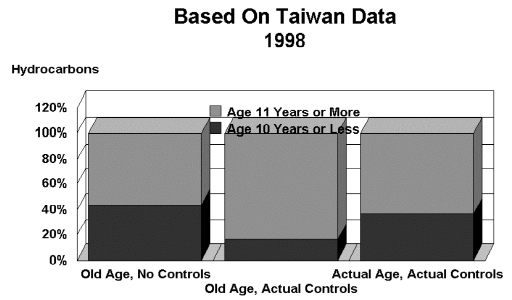
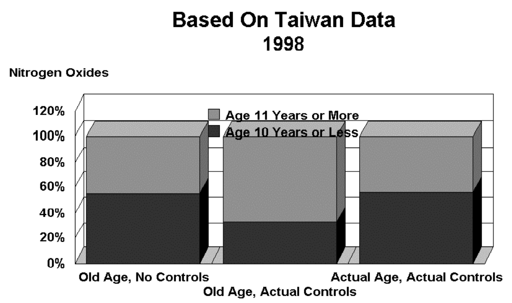


Figure 4: Impact of Vehicle Age Distribution On Emissions - NO_x



1/For the purposes of this analysis, older vehicles are defined as those 10 years old or more.

case (Scenario 3) since the average age of the vehicle fleet is younger in Taiwan, and there are correspondingly fewer old cars, the contribution of old cars is less than in Scenario 2.

2.2 - Case Study: Mexico

a) The Problem

While a great deal of progress has occurred in recent years Mexico City has one of the most serious air pollution problems in the world. Both ozone and particulate levels are very high and frequently exceed acceptable health standards.

Due to a combination of factors, the vehicle fleet composition in Mexico City has traditionally been quite old. First of all, being bordered on the North by the United States, Mexico has had easy access to a ready supply of relatively inexpensive used cars. Secondly, the temperate climate throughout Mexico assured that such problems as body rust were minimized allowing vehicles to remain on the roads for many years. Further, obtaining spare parts for these vehicles was not a problem. As a result in the late 1980' s Mexico City had one of the oldest vehicle populations in the world, with a measurable number of cars aged 40 years or more, and one of the most serious air pollution problems in the world.

b) Actions Taken

A number of steps have been taken to clean up vehicle emissions including the following:

- An important action has been the adoption of stringent emissions standards for both light and heavy duty vehicles (Table 1). As the older vehicles are retired and replaced with newer cleaner vehicles, the overall benefits to the environment will increase over time.

- During 1996, the existing inspection and maintenance program was upgraded. (See discussion in I/M section below .)

- Among the transport-related emission control measures were replacement of existing taxis and micro buses with new vehicles meeting emissions standards, and conversion of gasoline-powered cargo trucks to LPG fuel, incorporating catalytic converters.

- By the end of 1996, PEMEX was operating vapor recovery plants in each of the four distribution terminals in the MCMA. Since May 1, 1996, all fuel delivered to service stations in the MCMA complied with Stage 1 vapor recovery procedures.

- Refinery modifications have resulted in the reformulation of Mexico City Metropolitan Area (MCMA) gasoline in a manner which significantly reduces motor vehicle emissions. The most important changes already instituted are a reduction in gasoline vapor pressure, a reduction in the use of lead additives, a reduction in olefins in lead free magna, and a reduction in benzene levels. Table 2 summarizes historical and current gasoline properties in the MCMA.

Table 1: Emission standards for Mexico in g/mile (FTP test procedure)

Vehicle Type	HC	CO	NO_X
1989 cars only 1990 cars GVW up to 6012 lbs [1] GVW 6013-6614 lbs [2]	3.20 2.88 3.20 4.80	35.2 28.8 35.2 56.0	3.68 3.20 3.68 5.60
1991 cars GVW up to 6012 lbs [1] GVW 6013-6614 lbs [2]	1.12 3.20 3.20	11.2 35.2 35.2	2.24 3.68 3.68
1992 cars GVW up to 6012 lbs [1] GVW 6013-6614 lbs [2]	1.12 3.20 3.20	11.2 35.2 35.2	2.24 3.68 3.68
1993 cars GVW up to 6012 lbs [1] GVW 6013-6614 lbs [2]	0.40 3.20 3.20	3.4 35.2 35.2	1.00 3.68 3.68
1994 and newer cars GVW up to 6012 lbs [1] GVW 6013-6614 lbs [2]	0.40 1.00 1.00	3.4 14.0 14.0	1.00 2.30 2.30

1. Commercial vehicles (e.g., Nissan V ans & Combis)
2. Light Duty Trucks

c) The Importance of Old Cars

Considering both the actions taken and the age distribution of vehicles remaining in Mexico City , the contribution of older vehicles to emissions of HC, CO and NO_X was calculated and is summarized below . These indicate that older vehicles remain the dominant problem category for all three pollutants. They are responsible for approximately 60% of the vehicle kilometers traveled but almost 90% of the HC and CO and 80% of the NO_X.

Figure 5: Contribution of Older Vehicles To Emissions - Mexico

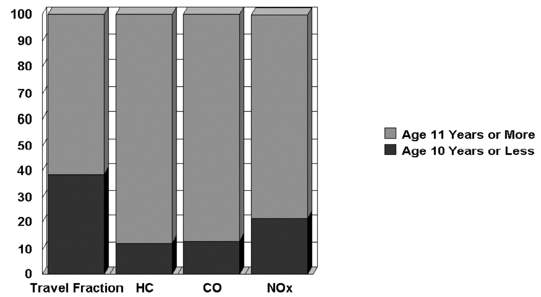


Table 2: Summary of typical gasoline properties-Mexico City Metropolitan Area (MCMA)

		NOVA		MAGNA SIN		PREMIUM
		1991	1996	1991	1996	1996
OCTANE NO.	(R+M)/2 RON MON	79.1 82.5 75.7	82.5	87.1 92.5 81.7	87.3 84	92.1 89.4
RVP	psi	9.1	7.5	9.1	7.4	7.8
SULFUR	ppm, wt	920	700	390	360	100
Pb	gm/gal	0.46	0.3	0	0	0
MTBE	vol %	3.7	4.0*	6.0	6.6*	5.4*
PARAFFINS	vol %	60.0		51.4		
OLEFINS	vol %	11.6	10.9	15.7	8.9	7.7
NAPHTHENES	vol %	9.4		7.6		
AROMATICS	vol %	19.0	22.5	22.8	22.6	21.7
BENZENE	vol %	1.5	1.0	1.8	0.81	0.6
OXYGEN	mass %	.68	.74	1.1	1.2	1.0
T90	°C		170		167	164

* Calculated from oxygen concentration assuming that the additive is MTBE.

2.3 - Case Study: Beijing

a) The Problem

In recent years, the vehicle population in China has increased sharply, with much of the growth taking place in cities. The total number of motorized vehicles in China, although very low by Western standards, is growing rapidly and has risen to about 1 million in Beijing and almost 400,000 in Guangzhou. For the country as a whole, the number of vehicles in 1995 climbed to about 28 million.

Focusing just on automobiles in Beijing, the growth has been very recent and quite rapid as illustrated in Table 3.

China's national NO_x air quality standards are currently exceeded across large areas, including but not limited to high traffic areas.

National CO air quality standards are also generally exceeded in high traffic areas. Although roadside monitoring data is very limited, it suggests that the standards are frequently exceeded at roadside where people normally walk and bicycle. It seems likely that a large number of people are routinely exposed to unhealthy levels of CO.

Table 3 : Beijing Private Automobile Population Trends

Year	Private Vehicles
1985	3,203
1986	5,122
1987	7,148
1988	12,947
1989	24,029
1990	27,890
1991	34,857
1992	48,643
1993	66,883
1994	85,474
1995	127,600

In spite of limited monitoring data, it appears that the national standards for particulates are also frequently exceeded in Beijing. There is no data available to draw conclusions about the exposure of the public to PM_{10}[2] although it appears likely that this exposure is high.

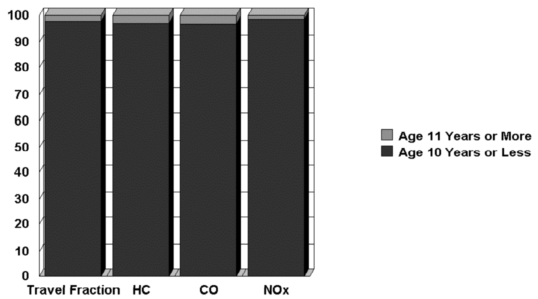
National standards for ozone, formed by the photochemical reaction of NO_x and HC, have also been exceeded during the last decade.

On average, mobile sources contribute approximately 45-50% of the NO_x emissions and about 85% of the CO emissions in typical cities at present.

b) The Importance of Older Cars

Even though control efforts to date in China have been modest, the vehicle age distribution is so young that older vehicles, as illustrated in Figure 6, make only a trivial contribution to air pollution problems at present. Older vehicles are responsible for 2% of the vehicle kilometers, 3% of the CO and HC and 1% of the NO_x. However, as the vehicle population continues to grow and as the existing fleet inevitably ages, this may change.

Figure 6: Contribution of Older Vehicles To Emissions - Beijing



2.4 - Case Study: Bangkok

a) The Problem

Air quality monitoring data indicate that the air pollutants of greatest concern in Bangkok are suspended particulate matter (SPM), especially respirable particulate matter (PM_{10}), and carbon monoxide (CO). They are accounted for mostly by the transport sector. The principal concern with these air pollutants is along the major roads in Bangkok where pollutant concentrations are high enough to result in significant adverse health impacts on the population. Current levels of SPM in Bangkok's air, especially along congested roads, far exceed Thailand's primary ambient air quality standard for SPM. In 1993, curbside 24-hour average concentrations exceeded the standard (0.33 mg/m ^{3}) at all stations; exceedences were recorded on 143 out of 277 measurement days.

Similarly, curbside 8-hour average concentrations of carbon monoxide at that time were close to and sometimes exceeded the Thai standard (20 mg/m ^{3}). Concentrations as high as 25 mg/m^3 were recorded.

Based on a careful review of available air quality data, it was estimated that roadside emissions of particulates and carbon monoxide had to be reduced by 85% and 47%, respectively, if acceptable air quality was to be achieved in Bangkok.[4] Recent data indicated that ozone levels downwind of the city might also be approaching unhealthy levels; therefore, it seemed prudent to adopt measures which would reduce HC and NO_x emissions, the ozone precursors, as well.

During 1997, air quality standards for TSP, PM_{10}, CO, ozone and NO_x were all exceeded in the general areas of Bangkok.[5] Curbside readings for all pollutants but ozone were consistently higher than the general values.

b) Control Efforts to Date

In response to the serious air pollution threat outlined above, Thailand's Seventh Plan placed a high priority on improving air quality and definite targets were set to control the amount of suspended particulate matter and carbon monoxide on Bangkok's major streets. A number of measures were adopted to mitigate air pollution problems, particularly those caused by the transport sector. Measures included exhaust gas emission controls, but also at the improvement of fuel specifications, implementation of an in-use vehicle inspection and maintenance program, public transport improvement through mass transit systems, and the improvement of traffic conditions through better traffic management. Measures directed toward reducing vehicle emissions included:

1. introduction of unleaded gasoline at prices below that of leaded gasoline (introduced in May 1991), followed by a reduction of the maximum allowable lead in gasoline from 0.4 to 0.15 grams per liter (effective as of January 1, 1992). Leaded gasoline was completely phased out by 1996.

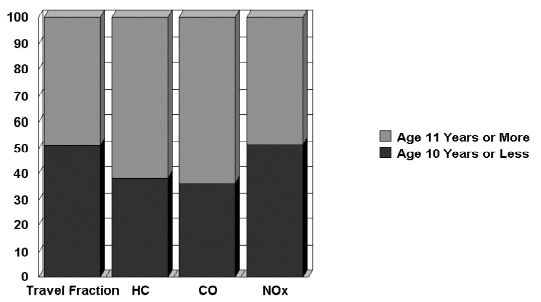
2. reduction of the sulfur content of diesel fuel from 1.0 to 0.5% as of April 1992 in the Bangkok Metropolitan Area and after September 1992 throughout the whole country; the use of low sulfur (0.5%) diesel fuel was made mandatory in Bangkok in September 1993. The Government then decided to reduce the sulfur level to 0.25% by 1996 and 0.05% by the year 2000.

2/Particulate matter in the size range of 10 microns or less. These particles are considered respirable and therefore more important than large particles from the standpoint of public health.

4/These emissions, especially particulate, come from many sources in addition to mobile sources and these other sources will need to be controlled as well. It is assumed in this first order analysis that the same percentage reduction will be needed from all sources including mobile sources to achieve the required overall emissions reduction.

5/"Thailand's Automotive Air Pollution Control Strategies", Dr. Supat Wangwongwatana, Presented in Delhi, India, April 1998.

Figure 7: Contribution of Older Vehicles To Emissions - Bangkok



3. reduction of the 90% distillation temperature of diesel fuel from 370 degrees C to 357 degrees as of April 1992 in the Bangkok Metropolitan Area and after September 1992 throughout the whole country.

4. requirement that all new cars with engines larger than 1600 cc meet the ECE R-83 standards after January 1993; all cars were required to comply after September 1, 1993. (These standards effectively required new gasoline fueled vehicles to be equipped with catalytic converters; the use of these vehicles was made possible because of the introduction of unleaded gasoline.)

5. Taxis and Tuk-Tuks[1] were converted to operate on LPG.

6. ECE R40 requirements for motorcycles were introduced in August 1993 and followed soon afterward by ECE R40.01; Taiwan phase 2 requirements were phased in starting in 1995.

7. ECE R49.01 standards for heavy duty diesel engine vehicles were introduced in 1994, followed by the EU Step 1 standards in 1997.

Noise and emission testing are required and are conducted under the Land Transport Department' s general vehicle inspection program. All new vehicles are subject to such inspection. For in-use vehicles, only those registered under the Land Transport Act (buses and heavy-duty trucks) and commercial vehicles registered under the Motor V ehicles Act (taxis, Tuk-Tuks and rental vehicles) are subject to inspection during annual registration renewals. V ehicles in use for ten or more years are subjected to an annual inspection.

c) Contribution of Older Vehicles

Because significant controls have been introduced for newer vehicles, older vehicles remain the dominant problem in Bangkok as shown in Figure 7. While responsible for 49% of the vehicle kilometers traveled, older vehicles emit over 60% of the HC and CO.

2.5 - Case Study: Romania

a) The Problem

As illustrated in Table 4, the vehicle population in Romania has been growing rapidly in recent years, averaging between 8 -10% per year.

However, at the same time vehicle production and assembly in Romania has declined significantly (T able 5). Replacing domestic production, imported used vehicles have increased even more significantly , at least until customs duties were increased in 1995.

Table 4: Vehicles In Use in Romania

	Cars	Buses	Commercial V ehicles	Motorcycles	Total
1989	1,189,754	27,370	326,481	306,154	1,849,759
1990	1,292,283	28,272	342,300	310,979	1,973,834
1991	1,431,566	31,550	345,170	311,870	2,120,156
1992	1,593,029	35,079	364,136	314,639	2,306,880
1993	1,793,054	37,731	389,564	322,891	2,543,240
1994	2,020,017	40,017	420,064	323,324	2,803,422
1995	2,197,477	42,047	448,630	327,458	3,015,612

6/motorized auto-rickshaws.

Table 5: Vehicle Production and Assembly in Romania

Year	Domestic Sales	Export	Commercial Vehicles	Used Import
1989	136,208	83,784	16,989	NA
1990	99,252	43,491	11,337	51,498
1991	83,574	23,363	10,223	84,522
1992	74,152	26,980	7,391	120,441
1993	93,330	47,265	7,169	160,420
1994	85,858	33,740	5,187	181,845
1995	87,708	17,578	4,907	97,430

b) The Contribution of Older Cars

Romania is typical of most Central European countries; during the 1990s there was a flood of used cars from the W est to satisfy pent up demand for af fordable transportation. Since domestically produced vehicles and imports both have very little functioning pollution controls, overall emissions are very high in relation to VKT . Because the vehicle population has grown rapidly in recent years, however , the main problem at present is not older cars; these vehicles will likely be a major problem in the future.

2.6 - Conclusions from Case Studies

As the above examples indicate, the situation and circumstances regarding older vehicles dif fer significantly among dif ferent countries. However, several general conclusions are warranted:

- Many developing countries have large populations of older uncontrolled vehicles which make a disproportionate contribution to their air pollution problems. For these countries, control efforts will need to focus on these vehicles if rapid progress in reducing emissions is to be achieved.
- Older vehicles tend not to be a serious problem at present in many rapidly industrializing developing countries such as China; because vehicles remain very valuable one can foresee problems in the future as these vehicles age.
- In some countries, especially in Central and Eastern Europe, the large and rapid influx of used vehicles in recent years appears to have created a special problem. As these vehicles age, it is likely that they will create long term problems unless preventive steps are taken.

Many countries could benefit from an increased focus on control strategies addressing older vehicles. Such strategies are the subject of the next several sections.

3. Strategies to Reduce Emissions from Older Vehicles

Several strategies have emerged over the years to address the problem of older vehicles. These fall into the following major categories:

- Inspection and Maintenance
- Retrofit
- Accelerated Retirement (Scrappage)
- Import Restrictions
- Alternative Fuel Conversions

Each of these approaches is discussed in the following sections.

4. Inspection and Maintenance (I/M) Programmes

4.1 - Description

Modern vehicles remain absolutely dependent on properly functioning components to keep pollution levels low. Minor malfunctions in the air and fuel or spark management systems can increase emissions significantly. Major malfunctions can cause emissions to skyrocket. A relatively small number of vehicles with serious malfunctions frequently cause the majority of the vehicle-related pollution problem. Unfortunately, it is rarely obvious which vehicles fall into this category, as the emissions themselves may not be noticeable and emission control malfunctions do not necessarily affect vehicle driveability. Effective I/M programs, however, can identify these problem cars and ensure their repair.

For countries with only minimal if any controls on vehicles, a simple I/M programme can be a good pollution control starting point as even vehicles with no pollution controls can benefit from improved maintenance. A simple idle check on CO and HC missions from gasoline vehicles or visible smoke check on diesel vehicles can be used to identify the highest polluters and those vehicles which would most benefit from remedial maintenance. Hong Kong, whose air quality problem is primarily excess particulate, trained a small group of smoke inspectors who then patrolled the streets, identifying vehicles with excess smoke and requiring them to be repaired or pay a fine. Such a programme requires minimal capital investment and resources.

As vehicle technology advances, more sophisticated test procedures may be necessary, including loaded mode tests that use a dynamometer to simulate the work that an engine must perform in actual driving.

Substantial advances are occurring in I/M programs. For the most advanced vehicles, those equipped with electronic controls of air-fuel and spark management systems and equipped with catalytic converters to reduce CO, HC and NO_x, a transient test, which includes accelerations and decelerations typical of actual driving, can provide additional emissions reduction benefits.

As a general matter, maximum I/M effectiveness occurs with centralized I/M systems. These programs also cost much less overall and are more convenient to the public.

Summarized below are some of the more recent experiences in different parts of the world with vehicle inspection and maintenance efforts.

4.2 - Actual Experience

a) The British Columbia Programme

In a recent demonstration of centralized I/M capability, in 1992, the province of British Columbia implemented an emissions inspection and maintenance (I/M) program in the Lower Fraser Valley (LFV) area which incorporated then state-of-the-art inspection procedures. It was the first I/M program to measure hydrocarbons (HC), carbon monoxide (CO) and the oxides of nitrogen (NO_x) using the acceleration simulation mode (ASM) test, which is a loaded mode test simulating vehicle acceleration. The inspection also included an idle test

Table 6: Results of the British Columbia I/M Program

	HC (g/km)		CO		NOx	
Model Year	Before Repair	After Repair	Before Repair	After Repair	Before Repair	After Repair
Pre-1981	3.5	1.9	33	17	3.3	1.4
'81-'87	2.2	1.2	29	12	2.8	2.1
Post-1987	0.49	0.24	8.6	2.9	3.0	1.7

and an anti tampering check to further ensure that high emitting vehicles were identified and repaired.

Table 6 summarizes the emissions reductions following repairs for HC, CO and NO_x for different model year groups and illustrates that repairs significantly reduced HC, CO and NO_x of the failed vehicles in all model year groups.[1] Overall, about 88% of the repairs were effective in reducing emissions.[2]

Based on audit results, overall emissions were reduced by approximately 20% for HC, 24% for CO and 2.7% for NO_x.[3] In addition to the emissions reductions, the audit program found that fuel economy for the failed vehicles improved by approximately 5.5% for an estimated annual savings of $72 per year per vehicle.

The audit program also demonstrated that the centralized program resulted in a very high quality test program. For example, after reviewing over 2 million tests, the auditor concluded that in only 1.1% were incorrect emissions standards applied. Not one instance was found where a vehicle was given a conditional pass or waiver inappropriately.[4] About 1% of the failed vehicles were found to receive waivers even though their emissions were excessive, i.e., they exceed either 10% CO, 2,000 ppm HC or 4,000 ppm NO_x. If the cost limits were increased such that this percentage were halved, the auditor concluded that HC and CO reductions from the program would each increase by about 5%.

Available data also indicated that many vehicles were repaired sufficiently that they remained low emitting. For example, almost 53,000 vehicles that failed the test the first year were repaired well enough to pass the following year.

Overall these data confirm that I/M programs, when properly performed in a centralized facility using a loaded mode test, can and do achieve a substantial reduction in emissions. These reductions are accompanied by substantial fuel savings. According to the auditor, improvements to the program such as including evaporative testing, reducing or eliminating cost waivers, adding the IM240 test or tightening the standards could increase the overall benefits significantly.

b) Mexico City

Until the end of 1995 a dual I/M system had been in effect in Mexico City combining both centralized (test only) facilities and decentralized private garages (combined test and repair). Over time, it became increasingly clear that the private garage system was not working. As one measure, for example, the failure rate in the private garages averaged about nine percent whereas in the centralized facilities, the failure rate was about 16 percent. Stations conducting improper or fraudulent inspections were taken to court on several occasions with the courts usually agreeing to shut them down. By the end of 1995, as part of the development of the "Programma para Mejorar la Calidad del Aire en el Valle de Mexico, 1995-2000" (the New Program), and in recognition of the critical role that I/M has and will play in the Mexico City strategy, the Federal District (DDF) decided to close all the private garage inspection stations and to switch to a completely centralized system. This politically difficult decision reflected a conclusion that it would be virtually impossible to police the private garage system on a case by case basis.

The upgraded I/M program contains the following primary elements:

Since January 2, 1996 all I/M tests in the DDF are taking place at one of the existing centralized facilities - approximately 39 facilities with about 215 lanes. An additional 36 facilities with approximately 3 lanes each will come on line shortly.

Standards (cut points) were tightened in 1996 such that the average failure rate rose to 26 percent.

The inspection frequency for all but intense use vehicles was reduced to once per year to relieve congestion at the lanes; taxicabs and other high use vehicles continue to be tested twice per year.

The existing stations are being upgraded such that all soon will have a dynamometer and be capable of running the ASM test.

ASM testing will begin at existing stations that have the necessary equipment for the ASM test. This test will not be used to pass/fail vehicles but rather to collect data necessary to select the cut points for the upgraded "hoy no circulo[5] " as well as the normal program. Three sets of standards will be needed - those necessary to pass the normal inspection, a more stringent set to allow a vehicle to be used during air pollution alerts (i.e., to be exempt from the two day hoy no circulo restriction, and the most stringent set which will exempt vehicles from the hoy no circulo program entirely. (This is discussed below.)

At present, all vehicles receive an idle and steady state (~40 MPH) test for CO and HC.

Independent auditors are present at each station at all times that tests are being run. These auditors are rotated monthly and their contracts are funded by the companies operating the stations. In addition, each test is recorded on video in real time and the tapes and computer print outs are spot checked to assure that the tests are valid.

Linkage To The Hoy No Circulo Program

In recognition of the fact that the public has adjusted to the "one day a week" ban on the use of vehicles largely by the purchase of a second car, the new program institutes two significant changes. These changes have two primary objectives: to make sure that only clean vehicles will be used

1/ "Audit Results: Air Care I/M Program", Prepared For B.C. Ministry of Environment, Lands and Parks and B.C. Ministry of Transportation and Highways, Radian, December 9, 1994.

2/ In its recent evaluation of its I/M program, which is probably the most advanced but certainly the most intensely enforced decentralized I/M program in the world, California found that only about 50% of the repairs were effective in reducing emissions, as measured by the full federal test procedure.

3/ These reductions are almost identical to those predicted by the US EPA Mobile 5a Emissions Model, 20%, 20% and 1%, respectively for HC, CO and NO_x.

4/If the vehicle is taken to an authorized technician and spends at least $200 on repairs, it can receive a conditional pass or waiver even if it does not meet the emissions standards.

5/ This means a "day without a car".

during high pollution days so that pollution will be minimized, and to stimulate the modernization of the fleet by encouraging people to replace their old, high polluting vehicle with new ones that could qualify for an exemption. The programmes exempts vehicles from the original programme if they demonstrate that they are low emitting. The exemption is based on the vehicle technology (catalytic converters with fuel injection, alternative fuels, etc.) as well as the emissions performance in the I/M test, which demonstrates that the technology is working.

The program has also been expanded to include restriction on the use of high polluting vehicles during high pollution episodes. When an air pollution alert is declared only vehicles that meet the technology and emissions performance criteria will be allowed to operate.

c) Denver, Colorado

Since 1981 Colorado has operated an I/M program in the metropolitan areas along the Front Range of the Rocky Mountains. Until 1995 the Automobile Inspection and Repair (AIR) program consisted of approximately one thousand independently operated facilities, performing a variety of idle-test procedures and analyzer technologies. In 1995 Colorado's AIR program was upgraded to meet USEPA requirements by implementing an enhanced I/M program in the six-county Denver metropolitan area.

The enhanced I/M program is a bifurcated network of centralized and independently-run decentralized test-only facilities. Decentralized facilities are authorized to test 1981 and older model year vehicles employing a two-speed idle test. Centralized contractor-operated facilities test both 1981 and older vehicles using the two-speed idle test procedure, and 1982 and newer model-year vehicles using the IM240 loaded-mode transient mass emissions test. There are 15 centralized facilities operating 72 lanes and about sixty independent facilities in the enhanced program area, conducting about one million tests per year.

The primary focus of the Colorado I/M program is to reduce carbon monoxide (CO) emissions. All vehicles are tested for CO and hydrocarbons emissions, while only newer vehicles subject to IM240 testing are also tested for NO_x emissions levels. With phase-in cutpoints in place, the enhanced program is responsible for reducing CO emissions 30-34 percent. As the enhanced program affects more vehicles and cutpoints are made increasingly more stringent, the emissions reduction benefit of the enhanced program will significantly increase. Colorado's 1997 IM240 failure rate was 7 percent with an average per vehicle CO emission benefit per repair of 66 percent. The average cost of repairs for vehicles failing the IM240 was $189 (US). Repair costs are partially offset by an average seven percent increase in fuel economy due to repair.

The administration of the Colorado I/M program is divided among several state agencies. The Department of Public Health and Environment is responsible for the technical aspects of the program and is required to report to the Air Quality Control Commission. The Air Quality Control Commission ensures the I/M program complies with state and federal laws. The Department of Revenue is responsible for licensing facilities, inspectors and mechanics, and all enforcement aspects of the program including auditing functions.

4.3 - Repair Vehicles

a) Service Industry Training Needs

One of the major challenges in maintaining low emissions among in-use vehicles is having a well-trained and well equipped cadre of vehicle repair technicians. This is an essential precursor to an effective I/M program. The rate of change in vehicle technology has accelerated over the past 20 years, making it very difficult for repair shops to keep up. With old technology vehicles, simple tools and on-the-job-training were often enough to allow a technician to properly tune a carburated vehicle. As the fleet moves toward fuel-injected computer controlled technology, this approach is no longer adequate. More sophisticated training and more advanced tools are needed. Rallying economic and political support for addressing this problem is hard because it is difficult to attach emission reduction benefits to a long-term program of training, technician support services, or equipment subsidies.

4.4 - Conclusions Regarding I/M

Based on the above review of available data, several conclusions can be drawn:

I/M programs have the potential to significantly reduce emissions of CO, HC, NO_x and particulate emissions from vehicles. Real world experience indicates that high quality I/M programs can reduce CO and HC exhaust emissions by approximately 20 to 30%.

As evidenced by the British Columbia program, to cite one well studied example, these reductions really do occur in a well run program.

Centralized programs are more likely to achieve substantial reductions because they tend to have better quality control, are easier to enforce, and can use in a more cost effective manner sophisticated test procedures. In Mexico City, where both types of programs were run in parallel, it was concluded that decentralized programs were much more corrupt and ineffective.

More advanced test procedures, such as the steady state loaded test or a dynamic test, tend not only to be much more effective in reducing emissions, but when run in centralized, high volume facilities are at least twice as cost effective as in decentralized facilities.

5. Vehicle Retrofit

5.1 - Description

Another approach to cleaning up older cars having little or no pollution controls is to retrofit them, i.e., to install pollution control devices after the vehicle is in use rather than during vehicle manufacture. Retrofit programs can be mandatory or voluntary with both positive and negative inducements.

5.2 - Actual Experiences

a) Budapest

By the end of 1993, catalytic converters became mandatory equipment on all **new** cars in Hungary, whether imported or assembled domestically. The government hoped to persuade owners of older cars to install converters and offered financial assistance (up to 60 percent) of the cost to motorists who did so. Part of the money for this effort came from the European Union's PHARE fund, set up initially to help Poland and Hungary in their economic reconstruction but since broadened to include other Eastern European nations.

The financial assistance was the positive inducement; the negative counterpart was that municipalities prohibited cars without catalytic converters from entering the centers of cities under certain conditions. Doing so was left up to municipal administrations, but during a smog alert the national authorities expected that municipalities would ban polluting cars from entering city centers.

b) California

In 1972, 100 vehicles were retrofitted with oxidation catalytic converters and each was driven for at least 20,000 miles. With the exception of two or three vehicles which were misfueled with leaded gasoline, the results were excellent - HC and CO emissions were reduced by more than 70%. Although the demonstration program was a technical success, no tax or other incentive or retrofit requirement was established. Consequently, no market for the retrofit converter developed.

In 1997, an emission upgrade program began in the County of San Diego. The program consisted of retrofitting a TWC catalyst and a closed-looped air/fuel ratio control system on vehicles originally equipped with oxidation catalysts and open loop engine controls. After 30,000 miles, the average emission reduction from six durability vehicles was 70% for HC, 68% for CO, and 50% for NO_x based on the US FTP-CVS emission test. Vehicles owners volunteer for the program and receive the kit at reduced cost. Most vehicles are high emitters that have failed emission inspection tests. Approximately 150 vehicles have been converted to date.

c) Germany

Germany conducted a voluntary retrofit program using tax credits as an incentive during the 1980s. A vehicle that had an approved system installed received a special certificate. The certificate was then used to obtain a 550 DM credit (about $275 at the time the program was in operation) for a TWC converter only or a 1100 DM credit ($550) for TWC with closed-looped control. The credit offset about 50% of the installation cost to the consumer. The converters used in this program were typically the original vehicle manufacturer's devices being installed on current production vehicles. Most of the vehicles involved in this program were Volkswagen, Mercedes, and BMW models. The German program focused primarily on privately owned vehicles. Since 1985, hundreds of thousands of vehicles have been retrofitted with catalysts. The program included several stages of increasingly stringent emission reductions with proportionally higher tax credits. The program is now being administered by individual German states and is expected to end around the year 2000.

Table 7: Summary of German Road Taxes

	Road tax rates in DM per 100cm3				
Car Group	Rate prior to 1.7.97	Rate from 1.7.97	Rate from 1.1.01	Rate from 1.1.03	Rate from 1.1.05
Euro 3 Euro 4 3 liter car -petrol -diesel		10.00 27.00	10.00 27.00	13.20 30.20	13.20 30.20
Euro 2 -petrol -diesel	13.20 37.10	12.00 29.00	12.00 29.00	14.40 31.40	14.40 31.40
Euro 1 -petrol -diesel	13.20 37.10	13.20 37.10	21.20 45.10	21.20 45.10	29.60 53.50
Other Vehicles used in ozone alerts -petrol -diesel	21.60 45.50	21.60 45.50	29.60 53.50	29.60 53.50	41.20 65.10
Cars not used in ozone alerts -petrol -diesel	13.20 37.10	33.20 57.10	41.20 65.10	41.20 65.10	49.60 73.50
Cars with partially clean or without clean exhausts -petrol* ** -diesel* **	18.80 21.60 42.70 45.50	41.60 65.50	49.60 73.50	49.60 73.50	49.60 73.50

* First registered before 1.1.86
** First registered after 1.1.86

The Federal Ministry of Transport in Bonn published, on March 14, 1997, new rates of road taxation to enter into force on July 1, 1997. As an incentive for drivers and manufacturers to further reduce the exhaust emissions generated by traffic, the road tax for private cars equipped with the latest exhaust technology (Euro 3 or 4) or that are especially fuel efficient (90 ("3 liter car") or 120 ("5 liter car") g/km CO_2), is lowered. The tax burden for other private cars that are permitted to be driven when the ozone warning is announced is unchanged for the time being, while cars with a high level of emissions of harmful substances are taxed more heavily. At the same time, consumers are urged to convert cars that are not equipped with clean exhausts if this is feasible and useful. An overview of the tax rates is shown in Table 7.

Euro 3 and Euro 4 cars benefit from tax relief until 31.12.05 or until they reach 250 DM (petrol) or 500 DM (diesel) for Euro 3 cars and 600 DM (petrol) and 1200 DM (diesel) for Euro 4 cars. Tax relief for Euro 3 cars applies from 1.7.97, but for Euro 4 applies as soon as emission values have been determined in Brussels. It is especially significant that the EU Commission approved this package prior to completing action on the Euro 3 and 4 proposals.

Under this program it is estimated that approximately 800,000 cars in Germany have now been retrofitted.

d) Non Car Retrofit Programs

While the focus of this paper is on older passenger cars, there have been some retrofit programs on buses and trucks that provide useful insights into effective programs. Two of these are discussed below.

London Buses

In an effort to save the traditional double decker bus, some of which are more than 40 years old, the London Bus Company has embarked on a retrofit program. An initial experiment was carried out with an older bus using the fuel typical at that time (about 0.2 Wt. % sulfur) and a CRT system; very rapidly the filter was blocked. Subsequently a very clean fuel similar to the Swedish Class 1 city diesel with 0.001% sulfur was tried and the CRT filter was still blocked. It was determined that the mix of NO_X and PM produced by the naturally aspirated engines in the buses was not appropriate for the CRT system, although in Sweden it works very well with turbocharged engines.

Using the very clean fuel, however, was found to reduce substantially visible smoke on the older engines. Further, the particulate mass was reduced by approximately 25-30%. When an oxidation catalyst was added, the overall PM reduction was about 40% with CO, HC and NO_X reductions of about 80%, 80% and 8-9%, respectively (Table 8).

Based on these very good results, no visible smoke and reductions of PM, CO, HC and NO_x, 300 old buses were fitted with catalysts and operated on city diesel for a year in typical London driving. The systems were found to be durable with none of the ceramic substrates cracking or breaking; based on laboratory testing of two buses the emissions performance only deteriorated by about 10%. An additional 600 buses are being fitted with oxidation catalysts and operated on city diesel.

The Millbrooke laboratory, which is equipped with a chassis dynamometer, has been able to simulate an actual London bus driving cycle and to measure emissions in grams/kilometer under conditions very similar to actual London bus operation. Using this laboratory a comparison has been carried out between converting to CNG or LPG and a Euro 2 diesel engine operating on city diesel fuel and equipped with a CRT system and an oxidation catalyst. All three were found to be quite clean with the diesel actually cleaner than the CNG engine and only slightly higher in emissions than the LPG. Conversions to CNG are seen to be especially difficult because of difficulty in locating the storage tanks with double decker buses.

Work is continuing and about 20 buses will soon be fitted with CRT systems for a 12 month durability test.

Table 8: Results of London Bus Test

	GRAMS PER KILOMETER				
Treatment	HC	CO	NO_X	CO_2	PM_{10}
E2 Diesel 0.05%S, no CAT or CRT	0.64	1.35	15	1386	0.23
E2 Diesel with ULSD only	0.63	1.38	14.2	1351	0.157
E2 Diesel with ULSD and CAT	0.328	0.274	13.41	1288	0.083
E2 Diesel with ULSD and CRT	0.136	0.203	11.93	1282	0.022
CNG with OXYCAT	3.01	0.66	9.92	1344	0.05
LPG with 3 way CAT	0.027	0.0132	5.4	1309	0.017

Swedish Trucks

Stockholm, Gothenburg and Malmo have placed restrictions on the types of heavy duty vehicles that can be used in their most heavily polluted centers. To be used in these areas, all trucks and buses are required to comply with the EURO 1 emissions standards. From 1999 all heavy duty diesel vehicles have to comply with the EURO 2 standards. A general exemption applies to vehicles manufactured after 1990, because it would be too costly to replace all these vehicles. A special exemption can be issued for older vehicles if they are retrofitted with approved kits that comply with one of two sets of requirements listed in Table 9.

Table 9: Emission Standards for Swedich Trucks

Pollutant	Type A	Type B
Particulate	-20%	-80%
Hydrocarbons	-60%	-60%
NO_x	No Increase	No Increase
Noise	No Increase	No Increase

To receive an exemption older vehicles must be retrofitted with a Type B system, except 9 and 10 year old vehicles, which can use either Type A or B. Eight different systems from two different manufacturers have been approved to date (Table 10).

Table 10: Control Device Test Results

Manufacturer	ID	Level	Applicable For
Eminox Ltd.	EMZ-B96-30	B	4 Stroke Turbodiesel, 5.9-12.0L, 150-210 kW
Eminox Ltd.	EMZ-B96-40	B	4 Stroke Turbodiesel, 7.9-15.0L, 211-300 kW
Eminox Ltd.	EMZ-B96-50	B	4 Stroke Turbodiesel, 8.9-18.0L, 280-350 kW
Eminox Ltd.	EMZ-B96-60	B	4 Stroke Turbodiesel, 10.0-25.0L, 330-450 kW
Eminox Ltd.	EMZ-B96-20	B	4 Stroke Turbodiesel, 3.9-10.0L, 90-160 kW
Unikat AB	AZ 90-V18	B	Samtliga, 185 kW
Unikat AB	U 170	A	Samtliga, 200 kW
Unikat AB	AZ 90	A	Samtliga, 220 kW

Test Results With The UNIKAT

	With			Without		Reduction
	Test 1	Test 2	Test 3	Test 1	Test 2	
CO	0.11	0.15	0.09	1.77	1.68	-93%
HC	0.09	0.12	0.05	0.59	0.62	-86%
NO_x	6.17	5.99	6.15	6.37	6.26	-3%
PM	0.15	0.15	0.13	0.25	0.24	-41%

Test Results With The UNIKAT AZ-90-V18

	With		Without		Reduction
	Test 1	Test 2	Test 1	Test 2	
CO	0.11	0.07	1.77	1.68	-95%
HC	0.05	0.03	0.59	0.62	-93%
NO_x	6.24	6.07	6.37	6.26	-3%
PM	0.01	0.00	0.25	0.24	-98%

All 1980 and older vehicles were banned in 1996. In 1997 this was expanded to include 1981 model year vehicles; in 1998,1982 model years; in 1999, 1983 and 1984 model years; in 2000, 1985 and 1986 model years; and in 2001, 1987 and 1988 model years.

Preliminary results indicate that the overall emissions reductions during the first year of the program were significant, as shown in Table 11.

Table 11: Estimated Emissions Reductions In Environmental Zones

Pollutant	Emissions Reduction (%)
Particulate	15-20%
Hydrocarbons	5-9%
Oxides of Nitrogen	1-8%

Still the results were originally not as good as expected because the system allowed (unintentionally) a change of the vehicle engine without making any improvement of the emission performance. In other words, an old EURO 0 in a 1988 bus was allowed to be exchanged with a new Euro 0 engine; the original intention was to only allow an exchange with a EURO 1 or EURO II engine. This loophole is no longer allowed.

In the three cities, the official situation is summarized in Table 12.

These estimates, however, seem grossly understated. Officials at the Motortestcenter verified that they have approved more than 1,500 units. Eminox has indicated that it has installed close to 2,000 units. The intention from the cities at this point is to introduce similar requirements for off road engines used in the city centers.

Table 12: Waivers Granted and Costs (through 1998)

City	General Waiver *(Depending on Age)*	Special Waiver		Cost - Swedish Krona (USD)
		Catalysts	Catalysts Plus Filters	
Stockholm	4,823	70	199	37 Million SKR (4.9 M US$)
Gothenburg	3,103	46	190	14 Million SKR (1.8 M US$)
Malmo	2,134	39	139	11 Million SKR (1.4 M US$)

5.3 - Emissions Reduction Potential

Real world experience indicates that retrofit programs can be very successful, especially if they are focused on specific vehicle categories. A combination of tax incentives coupled with restrictions on the use of non retrofitted vehicles has worked well in stimulating successful retrofit programs.

Catalyst retrofit programs require careful planning, dependable unleaded fuel supplies, and effective oversight of the equipment suppliers, installation facilities, and vehicle operators. Programs should include retrofit of closed-loop engine management systems for best catalyst durability and emission benefit.

Although difficult to implement and administer, vehicle retrofit programs are an option that should be considered for reduction of harmful pollutants from the existing motor vehicle population. Care should be taken in evaluating the costs and benefits of such a strategy based on specific vehicle populations and the particular air quality problems that need to be addressed for the area in which such a program might be implemented. In general, retrofit programs are most likely to succeed if focused on dedicated, controlled and well maintained fleets.

If the decision is made to proceed with a retrofit program, public education and effective enforcement are essential. Finally, an incentive must be established to bring about a significant number of actual retrofits. The incentive can be either in the form of mandatory requirements or economic incentives such as tax credits. It appears extremely difficult to institute a successful retrofit program unless a good I/M program is also in place.

Accelerated Retirement (Scrappage) Programmes

6.1 - Description

Accelerated vehicle retirement (scrappage) programs encourage vehicle owners to retire their vehicle sooner than they would have otherwise. These programs are usually voluntary, and vehicle owners decide whether or not the compensation offered is sufficient to induce them to turn in their vehicles.

6.2 - Actual Experiences

a) British Columbia

Background

"Scrap-It" is an emissions reduction program designed to take older, high-polluting vehicles off the road. Following a feasibility study sponsored by the B.C. Lung Association, a pilot demonstration program began in April, 1996, with a target of removing 1,000 vehicles in the Lower Mainland and 100 vehicles in Victoria. The program is strictly voluntary.

An evaluation was recently sponsored by the Scrap-It Program Steering Committee.[1] Program funding was provided by the British Columbia Automobile Dealers Association (BCADA), the Canadian Petroleum Products Institute (CPPI), BC Hydro and the Vancouver and Victoria Regional Transit Commissions. The evaluation incorporates information from similar vehicle scrapping programs elsewhere and makes use of up-to-date emissions data.

To be eligible for Scrap-It, the vehicle must have failed an AirCare (I/M) test, have been insured within British Columbia for the past two years and be capable of being driven to the recycling contractor's scrap yard.

Owners of 1983 model year and older vehicles who meet the qualifying criteria can choose to scrap their vehicle and receive one of three types of incentive compensation: $750 toward the purchase of a new car, $500 toward the purchase of a used car, or a B.C. Transit pass for one year.

b) Results

By early June, 1997, Scrap-It had achieved the results shown in Table 13.

Table 13: Program Statistics

	Incentive Chosen	Lower Fraser Valley	Victoria
Cars approved for Scrapping		696	53
Cars Scrapped	New Car	154	21
	Used Car	57	7
	Transit Pass	234	9

1/"Evaluation of the Scrap-It Pilot Program", August 1997

The emissions of the scrapped vehicles were determined by testing a sample (63) of the scrapped vehicles in the AirCare laboratory. The emissions reduction was calculated for a scrapped vehicle as the difference between the average measured scrapped vehicle emission and the baseline emission estimated for the respective replacement (new car, used car or transit).

The transit pass was the most popular incentive in the Lower Mainland, with fifty-three percent of the participants in the program choosing this incentive. A survey of recipients of the transit pass incentive indicated a high level of satisfaction with the program and confirmed that increased commitment to transit was a result. The survey confirmed that most pass users were rush hour commuters. Seventy percent of transit pass recipients have not bought a car to replace the scrapped vehicle. It is noteworthy that the transit pass incentive appears to be unique to Scrap-It among North American scrapping programs for which information was available.

Anecdotal evidence indicates that participants were generally pleased with the administration of the program.

Assuming a remaining life of three years for the scrapped vehicles (a conservative assumption), the emission reductions achieved by the program per thousand vehicles scrapped are as shown in Table 14, for hydrocarbons (HC), carbon monoxide (CO), nitrogen oxides (NO_x) and combinations of these pollutants. The weighting of CO in the final column of the table reflects the discount typically assigned to CO.

The emissions of the scrapped vehicles are much greater than the emissions of any of the incentives, resulting in reductions that are similar for all three incentives. Still, Table 14 indicates that transit is the cleanest, followed closely by a new car.

Table 14: Emissions Reductions (Tons per 1000 Vehicles over Remaining Life)

Incentive	HC	CO	NO_x	HC+NO_x	HC+NO_x +(CO/7)
New Car	189	1224	51	240	417
Used Car	171	1089	36	207	363
Transit Pass	192	1284	51	243	426

The cost-effectiveness for the different pollutants is summarized in Table 15. Note that the dollar values for individual pollutants (HC, CO, and NO_x) assume that the entire cost of the program is applied to the reductions of only that emission type.

Focusing on the combined HC plus NO_x values as an indication of smog reduction potential, the cost-effectiveness of Scrap-It is estimated at $3,800 per tonne. The cost of the incentive effectively determines the ranking since the emission reductions are similar among the incentive options.

Table 15: Cost Effectiveness by Pollutant

Incentive	Cost-Effectiveness ($/ton)				
	HC Only	CO Only	NO_x Only	$HC+NO_x$	$HC+NO_x$ +(CO/7)
New Car	$4,574	$704	$16,453	$3,579	$2,073
Used Car	$3,581	$563	$16,640	$2,947	$1,686
Transit Pass	$5,247	$786	$19,835	$4,146	$2,364
Program Average	$4,798	$729	$18,255	$3,796	$2,177

Scrap-It also reduced greenhouse gas emissions in addition to the common pollutants. Carbon dioxide reductions ranged from 1,500 to 4,300 tonnes per year per 1,000 vehicles for the three incentives. Cost effectiveness was on average $130 per tonne of CO_2 per year.

In addition, there are unquantified benefits associated with the Scrap-It program and the removal of older vehicles from the road:

- Reduced emissions of fine particles (PM_{10} and $PM_{2.5}$) and fuel toxics such as benzene,
- Reduced environmental impacts of leaking fluids (motor oil and coolant, for example) and leaking exhaust systems,
- A safety benefit of removing vehicles with mechanical deficiencies (braking and steering, especially),
- Support of transportation planning initiatives (for example, public transit use), and
- More fuel efficient replacements compared with scrapped vehicles.

Scrap-It cost-effectiveness results compare favorably with other vehicle scrappage programs and with measures generally considered to be the most cost-effective as indicated in the GIRD AQMP. The cost-effectiveness of Scrap-It is similar to the cost-effectiveness of the AirCare program.

Conclusions
Scrap-It removed vehicles with emissions that are typical for their model years — emissions were much higher than for recent model-year vehicles — but the scrapped vehicles were not gross emitters for the most part.

Scrap-It was cost-effective in reducing vehicle emissions.

The availability of a variety of incentives worked positively to encourage participation.

Administrative difficulties in the Lower Fraser Valley region have been minimal. The Victoria Program was administratively difficult, partly because of the lack of AirCare centers.

Several concerns raised in advance of the program were dealt with satisfactorily by the pilot program design and administration, e.g., the concern that 'collector' vehicles would be scrapped was solved by a system whereby the scrap yard contacts the Specialty Vehicle Association of B.C. if a noteworthy vehicle is delivered. Also, the main recycling contractor (Slater Iron and Steel) meets the environmental codes and regulations set out in the automobile recycling industry's Auto Recycling Code of Practice.

Given the composition of the vehicle fleet, a Scrap-It program target of 2,000 to 4,000 vehicles per year for five years is achievable.

Recommendations for Program Administration
Future scrapping programs need to market the program more aggressively to ensure participation.

It would be desirable in the future to be able to target the highest emitting vehicles ("gross polluters") among the older vehicle model years to enhance the emission reduction benefit.

Scrap-It should consider reducing the time requirement for insurance coverage to one year, since a year's coverage is more than the value of the incentives and effectively assures that the scrapped vehicle is in regular use.

Scrap-It should review whether excluding vehicles insured for "pleasure-only" use may be advisable, since high distance traveled, commuter use is the preferred target.

c) Budapest

About 120,000 Trabants and Wartburgs were on Budapest's streets in the early 1990s. The two types of cars, made in the former East Germany, are notorious for spewing pollutants from their two-stroke engines into the environment. Because of their low price, they were the cars of choice in Hungary.

In 1994, businesses that owned two-stroke-engine vehicles were required to get rid of them. Individuals were encouraged to replace two-stroke vehicles with four-stroke engines or even install catalytic converters for the two-stroke engines.

The city government of Budapest gave away public transportation passes to motorists who turned in their two-stroke-engine automobiles for destruction. A second aspect of the same program allowed motorists to sell their Trabants and Wartburgs to the city for a price higher than the going market rate and use the money as part of a down payment on a new, more environmentally friendly car.

The program coordinator of the "green-two-stroke" program has reported that 1,451 owners of the cars — two-thirds own Trabants and one-third own Wartburgs — have applied to exchange their cars for the city transportation system. For each Trabant, the city awarded four year-long passes and for each Wartburg six year-long passes. Pass holders can use them on any of the city's public transport systems. The program cost the city 90 million forints (US$918,367).

At the time of the program's launching, the administration displayed five selected kinds of cars in the city hall's courtyard. Dealers for 43 kinds of cars had submitted their cars for consideration. A committee chose the finalists on the basis of engine characteristics, the existence of a catalytic converter, availability of service, price, and credit conditions. It negotiated with city banks to set up purchase terms. The cars chosen for the program were the SEAT Marbella, Suzuki Swift, Opel Corsa, Renault, and Volkswagen Polo. More than 700 owners of Trabants and Wartburgs sold their cars to the city for coupons worth 20,000 forints ($200) and 33,000 ($333) each, respectively. The motorists could add the coupons to cash for a one-third down payment on one of the five types of cars, with the opportunity to pay off the balance of the car's purchase price over five years at annual interest rates of 13 percent to 15 percent, a rate considered highly favorable in Hungary. The cars' prices were 60,000 forints to 190,000 forints ($600-$1,900) lower than their showroom prices.

The Trabants and Wartburgs turned in by the motorists were destroyed. The cost of the program was about 17 million forints ($170,000). Taking more than 2,000 Trabants and Wartburgs off the streets was estimated at the time to eliminate 331,000 kilograms (728,200 pounds) of pollutants per year.

6.3 - Emissions Reduction Potential

Analysis indicates that early retirement programs for older vehicles can exhibit a wide range of outcomes, depending on both the structure of the programmes and the values of a number of key variables that are very uncertain. However, it is quite likely that a carefully designed early retirement program, targeted at areas that exceed air quality standards, can achieve environmental benefits at costs equal to or lower than those of other emissions-reduction options. These programs can also achieve significant gasoline savings as a byproduct. Another byproduct of the programs is the positive impact on fleet safety, primarily because of the improved safety design of newer cars and the likelihood that the brakes and other safety systems on the vehicles retired are in worse condition than those on the replacement vehicles.

An important side effect of a very large early retirement program is to increase the demand for, and raise the prices of, the remaining cars in the fleet, because many of the former owners of the retired vehicles seek to purchase replacement vehicles. This adversely affects lower income vehicle buyers just entering the car market. The money used to purchase the vehicles however goes directly to former owners of retired vehicles, many of whom have lower incomes.

The actual benefits of a scrappage program depend critically on assumptions. For example, one cannot be sure what types of vehicles will be attracted to a large-scale scrappage program, particularly their emissions levels and the extent to which they would have been ready for retirement anyway or else would have been kept operative but used much less than average vehicles. If the assumed values for the emissions and remaining lifetimes of the vehicles in the program are too high (or too low), then the benefits will overstated (or understated).

Estimated net benefits also depend on assumptions about the nature of replacement vehicles for those that are scrapped, and the nature of resulting changes in the existing fleet in the area affected by the scrappage program. It is unclear whether the "vehicle miles lost" by scrapping cars before their normal retirement dates will be made up by increased driving of the remaining fleet or whether these miles will be made up in large part by increased sales and use of new vehicles. Another uncertainty is whether, in a scrappage program confined to limited areas, the owners of the scrapped cars replace them primarily with cars of more recent vintage (with better fuel economy and lower emissions) or "import" older cars from outside the program area, sharply reducing emission benefits and fuel savings.

Past emissions testing programs have demonstrated wide variations in emissions performance among older vehicles of the same model type and vintage, probably because of different maintenance regimes as well as the random nature of failures of emission control systems. Policymakers concerned about obtaining a better cost/benefit ratio from a scrappage program should examine options that tie participation in such a program to emissions performance. For example, scrappage bonuses might be offered only to vehicles that fail scheduled emissions tests in a State I/M program, or that are identified as high polluters by remote sensing. Although some vehicle owners might deliberately sabotage their vehicles to cause them to fail an emissions test, the effectiveness of a "selective" program in the face of such tampering would be no worse than that obtained by a program offering scrappage bonuses to all willing participants, and most likely would be considerably better. If a vehicle retirement program can selectively retire vehicles with average emissions double the average for their age group, program benefits are much more likely to greatly exceed costs.

Another option for removing polluting vehicles from the fleet is to insist that vehicles failing I/M emission tests be removed from service if they cannot be repaired. More effective I/M programs will reduce the incremental emissions benefits of a vehicle retirement program by removing the highest emission (and highest net benefit) vehicles from the fleet.

Still another option is vary the size of the bonus (or the magnitude of the corporate incentive, e.g., emission credit) according to some measure of the potential emissions benefits. The measure could be based on previous emissions experience with different engine classes, data on average remaining lifetime and average emissions of different vintages, etc. Given an accurate basis for estimating emissions and lifetimes, this approach would yield an improvement in the cost-effectiveness of the program. However, there may be important concerns here about the availability of adequate data, especially about remaining vehicle lifetime.

7. Alternative Fuels Conversions

7.1 - Description

Alternative fuels include methanol (made from natural gas, coal or biomass), ethanol (made from grain or sugar); vegetable oils; compressed natural gas (CNG) mainly composed of methane, liquefied petroleum gas (LPG) composed of propane and butane; electricity; hydrogen; synthetic liquid fuels derived from hydrogenation of coal; and various fuel blends such as gasohol.

The possibility of substituting cleaner-burning alternative fuels for gasoline has drawn increasing attention during the last decade. The motives for this substitution include conservation of oil products and energy security, as well as the reduction or elimination of pollutant emissions. Some alternative fuels do offer the potential for large, cost-effective reductions in pollutant emissions in specific cases. Care is necessary in evaluating the air-quality claims for alternative fuels, however; in many cases, the same or even greater emission reduction could be obtained with a conventional fuel through the use of a more advanced emission control system. Which approach is the more cost-effective will depend on the relative costs of the conventional and alternative fuels and control technologies.

7.2 - Natural Gas

Natural gas (which is 85-99% methane) has many desirable qualities as a fuel for spark-ignition engines. Clean-burning, cheap, and abundant in many parts of the world, it already plays a significant vehicular role in Russia, Argentina, Italy, Canada, New Zealand, and the U.S. Recent advances in the technology for natural gas vehicles and engines, new technologies and international standardization for storage cylinders, and the production of new, factory-manufactured natural gas vehicles in a number of countries have all combined to boost the visibility and market potential of natural gas as a vehicle fuel.

Most of the natural gas vehicles (NGVs) now in operation are retrofits, converted from gasoline vehicles. The physical properties of natural gas make such a conversion relatively easy. Typical conversion costs are in the range of US$ 1,500 to $ 4,000 per vehicle, and are due mostly to the cost of the onboard fuel storage system. At present fuel prices many high-use vehicles can recover this cost in a few years, from cost fuel savings.

The Government of Japan has targeted natural gas as an important motor vehicle fuel and is promoting a plan to introduce approximately 200,000 NGVs by the year 2000. According to the plan, an estimated 80 percent will be used as substitutes for diesel powered vehicles; the remainder will be small vans and other vehicles. To accommodate refueling needs, plans call for 600 quick refueling stations and 39,000 vehicle refueling appliances. Nearly 730 million cubic feet of natural gas will be sold; NO_x emissions will be reduced by 7,000 tons per year; CO_2 emissions will be reduced by 0.4 percent.[1]

Natural gas engines can be grouped into three main types on the basis of the combustion system used. These types are: stoichiometric, lean-burn, and dual-fuel diesel. Most of the natural gas vehicles now in operation have stoichiometric engines, which have been converted from engines originally designed for gasoline. Such engines may be either bi-fuel (able to operate on either natural gas or gasoline) or dedicated to natural gas. In the latter case, the engine can be optimized for natural gas by increasing the compression ratio and making other changes, but this is not usually done in retrofit situations because of the cost. Nearly all present light-duty natural gas vehicles use stoichiometric engines, with or without three-way catalysts, as do a minority of heavy-duty natural gas vehicles.

Lean-burn engines use an air-fuel mixture with much more air than is required to burn all of the fuel. The extra air dilutes the mixture and reduces the flame temperature, thus reducing engine-out NO_x emissions, as well as exhaust temperatures. Because of reduced heat losses and various thermodynamic advantages, lean-burn engines are generally 10-20% more efficient than stoichiometric engines. Without turbocharging, however, the power output of a lean-burn engine is less than that of a stoichiometric engine. With turbocharging, the situation is reversed. Because lean mixtures knock less readily, lean-burn engines can be designed for higher levels of turbocharger boost than stoichiometric engines, and can thus achieve higher power output. The lower temperatures experienced in these engines also contribute to engine life and reliability. For these reasons, the great majority of heavy-duty natural gas engines are of the lean-burn design. These include a rapidly-growing number of heavy-duty, lean-burn engines developed and marketed specifically for vehicular use. The Nissan UD 6.9 liter engine has recently been approved in Japan as a low emissions engine with only half the emissions from a typical engine. It is derived from a diesel engine and employs lean burn technology. A small oxidation catalyst has been added to reduce the odor of the exhaust.

Dual-fuel diesel engines are a special type of lean-burn engine in which the air-gas mixture in the cylinder is ignited not by a spark plug but by injection of a small amount of diesel fuel, which self-ignites. Most diesel engines can readily be converted to dual-fuel operation, retaining the option to run on 100% diesel fuel if gas is not available. Because of the flexibility this allows, the dual-fuel approach has been popular for heavy-duty retrofit applications. Current dual-fuel engine systems tend to have very high HC and CO emissions, due to the production of mixtures too lean to burn at light loads. New developments such as timed gaseous fuel injection systems promise to overcome these problems.

Because natural gas is mostly methane, natural gas vehicles (NGVs) have lower exhaust non-methane hydrocarbon

1/ "NGVs in Japan: Poised to Take the Market by Storm", Natural Gas Fuels, July 1995.

(NMHC) emissions than gasoline vehicles, but higher emissions of methane. Since the fuel system is sealed there are no evaporative or running-loss emissions, and refueling emissions are negligible. Cold-start emissions from NGVs are also low, since cold-start enrichment is not required, and this reduces both NMHC and CO emissions. NGVs are normally calibrated with somewhat leaner fuel-air ratios than gasoline vehicles, which also reduces CO emissions. Given equal energy efficiency, CO_2 emissions from NGVs will be lower than for gasoline vehicles, since natural gas has a lower carbon content per unit of energy. In addition, the high octane value for natural gas (RON of 120 or more) makes it possible to attain increased efficiency by increasing the compression ratio. Optimized heavy-duty NGV engines may approach diesel efficiency levels. NO_x emissions from uncontrolled NGVs may be higher or lower than comparable gasoline vehicles, depending on the engine technology, but are typically somewhat lower. Light-duty NGVs equipped with modern electronic fuel control systems and three-way catalytic converters have achieved NO_x emissions more than 75% below the stringent California ULEV standards.

In the last few years, a number of heavy-duty engine manufacturers have developed diesel-derived lean-burn natural gas engines for use in emissions-critical applications such as urban transit buses and delivery trucks. These engines incorporate low-NO_x technology used in stationary natural gas engines, and typically an oxidation catalyst as well. They are capable of achieving very low levels of NO_x, particulate, and other emissions (less than 2.0 g/BHP-hr NO_x and 0.03 g/BHP-hr particulate with high efficiency, high power output, and (it is anticipated) long life. Three such engines - the Cummins L10 engine for transit buses, and the Hercules 5.6l and 3.7l engines for school buses and medium trucks - have been certified in California.

Owing to the difficulty of transportation, the costs of natural gas vary greatly from country to country, and even within countries. Where gas is available by pipeline from the field, its price is normally set by competition with residual fuel oil or coal as a burner fuel. The market-clearing price of gas under these conditions is typically about $3.00 per million BTU (equivalent to about $0.41 per gallon of diesel fuel equivalent). Compression costs for CNG use can add another $0.50 to $2.00 per million BTU, however, depending on the size of the facility and the natural gas supply pressure.

The cost of LNG varies considerably, depending on specific contract terms (there is no effective "spot" market for LNG). The cost of small-scale liquefaction of natural gas is about $2.00 per million BTU, making it uneconomic in comparison to CNG in most cases. Where low-cost remote gas is available, however, LNG production can be quite economic. Typical 1987 costs for LNG delivered to Japan were about $3.20 to $3.50 per million BTU. The costs of terminal receipt and transportation would probably add another $0.50 or so to this cost at the wholesale level.

Several real world evaluations of CNG have been carried out in Sweden; the results of two in particular are summarized below.

a) Co-Nordic Natural Gas Bus Project

The project was initiated in 1986 and was reported (final report) in June 1993.

In the project two engine laboratories modified one Scania diesel engine (11 liters) to a natural gas engine with TWC (Ricardo) and one Volvo diesel engine (9.6 liters) to a natural gas engine with oxcat (Southwest research).

Tested with the R-49 (13 mode test) and the FTP transient test procedure the results presented in Table 16 were achieved (for comparison a Scania low emitting bus engine is presented as well).

Table 16: Nordic CNG Bus Test Results

Engine	CO	HC	NO_x	PM	Test Procedure
	G/kWH				
Scania 11l TWC	1.36	1.48	2.46	0.02	FTP
Design Goal	2	1	2	0.1	
Scania 11l TWC	1.1	0.9	0.97	-	13-Mode
Volvo 9.6l OxCat	0.21	1.1	2.97	-	
Design Goal	1	1	2	-	
Scania 11l Diesel with OxCat	0.11	0.11	5.57	0.07	

From the project, which was carried out in five Nordic cities, the following conclusions were drawn:

- Gas buses with an action radius of more than 400 kms should be economically attractive for serial production where gas is available.
- A correct design of the fuel system will eliminate security risks (including fuel distribution).
- Maintenance costs for natural gas buses is of the same magnitude as for diesel buses.
- Emissions measured are very low.

b) Emissions from two CNG fueled buses; Swedish Vehicle Inspection Company - Motortest Center 1995

Two buses were tested - Volvo B10 — equipped with THG 103 KF diesel engines modified for CNG fueling.

Engine data of the buses are summarized below:
- Cylinder volume: 9.6 liters
- Compression ratio: 12.7:1
- Maximum power: 185 kW at 2200 rpm
- Spark-plug engine with l = 1.2 - 1.5
- Gas mixing unit with electronic valve operating/timing
- Pressure regulation from the maximum pressure of 200 bars in the gas tanks to 10 bars before the gas injection valves
- Electronic control unit for gas injection, fueling and ignition
- Oxidation catalyst (Engelhard) for reduction of carbon monoxide and hydrocarbons

Main results can be summarized as follows:

The NO_x emission rate was very low, 0.5 g/kWh, tested according to the ECE 13-mode test. Tested with the Braunschweig bus cycle test the NO_x emission level was 2.5 g/km, which is low compared with 6g/km or more for ethanol fueled vehicles. At the steady state tests the l value was higher (81.7 at the load steps and 1.5 at idling) than the value given by the manufacturer (1.2 - 1.5).

The CO emission as well as the emission of particulate matter was low.

The total HC emission was measured and calculated as diesel emissions and as methane. The HC emission was low, but varying, at steady state tests. At Braunschweig cycle tests the HC emission varied from 1.8 to 6.7 g/km for one of the two buses. The other one was more stable with 1 g/km HC emission. Most of the HC was methane.

One of the buses was tested regarding unregulated emissions (alkenes, aldehydes, polycyclic aromatic hydrocarbons (PAH) and biological tests (Ames test and TCDD receptor binding test). The emission of alkenes and aldehydes was low. The PAH emission was low, that is at the same level as from new vehicles fueled with environmental class 1 diesel fuel. Ames test results showed a very low mutagenic activity. TCDD receptor binding test showed an activity at the same level as with diesel fuel of environmental class 1.

The PAH emission was dominated by semi-volatile phenanthrene and pyrene. The sources could not be explained.

7.3 - Liquefied Petroleum Gas (LPG)

Liquefied petroleum gas is already widely used as a vehicle fuel in the U.S., Canada, the Netherlands, Japan and elsewhere. In Japan, 260,000 taxis, 94% of the total number of taxis, use LPG as their fuel. As a fuel for spark-ignition engines, it has many of the same advantages as natural gas, with the additional advantage of being easier to carry aboard the vehicle. Its major disadvantage is the limited supply, which would rule out any large-scale conversion to LPG fuel. As with natural gas, nearly all LPG vehicles presently in operation are retrofitted gasoline vehicles. The costs of converting from gasoline to propane are considerably less than those of converting to natural gas, due primarily to the lower cost of the fuel tanks. For a light-duty vehicle, conversion costs of US$800-1,500 are typical. As with natural gas, the cost of conversion for high-use vehicles can typically be recovered through lower fuel costs within a few years.

Engine technology for LPG vehicles is very similar to that for natural gas vehicles, with the exception that LPG is seldom used in dual-fuel diesel applications, due to its poorer knock resistance.

LPG has many of the same emissions characteristics as natural gas. The fact that it is primarily propane (or a propane/butane mixture) rather than methane affects the composition of exhaust VOC emissions, but otherwise the two fuels are similar.

LPG is produced in the extraction of heavier liquids from natural gas and as a byproduct in petroleum refining. Presently, LPG supply exceeds the demand in most petroleum-refining countries, so the price is low compared to other hydrocarbons. Wholesale prices for consumer-grade propane in the U.S. have ranged between $0.25 and $0.30 per gallon for several years, or about 30% less than the wholesale cost of diesel on an energy basis. Depending on the locale, however, the additional costs of storing and transporting LPG may more than offset this advantage.

7.4 - Methanol

Widely promoted in the U.S. as a “clean fuel,“ methanol in fact has many desirable combustion and emissions characteristics, including good lean combustion characteristics, and low flame temperature (leading to low NO_x emissions) and low photochemical reactivity. The major drawback of methanol as a fuel is its cost, and the volatility of pricing. While methanol prices have proven highly volatile in the past, there is little prospect for it to become price-competitive with conventional fuels unless world oil prices increase greatly.

With a fairly high octane number of 112, and excellent lean combustion properties, methanol is a good fuel for lean-burn Otto-cycle engines. Its lean combustion limits are similar to those of natural gas, while its low energy density results in a low flame temperature compared to hydrocarbon fuels, and thus lower NO_x emissions.

Light-duty vehicles using M85 tend to have emissions of NO_x and CO similar to gasoline vehicles. The total mass of tailpipe non-methane organic gas (NMOG) emissions tends to be similar to or somewhat higher than for gasoline vehicles, but the lower ozone reactivity of the NMOG results in similar or somewhat lower ozone impacts overall. Emissions of formaldehyde (a primary combustion product of methanol) tend to be significantly higher than those from gasoline or other alternative fuel vehicles, but emissions of other toxic air contaminants (especially benzene) tend to be lower. Formaldehyde emissions have been controlled successfully by catalytic converters, however.

Heavy-duty methanol engines are capable of much lower NO_x and particulate emissions than similar heavy-duty bus diesel engines, while NMOG, CO and formaldehyde emissions tend to be higher. Again, emissions can be controlled by catalytic converters.

Methanol is produced from natural gas, coal, or biomass. At current and foreseeable prices, the most economical feedstock for methanol production is natural gas, especially natural gas found in remote regions where has no ready market exits. The current world market for methanol is as a commodity chemical, rather than a fuel, and world methanol production capacity is limited and projected to be tight at least through the 1990s. Methanol is a feedstock in the production of MTBE, and the anticipated increase in MTBE demand for reformulated gasoline will place strong pressure on price and supply for the foreseeable future.

The price of methanol on the world market has fluctuated dramatically in the last decade, from around $0.25/gallon in the early 1980s to $0.60-0.70 in the late 1980s. The lower price reflected the effect of a glut, while the higher value reflected a temporary shortage. Recent estimates of the long-term supply price of methanol for the next decade range from $0.43 to $0.59 per gallon. This would be equal to US$ 0.90 to 1.23 on an energy-equivalent basis (compared to present spot gasoline prices of the order of US$ 0.70 per gallon). In addition to new methanol supply capacity, any large-scale use of methanol for vehicle fuel would require substantial investments in fuel storage, transportation, and dispensing facilities, which would further increase the delivered cost of the fuel.

7.5 - Ethanol

Ethanol has attracted considerable attention as a motor fuel due to the success of the Brazilian Prooalcool program. Despite the technical success of this program, however, the high cost of producing ethanol (compared to hydrocarbon fuels) means that it continues to require heavy subsidies.

As the next higher of the alcohols in molecular weight, ethanol resembles methanol in most combustion and physical properties. The major difference is in the higher volumetric energy content of ethanol. Fuel grade ethanol, as produced in Brazil, is produced by distillation, and contains several volume percent of water. In addition, pure (anhydrous) ethanol is used as a blend stock for gasoline both in Brazil and in the U.S. By blending 22% anhydrous ethanol with gasoline to produce gasohol, Brazil has been able to eliminate completely the requirement for lead as an octane enhancer.

Emissions from ethanol fueled engines are not well characterized, but are believed to be high in unburned ethanol, acetaldehyde, and other aldehydes. These can be controlled with a catalytic converter. Uncontrolled NO_x emissions should be somewhat higher than for methanol, but still lower than for gasoline engines. Cold-starting of ethanol engines is not a serious problem in the warm Brazilian climate, but would be a concern in countries with cold winters.

Ethanol is produced primarily by fermentation of starch from grains or sugar from sugar cane. As a result, the production of ethanol for fuel is in direct competition with food production in most countries. The resulting high price of ethanol (ranging from $1.00 to $1.60 per gallon in the U.S. in the last few years - equivalent to US$ 1.56-2.5 per gallon of gasoline on an energy basis) has effectively ruled out its use as a motor fuel except where (as in Brazil and the U.S.) it is heavily subsidized. The Brazilian Prooalcool program to promote the use of fuel ethanol in motor vehicles in that country has attracted worldwide attention as the most successful example of an alternative fuel implementation program extant. Despite the availability of a large and inexpensive biomass resource, however, this program still depends on large government subsidies for its viability.

7.6 - Biodiesel

Biodiesel is produced by reacting vegetable or animal fats with methanol or ethanol to produce a lower-viscosity fuel that is similar in physical characteristics to diesel, and which can be used neat or blended with petroleum diesel in a diesel engine. Engines running on biodiesel instead of or blended with petroleum diesel tend to have lower black smoke and CO emissions, but higher NO_x and possibly higher emissions of particulate matter. These differences are not very large, however. Other advantages of biodiesel include high cetane number, very low sulfur content, and the fact that it is a renewable resource. Disadvantages include high cost ($1.50 to $3.50 per gallon before taxes), reduced energy density (resulting in lower engine power output), and low flash point, which may make it hazardous to handle. The effects of biodiesel on engine performance and emissions over a long time in actual service are not well documented.

Although there are no published field test data on engine emissions, performance and durability for vehicles using blended or neat biodiesel, there are some reports in the literature on short-term effects measured in the laboratory. The general consensus of these studies is that blended or neat biodiesel has the potential to reduce diesel CO emissions (although these are already low), smoke opacity, and measured HC emissions. However, the studies show an increase in NO_x emissions for biodiesel fuel when compared to diesel fuel at normal engine conditions. The higher NO_x emissions from biodiesel-powered engines are partly due to the higher cetane number of biodiesel, which causes a shorter ignition delay and higher peak cylinder pressure. Some may also be due to the nitrogen content in the fuel. The reduction in smoke emissions is believed to be due to better combustion of the short chain hydrocarbons found in biodiesel, as well as the effects of the oxygen content. Other data have also shown that mixing oxygenates with diesel fuel helps to reduce smoke.

As for the HC emissions, research shows a reduction in HC emissions whith biodiesel fuel. However, the effect of the organic acids and/or oxygenated compounds found in biodiesel may affect the response of the flame ionization detector, thus understating the actual HC emissions. The behavior of these compounds with respect to adsorption and desorption on the surfaces of the gas sampling system is not known. Thus more studies are needed to understand the organic constituents in the exhaust gases from biodiesel-powered engines before firm conclusions can be drawn regarding the effects on HC emissions. There is controversy concerning the effect of biodiesel on particulate matter emissions.

The cost of biodiesel fuel is one of the principal barriers making it less attractive to substitute for diesel fuel. The cost for vegetable oils is about $2 to $3 per gallon. If the credit for glycerol, which is a by-product of the biodiesel transesterification process and a chemical feedstock for many industrial processes, is taken into account, the cost of converting vegetable oils to biodiesel is approximately $0.50 per gallon. Thus, the total cost for biodiesel fuel is about $2.50 to $3.50 per gallon. This is substantially higher than for conventional diesel, which presently costs about $0.75 per gallon before taxes. If waste vegetable oil is used, the cost of biodiesel is claimed to be reduced to about $1.50 per gallon. Since the heating value for biodiesel is less than that for diesel, more fuel must be burned to provide the same work output as diesel fuel. This adds further to the cost disadvantage of biodiesel.

7.7 - Hydrogen

While having the potential to be the cleanest burning motor fuel, hydrogen has many properties that make it difficult to use in motor vehicles. Hydrogen's potential for reducing exhaust emissions stems from the absence of carbon atoms in its molecular structure. Because of the absence of carbon, the only pollutant produced in the course of hydrogen combustion is NO_x (of course, the lubricating oil may still contribute small amounts of HC, CO, and particulate matter). Hydrogen combustion also produces no direct emissions of CO_2. Indirect CO_2 emissions depend on the nature of the energy source used to produce the hydrogen. In the long term event of drastic measures to reduce carbon dioxide emissions (to help reduce the effects of global warming), the use of hydrogen fuel produced from renewable energy sources would be a possible solution.

Hydrogen can be stored on-board a vehicle as a compressed gas, as a liquid, or in chemical storage in the form of metal hydrides. Hydrogen can also be manufactured on-board the vehicle by reforming natural gas, methanol, or other fuels, or by the reaction of water with sponge iron.

7.8 - Factors Influencing Large Scale Use of Alternative Fuels

The introduction of alternative fuels requires changes in distribution, marketing and end-use systems. Irrespective of the economics, inadequate supply of fuel or unreliable distribution systems could adversely affect consumer acceptance of alternative transportation fuels. Experience with the use of ethanol in Brazil and CNG in New Zealand and elsewhere suggests that the main factors influencing large-scale introduction of CNG and alcohol fuels are price competitiveness, availability and cost of feedstock (e.g., sugarcane for ethanol, or natural gas for CNG), fuel safety and quality standards, reliable system of distribution, and technical quality of vehicles (driveability, durability, safety). The Brazil experience with ethanol and the New Zealand experience with CNG clearly show that it is possible to develop a large market for alternative fuels within a reasonable time frame if the financial incentives are favorable and efforts are made to overcome uncertainty on the part of industry and consumers. In both instances, substantial subsidies had to be offered to private motorists to persuade them to convert to alternative fuels.

7.9 - Conclusions Regarding Alternative Fuels

The Swedish EPA has carefully analyzed the attributes of alternative fuels with the results summarized in Tables 17 and 18.

It should also be noted that most of the distribution concerns with alternative fuels are alleviated when these fuels are used in dedicated fleets.

Table 17: Alternatives to diesel for Heavy Duty Vehicles

	Green-house gases	Acidification; nutrification	VOC	Local air quality	Noise	Metals	Use of renewable resources	Infrastructural problems	Potential	Time frame	Notes
Ethanol (low blended) in diesel (environment class 2)	+	0	0	0	0	0	0	No	Good	5 years	Ongoing projects
D:o by RME	0	-/0	+	0	0	0	-/0	No	Good	Existing	In use
RME	+/++	-	+	+	0	0	-/0	NO	Limited	Existing	In use
Alcohols (bio)	++	+	0	+/++	0	0	0(?)	Yes	GOOD	Good (but)	Ongoing projects
Natural gas	-	++	+	++	+	0	0	Yes	Good (but)	5 years	
Biogas	++	+	+	++	+	0	+(?)	Yes	Limited	5 years	Ongoing projects
LPG	-	++	+	++	+	0	0	Yes	Limited	0-5 years	
Hydrogen	++ (if ..)	++	++	++	+	0	?	Yes	??	15-25 years	Further technical development needed
Advanced diesel	0	+/++	+	+/++	0	0	0	No	Good (but)	5-10 years	
Advanced gasoline	-	++	-/0	0/++	0	0	0	No	Good (but)	0-5 years	Only for "light" HDVS

+ = 10-50% better; ++ = more than 50% better - = 10-50% worse; -- = more than 50% worse and Off Road Vehicles

Table 18: Alternatives to gasoline for Light Duty Vehicles

	Green house gases	Acidification; nutrification	VOC	Local air quality	Noise	Metals	Use of renewable resources	Infrastructural and vehicle fleet problems	Potential	Time frame	Notes
Gasoline blended with less than 6% by vol of Ethanol	0	0	0	0	0	0	0	Some problems with non catalyst vehicles	Good	0-5 years	
D:o by ETBE	0	0/-	0	0/+	0	0	0	0	Good	0-5 years	
Alcohols/gasoline in flexible fuel vehicles	+/++	0	0/+	+	0	0	0(?)	Yes	Good (but)	5 years	
Alcohols (bio)	++	-	+	+	0	0	0(?)	Yes	Good (but)	5-10 years	
Natural gas	0	0	+	+	0	0	0	Yes	Good (but)	5-10 years	
Biogas	++	-	+	+	0	0	+(?)	Yes	Low	5 years	
LPG	0	0	+(?)	0	0	0	0	Yes	Low	5 years	
Hydrogen	++	++	++	+	+	0	?	Yes	??	15-25 years	Further technical develop-ment needed
Advanced gasoline	0	+	+	+	0	0	0	0	Yes (but)	5 years	
Advanced diesel	+	0	+	0	0	0	0	0	Yes (but)	5 years	

+ = 10-50% better; ++ = more than 50% better - = 10-50% worse; -- = more than 50% worse

8. Restricting Imports of Used Vehicles

8.1 - Description

As noted earlier, a large influx of used vehicles occurred in Central and Eastern Europe in the late 1980s and early 1990s. Many of these vehicles had faulty or inoperable pollution control systems. Similarly, for many years large numbers of old, high polluting vehicles flowed from the United States into Latin America and from Japan into Southeast Asia. In some countries, such as the Philippines, large numbers of used engines were imported from Japan, particularly used diesel engines to be installed in Jeepneys.

To solve this problem, Poland adopted stringent I/M requirements that effectively ensured that all vehicles imported after July 1995 would have a functioning catalyst (Table 19).

Motor vehicles not subject to type approval were required to undergo a pre-registration inspection. They can be registered only if they meet the requirements specified above for in-use vehicles.

Table 19: Polish Emissions Requirements for in Use Vehicles

Vehicle Category	Date of First Registration	Idle CO (%)	Idle HC (ppm)	Air Fuel Equivalence Ratio (λ)	Smoke Level
Spark Ignition Engines (Except Motorcycles)[1]	Before 1/10/86	4.5	-	-	-
	Between 1/10/86 and 1/7/95	3.5	-	-	-
	After 1/7/95	0.5	100	.97-1.03	-
Motorcycles	Before 1/10/86	5.5	-	-	-
	After 1/10/86	4.5	-	-	-
Diesel Vehicles[2]	Naturally Aspirated	-	-	-	2.5 m^{-1}
	Turbocharged	-	-	-	3.0 m^{-1}

Compliance with these in-use requirements is checked during mandatory periodic inspections and also random road-side checks, the frequency of inspections depending on the vehicle category and age. The basic sequence is as follows:

- for passenger cars and light duty vehicles subject to type approval: three years from the first re-registration, next after two years and there after every year;
- for passenger cars and light duty vehicles not subject to type approval: every year;
- for trucks having a maximum weight exceeding 3500 kg: every year;
- for buses having more than 15 seats: one year from the first re-registration and thereafter every half a year.

Romania or Hungary have also restricted imported used vehicles. In these two countries import used cars and engines were either banned outright or heavly taxed.

1/Applicable to Passenger Cars and Light Duty Vehicles For Heavy Duty Spark Ignition Vehicles, CO limits of 4.5% apply..
2/Applicable to Passenger cars, Light Duty Vehicles, Heavy Duty Vehicles, Agricultural Tractors and Slow-moving Machines.

8.2 - Conclusions

Imported used vehicles or engines remain a serious problem in many countries. Three primary approaches have emerged that have been demonstrated to stop or drastically reduce the problem:

- Require imports to pass a stringent emissions requirement as a condition of registration,
- Ban imports of used vehicles or engines, or
- Place a high tax on imported used vehicles or engines.

Each of these approaches can be successful.

What is striking is the lack of restrictions by countries exporting used vehicles or engines. In general the philosophy seems to be that it is up to each importing country to determine its own environmental priorities and to decide whether the social benefits of used vehicles outweigh the environmental and haman health related risks.

9. Using Lead Free Fuel in Older Vehicles : Mechanical Implications

While lead is added to gasoline for the purpose of raising octane number and therefore allowing higher compression and more efficient engines, it also has other effects on engine operation. Lead salts are formed by the combustion of lead additives and are deposited on the walls of the combustion chamber. These deposits serve as lubricants between valves and valve seats; at the same time, these deposits can corrode exhaust valves, foul spark plugs, increase emissions of unburned hydrocarbons and degrade lubricating oil in the crankcase.

9.1 - Potential Concerns with Valve Seat Recession

a) The Nature of the Problem

In modern high speed gasoline engines, exhaust valves and the surfaces they rest on (the valve seats) operate at high temperatures and are subject to severe mechanical stresses. Under conditions of high speed, and to a lesser extent high load, and in the absence of special protection of the valve seat, it has been found that the material of the valve seat can be eroded away, i.e., "recede" into the cylinder head. In the extreme, this can cause lower compression, poor fuel economy, high emissions, and mechanical problems.

Lead compounds formed by the combustion of lead anti-knock additives prevent valve seat recession by forming a thin non-metallic layer of lead oxides and sulfates on the surface of the seat. This acts as a lubricant preventing metal - metal contact and welding, which cause valve seat recession.[1]

b) International Experience

While concern over valve seat recession in older vehicles has been raised as an argument against the complete conversion to unleaded fuel, the actual incidence of valve seat recession in countries around the world is small even in vehicles with "soft" valve seats.[2] Only vehicles that travel consistently at very high loads and speeds appear to be at all vulnerable in actual use. And even for these vehicles, additives other than lead have been shown to protect valve seats.

Typically, when unleaded gasoline is introduced, government authorities with the assistance of vehicle manufacturers prepare a list of existing vehicles in the country able to operate with unleaded gasoline without fear of valve seat recession.

Other vehicles with soft valve seats may face some theoretical risk if operated exclusively with lead free fuel, but even for these vehicles the risk has tended to be minimal in typical operation. As noted by the World Bank, "As a result of extensive tests and studies, the conclusion was drawn that much of the concern about valve seat recession in normal use had been misdirected and exaggerated".[3]

c) Alternative Additives To Address Any Problems

Where concerns remain, various gasoline additives are available to substitute the lubricating function of lead. Compounds based on sodium and potassium, for example, have been shown to provide sufficient protection against valve seat recession. Special sodium naphthenate lubricating additives have been used in Austria, Denmark and Sweden where leaded gasoline has been completely phased out but where some old cars with soft valves are still running. In the Slovak Republic, where approximately 70 percent of the car fleet was estimated to still have soft valves at the time leaded gasoline was phased out, a special additive was introduced that enabled all motorists to use unleaded gasoline; the cost has been estimated at US$0.003 per liter.

Use of anti valve seat recession additives has generally fallen into one of two categories:

- bulk treatment of unleaded gasoline
- sale of aftermarket additives for application to unleaded gasoline by individual consumers.

The relative advantages and disadvantages of each approach are summarized in Table 20.

d) The Potential For Valve Seat Inserts

Valve seat recession can be greatly reduced by hardening the seat, thus increasing its resistence to abrasive wear. Techniques to do this include valve seat hardening by heat treating the seat area or the use of special hard alloy seat inserts.

1/"Prevention of Valve-Seat Recession in European Markets", McArragher, Clark & Paesler, CEC/93/EF19, May 1993.
2/Weaver, C.S. 1986. The Effects of Low-Lead and Unleaded Fuels on Gasoline Engines. SAE Paper No. 860090. SAE International, Warrendale, Pennsylvania.
3/"Phasing Out Lead from Gasoline: World-Wide Experience and Policy Implications", Environment Department Papers, Paper No. 40, Magda Lovei, August 1996.
4/"A Review of Worldwide Approaches to the Use of Additives to Prevent Exhaust Valve Seat Recession", Vincent & Russel, 4th Annual Fuels & Lubes Asia Conference, January 14-16, 1998.

Table 20: Comparison of Different Approaches to Anti Valve sent Recession Additives

Approach	Advantages	Disadvantages
Bulk Treatment	all cars requiring lead replacement gasoline receive additive treated fuel controlled level of additive in treated fuel	cost: additive cost borne by retailer requires segregated pumps and tanks for lead replacement gasoline additive selected to be compatible with catalysts generally lower level of additive use less effective additives used wasteful: some older cars not requiring anti valve seat recession additives use treated fuel
Aftermarket	low cost: additive purchased by customer only those requiring additive use it greater operating flexibility: no need to segregate tanks and pumps to sell lead replacement gasoline wider choice of additive products: more effective additives can be sold additional margin for retailer	less well controlled: use is at owner's discretion cars requiring additive may not be adequately protected

9.2 - Maintenance Savings with Lead Free Fuel

The elimination of lead from gasoline has several additional benefits. The use of lead free gasoline can save money for motorists by reducing the need for frequent replacements of spark plugs, mufflers and the automobile hardware exposed to gasoline and its combustion products.[6] A major reason is that the lead scavengers are highly corrosive and reactive. Several surveys carried out when leaded gasoline was widely used in the United States and Canada demonstrated that motorists who use lead free gasoline spend much less for exhaust system and ignition servicing than motorists who use leaded gasoline.[7] As a rough rule of thumb, spark plug change intervals are roughly doubled by the use of unleaded gasoline and at least one exhaust system and exhaust silencer (muffler) replacement is eliminated. Lead free gasoline has also been linked to a cost advantage regarding carburetor servicing but this has been more difficult to quantify.

Another significant advantage associated with the use of lead free gasoline is the lengthened oil change interval. The use of unleaded fuel has been demonstrated to significantly reduce engine rusting and ring wear and to a lesser degree sludge and varnish deposits and cam and lifter wear.[8,9] Because of this, oil change intervals on cars in the United States using unleaded fuel were at least twice as long as had traditionally been the case. Intervals of 10,000 miles are not uncommon with late model cars. Increased oil change intervals cannot be attributed solely to lead removal (as is indicated by some increases in vehicles using leaded gasoline) but the lead removal appears to be a major contributing factor. This is significant not only because of the reduced cost to the motorist but also because of the oil savings over the life of the vehicle and the reduction of the potential pollution problem resulting from the disposal of used oil. Experience had shown that in the United States significant quantities of used oil are disposed of in ecologically unacceptable ways, such as dumping it on the ground.

According to a Canadian review,[10] the cost savings associated with maintenance reductions from lead free gasoline would be significant. Expressed as 1980 Canadian cents per liter, the results of the principal studies are:

Wagner (American Oil Co.); 1971;	1.4c/liter
Gray and Azhari (American Oil Co.) 1972	2.1c/liter
Pahnke and Bettoney (DuPont) 1972	0.3c/liter
Adams (Ethyl Corp.) 1972	0.4c/liter
Environment Canada 1979	1.2c/liter

Using the Environment Protection Agency of Canada study, Australia concluded that the following savings would result if unleaded gasoline were used instead of leaded gasoline:

	leaded	unleaded
spark plug changes	every year	every other year
oil changes and filter	twice per year	one per year
muffler replacements	twice per 5 yrs	one per 5 yrs
exhaust pipe replacements	one per 5 yrs	None

5/*Personal communication from Nancy Homeister, Ford Motor Company.*
6/*"Saving Maintenance Dollars with Lead Free Fuel", Gray and Azhari, SAE # 720014.*

7/ *"Gasoline Lead Additive and Cost Effects of Potential 1975-1976 Emission Control Systems", Hinton et. al., SAE # 730014.*
8/ *"Ibid".*
9/ *"A Study of Lengthened Engine Oil-Change Intervals", Pless, SAE # 740139.*
10/*"The Benefits of Unleaded Petrol", M.G. Mowle, Institution of Engineers Transportation Conference 1981.*

Overall maintenance savings from unleaded fuel were estimate to average about $38 per year; for a car averaging 10 liters per 100 kilometers fuel consumption, this is equivalent to 2.4c per liter of gasoline.[11]

With regard to maintenance savings, it is important to note several points:

- the potential benefits may not always be readily apparent to the motorist, especially if the vehicle manufacturer does not modify his recommended maintenance schedule.
- the studies cited above reflect experiences gained in industrialized countries; extrapolating these estimates to developing countries may not be fully valid.

9.3 - Conclusions Regarding Mechanical Effects

One of the most definitive reviews of the impact of unleaded fuels on gasoline engines reached the following overall conclusion:

"In summary, the potentially detrimental effects of eliminating leaded gasoline appear to have been greatly exaggerated in the public mind, while the potentially beneficial effects have been understated or ignored. The present widespread public alarm over the effects of this change has little foundation in fact."[12]

Further as noted by US EPA at a Workshop on lead free gasoline heed in China in March 1997, the maintenance savings are well documented.[13]

Annual savings related to exhaust systems, spark plugs and oil changes amount to $18.36, $2.66 and $16.07 respectively (19.95 $).

11/ "Ibid".
12/Weaver, C.S. 1986. The Effects of Low-Lead and Unleaded Fuels on Gasoline Engines. SAE Paper No. 860090. SAE International, Warrendale, Pennsylvania.
13/Comments of Chuck Freed, Director Fuels and Energy Division, US EPA.

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10. Using Lead Free Fuel in Older Vehicles: Emissions Implications

To replace the octane formerly contributed by lead additives, refiners have used a number of techniques. Increased catalytic cracking and reforming are used to increase the concentrations of high-octane hydrocarbons such as benzene, toluene, xylene, and other aromatic species, and olefins. Alkylation and isomerization are also used to convert straight-chain paraffins (which have relatively low octane) to higher-octane branched paraffins. Increased quantities of light hydrocarbons such as butane are also blended. Use of high octane oxygenated blending agents such as ethanol, methanol (with cosolvent alcohols), and especially methyl tertiary-butyl ether (MTBE) has increased greatly. In addition, the antiknock additive methylcyclopentadienyl manganese tricarbonyl (MMT) is permitted in leaded gasoline in the U.S., and in both leaded and unleaded fuel in Canada.[1]

Some of these solutions have created or aggravated environmental problems of their own. For example, the increased use of benzene and other aromatics (which tend to increase benzene emissions in the exhaust) has led to concern over human exposure to benzene. The xylenes, other alkyl aromatics, and olefins are also much more reactive in producing ozone than most other hydrocarbons. Increased use of light hydrocarbons in gasoline produces a higher Reid vapor pressure (RVP), and increased evaporative emissions.

Most of these lead substitutes are not a serious concern if the switch to lead free petrol is combined with the introduction of catalysts as catalysts tend to be especially effective with many of the more reactive or toxic hydrocarbons. However, in order to maximize the health benefits of unleaded petrol use in vehicles without catalysts, it is prudent to assure that acceptable alternatives are used.

In considering lead alternatives that result in the least risk to public health, it is important to note that gasoline per se is a toxic melange, whatever its formulation, and the incremental risk from MTBE in the air is non-existent to marginal.[2]

10.1 - Strategies to Reduce or Eliminate the Health Risks Associated with Lead Substitutes

a) Low Lead Gasoline as a Transition Fuel

Vehicles equipped with catalytic converters *require* unleaded gasoline to prevent the catalyst being poisoned by lead deposits. Vehicles without catalytic converters can use unleaded gasoline but do not *require* it. Reducing or eliminating gasoline lead is strongly desirable for public health reasons. Therefore, one transition strategy to be used while catalyst technology is being phased in is to continue to market leaded fuel with minimal lead content.

The octane boost due to lead does not increase linearly with lead concentration. The first 0.1 g/liter of lead additive gives the largest octane boost, with subsequent increases in lead concentration giving progressively smaller returns. This means that supplying two units of low-lead gasoline will result in lower lead emissions than one unit of high-lead and one unit of unleaded gasoline having the same octane value. If octane capacity is limited, the quickest and most economical way to reduce lead emissions may thus be to reduce the lead content of existing leaded gasoline grades as much as possible, rather than by encouraging non-catalyst cars to use unleaded fuel. This also helps to reserve supplies of unleaded gasoline (which may be feasible to produce and distribute only in limited quantities) for those catalyst-equipped vehicles that truly require it.

Reducing the allowable lead content will also reduce the refining cost difference between leaded and unleaded gasoline. If this is reflected in retail prices it will reduce the temptation for owners of catalyst-equipped vehicles to misfuel with leaded gasoline. In the United States between 1985 and 1995 the leaded content of leaded petrol was limited to 0.1 grams per gallon. In Europe, the maximum lead content of leaded petrol is 0.15 grams per liter. Auto manufacturers have indicated that levels as low as 0.05 grams per liter should be sufficient to protect against the potential risk of valve seat recession.

b) Non-Hazardous Lead Substitutes

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 the volumetric energy content of the fuel, while improving the antiknock performance. Thus, the amount of lead can be reduced or even eliminated without the substitution of potentially hazardous 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.

Exhaust HC and CO emissions are reduced by the use of oxygenates, but NO_x emissions may be increased slightly by the leaner operation. The Auto/Oil study in the U.S. tested the effects of adding 10% ethanol (3.5 Wt.% oxygen) and adding 15% MTBE (2.7% Wt.% oxygen) to industry average gasoline. For late-model gasoline vehicles, the ethanol addition results showed a net decrease in NMHC and CO of 5.9% and 13.4%, respectively, and a net increase in NO_x emissions of 5.1%. The MTBE addition results showed a net decrease in NMHC and CO of 7.0% and 9.3%, respectively, and a net increase in NO_x emissions of 3.6%.

The State of Colorado (USA) initiated a program to mandate

1/*The Canadian government has recently reversed its ban on the use of MMT in unleaded petrol in the face of a legal challenge by the Ethyl Corporation.*

2/*Personal Communication from Dr. John S. Young, the Hampshire Research Institute.*

the addition of oxygenates to gasoline during winter months when high ambient CO tends to occur. The mandatory oxygen requirement for the winter of 1988 (January to March) was 1.5% by weight, equivalent to about 8% MTBE. For the following years, the minimum oxygen content required was 2% by weight (equivalent to 11% MTBE). These oxygen requirements were estimated to reduce CO exhaust emissions by 24-34% in vehicles already fitted with 3-way catalyst systems. The success of this program lead the U.S. Congress to mandate the use of oxygenated fuels (minimum 2.7% oxygen by weight) in areas with serious winter-time CO problems.

Alcohols such as ethanol tend to increase evaporative emissions and can therefore produce higher total HC emissions than straight gasoline, unless ambient temperatures are so low that evaporative emissions are negligible. Similar adverse effects have not been reported for MTBE and other ethers. Corrosion, phase separation on contact with water, and materials compatibility - other problems sometimes experienced with alcohol fuels - are much less serious for the ethers. For this reason, MTBE and other ethers are strongly preferred as oxygenated blending agents by many fuel marketers, as well as for air-quality purposes. The costs of using ethers are also relatively moderate (approximately US$ 0.01-0.03/liter at present prices), so that this can be a relatively cost-effective approach as well.

Thus it is possible to substitute certain oxygenates in place of lead to produce unleaded petrol of maximum health benefit - no lead and no increase in other toxic compounds. In part due to the use of oxygenates, unleaded petrol in Hong Kong, for example, has virtually the same aromatic content as leaded petrol.[3]

c) Potential Adverse Health Effects With MTBE

Air

Recently, a substantial amount of health-related research has been conducted on MTBE. Based on these studies there is no evidence that MTBE at ambient concentrations causes acute health effects. Approximately 20 studies in animals and humans have been conducted since 1987. Possible acute effects of MTBE include nonspecific complaints such as nausea, headaches, dizziness, rashes, and spaciness. Allegations about these effects have been investigated in "retrospective" epidemiology studies of individuals who complained of headaches, dizziness, and respiratory problems after introduction of oxygenated gasoline; in human subjects exposed to a known amount of MTBE in chamber studies; from the analysis of health surveys of workers exposed to MTBE in the workplace; and literature reviews. None of these studies have demonstrated a correlation between MTBE exposure at ambient or occupational levels and alleged acute effects.

Animal evidence suggests that MTBE may be a weak carcinogen. The petrochemical industry and U.S. EPA reviewed the results of a $3.5 million study on mice and rats exposed by inhalation to MTBE. At high concentrations, rats exhibited kidney lesions and tumors, and mice developed liver tumors.

3/Kong Ha, 1994.

These data implied that MTBE may be a weak carcinogen and the U.S. EPA has indicated that MTBE could be classified in Group C "Possible Carcinogen (limited evidence of carcinogenicity in animals in the absence of human data)." The U.S. EPA evaluated the data and calculated two preliminary cancer potency estimates: 1.5 x 10-7 per mg/m^3 based on the mouse liver tumors and 1.7 x 10-7 per µg/m3 based on the rat kidney tumors. For comparison purposes, potency values for benzene and 1,3-butadiene are 2.9 x 10-5 per mg/m^3 and 1.7 x 10-4 per mg/m^3, respectively, or 180 to 1060 times the potency estimates for MTBE.

Ambient air concentrations and health effects data suggest the 70-year lifetime potential cancer risk from MTBE air exposures is typically one to two per million. This is in contrast to general ambient cancer risks in the U.S. which average over 500 per million statewide from air toxics. New increases in air exposures typically become a concern at the 10 per million risk level. The very slight increase in risk from MTBE in ambient air is overwhelmingly offset by the reduced cancer risk from the use of cleaner burning gasoline.

Water

The following is a history and the scientific basis of the California and U.S. EPA health advisories proposed for MTBE in water. A "health advisory" is a level (or range of levels) for drinking water which, if exceeded, indicate that the water supplier should find another source of drinking water. It is not a regulatory or enforceable cleanup number. (These are called Maximum Contaminant Levels or MCLs.) Health advisories are set for compounds (e.g., MTBE) for which complete toxicological information, such as federal or state approved cancer potency numbers for carcinogens, or chronic toxicity data for noncarcinogens, is not available.

In 1991, the Department of Health Services (DHS) requested the Office of Environmental Health Hazard Assessment (OEHHA) to develop an action level for MTBE in water. (An action level is analogous to a health advisory.) In response, an interim action level of 35 parts per billion (ppb) was proposed by OEHHA based on the U.S. EPA's reference dose (RfD). The RfD applies a 10,000-fold safety factor to a subchronic animal lowest observable adverse effect level (LOAEL).

In 1993, the U.S. EPA developed a draft long-term health advisory for MTBE in drinking water of 20-200 ppb based on a subchronic drinking water toxicity study in mice. The reason for the range is the uncertainty regarding the carcinogenic potential of MTBE.

In 1995, DHS requested OEHHA to review MTBE again and set an action level that would replace the interim action level recommended by OEHHA in 1991. Rather than devote limited OEHHA resources to an independent analysis, OEHHA and DHS agreed to wait until the U.S. EPA update is completed. However, if the U.S. EPA does not soon provide guidance, OEHHA/DHS may have to fund such analysis or at least assist the U.S. EPA in completing a study.

In December 1996, the U.S. EPA released a new draft Lifetime Health Advisory of 70 ppb for public comment which would replace the 20-200 ppb range set in 1993. This recent analysis is based on a 90-day study of effects of MTBE by ingestion in rats.

The issue of the potential impacts of MTBE on water is the subject of continuing ongoing evaluations in California and nationally. EPA has recently appointed a "blue ribbon" committee to investigate the issue and to make recommendations.

Taste and Odor Thresholds
Previous investigations have reported taste (39-134 ppb) and odor (15-95 ppb) threshold ranges for MTBE in water. More recent research, presented at the annual American Chemical Society (ACS) meeting in San Francisco on April 16 and 17, 1997, confirmed that MTBE may be detected by odor at levels as low as 15 ppb depending upon the temperature and purity of the water. This indicates that the odor threshold of MTBE in water is much lower than the U.S. EPA draft health advisory level of 70 ppb. Because water agencies refuse to supply water with an objectionable taste or odor, the odor threshold may well be more limiting than the U.S. EPA advisory level.

Ecotoxicity
Concern has been raised about the effects of MTBE in water on plants and animals. However, the species tested so far for short-term toxicity have high (mg/L) thresholds for effects of MTBE. The levels tested are in the range of 100-1000 mg/L and the species tested include green alga, tadpoles, shrimp, minnows, and rainbow trout. Research by the American Petroleum Institute and others on ecological hazards of MTBE exposure is continuing.

10.2 - Reformulated Gasoline

Beyond the substitution of less hazardous oxygenates for lead, it is possible to make additional modifications to gasoline — to "reformulate" it — to reduce both regulated and unregulated emissions of concern. As part of a comprehensive policy to reduce vehicle emissions, fuel reformulation has the potential not only to offset any increased risks associated with the introduction of unleaded petrol but to complement the elimination of lead health risks with an overall reduction of the toxic and ozone forming potential of gasoline and gasoline vehicle emissions.

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 1980s. One result was a major cooperative research program between the oil and auto industries. During the early 1990s, 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 that 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 that might otherwise be required). The potential benefits of improving various 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 on vehicles without evaporative emission controls showed that increasing the fuel RVP from 9 pounds per square inch (psi) (62 kilopascals) to approximately 12 psi (82 kPa) roughly doubled evaporative emissions.[4] The percentage effect is even greater in controlled vehicles. In going from 9 psi (62 kPa) to 12 (81 kPa) RVP fuel, the US EPA found that average diurnal emissions in vehicles with evaporative controls increased by more than five times, and average hot-soak emissions by 25-100%.[5] 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).[6] 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. Unlike new-vehicle emissions standards, it is not necessary to wait for the fleet to turn over before they take effect. The emissions benefits and cost-effectiveness of lower volatility are greatest where few of the vehicles in use are equipped with evaporative controls. Even where evaporative controls are in common use, as in the U.S., control of volatility may still be beneficial to prevent in-use volatility levels from exceeding those for which the controls were designed.

In its analysis of the RVP regulation, the U.S. EPA (1987) estimated that the long-term refining costs of meeting a 9 psi (62 KPA) RVP limit throughout the U.S. would be approximately US$0.0038 per liter, assuming crude oil at US$20 per barrel. These costs were largely offset by credits for improved fuel economy and reduced fuel loss through evaporation, so that the net cost to the consumer was estimated at only US$0.0012 per liter.

4/McArragher, J.S. et al. 1988. Evaporative Emissions from Modern European Vehicles and their Control. SAE Paper No. 880315. SAE International, Warrendale, Pennsylvania.
5/U.S. EPA. 1987. Draft Regulatory Impact Analysis: Control of Gasoline Volatility and Evaporative Hydrocarbon Emissions From New Motor Vehicles, Office of Mobile Sources, United Sates Environmental Protection Agency, Washington, DC.
6/Braddock, J.N. 1988. "Factors Influencing the Composition and Quantity of Passenger Car Refueling Emissions - Part II". SAE Paper No. 880712. SAE International, Warrendale, Pennsylvania.

b) Oxygenates

As noted earlier, 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 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.

10.3 - Overall Toxic Impacts of Reformulated Gasoline

The impact of reformulated gasolines on toxic air pollutants has been extensively studied in recent years with the major results for older vehicles summarized in Table 21 below.[7]

Table 21: Summary of Toxic Air Pollutants: Reformulated Gasolines and Old Vehicles

Emissions Constituent	Change in Fuel Variable			
	Aromatics	MTBE	Olefins	T90
	45%>20%	0%>15%	20%>5%	360F>280F
Benzene	-30.9 +/- 6.2	-10.5 +/- 7.0	-6.1 +/- 7.1	-1.3 +/- 8.4
1,3 Butadiene	-0.6 +/- 14.8	-3.3 +/- 14.6	-31.3 +/- 12.0	-37.4 +/- 13.3
Formaldehyde	18.8 +/- 16.4	18.1 +/- 19.2	-2.3 +/- 14.5	-2.3 +/- 17.1
Acetaldehyde	32.8 +/- 21.9	4.0 +/- 19.2	-6.7 +/- 17.8	- 9.3 +/- 2-.2

1/"Toxic Air Pollutant Vehicle Exhaust Emissions with Reformulated Gasolines", Gorse, Benson, Burns, Hochhauser, Koehl, Painter, Reuter and Rippon, SAE # 912324, October 1991.

11. Overall Benefits and Costs of Lead Free Gasoline

The overwhelming conclusion considering the health benefits and maintenance savings associated with lead free fuel, the conversion to completely lead free seems well worth the costs. Table 22 summarizes the costs and benefits of lowering lead levels in gasoline to a maximum of 0.1 grams per leaded gallon (gplg) in the US. Completely eliminating leaded gasoline would provide even greater benefits.

Table 22: Benefits and Costs of Reduction to 0.10 grams per leaded gallons gasoline[1].

Effect	Benefits and (Cost)
Childrens Health	$918
Adult Blood Pressure	$9,023
Conventional Pollutants (ozone, benzene)	$340
Maintenance	$1,399
Fuel Economy	$286
TOTAL MONETIZED BENEFITS	$11,967
TOTAL REFINING COSTS	($930)
NET BENEFITS	$11,037

Extrapolating these monetization results from the United States to other countries, especially in the developing world, is not straightforward but the above estimates indicate that benefits greatly outweigh the costs.

1/Ibid

12. Conclusions and Recommendations

The situation and circumstances regarding older vehicles differ significantly among different countries. However, several general conclusions appear warranted:

- Many developing countries have large populations of older uncontrolled vehicles that make a disproportionate contribution to their air pollution problems. For these countries, control efforts will need to be focused on these vehicles if rapid progress in reducing emissions is to be achieved.

- Older vehicles tend not to be a serious problem at present in many rapidly industrializing developing countries such as China; however, because vehicles remain very valuable one can foresee problems in the future as these vehicles age.

- In some countries, especially those in Central and Eastern Europe, the large and rapid influx of used vehicles in recent years appears to have created a special problem. As these vehicles age, it is likely that they will create long term problems unless those are addressed.

- Many countries could benefit from an increased focus on control strategies addressing older vehicles.

12.1 Conclusions Regarding I/M

- I/M programs continue to have the potential to significantly reduce emissions of CO, HC, NO_x and particulate emissions from vehicles.

- As evidenced by the British Columbia program, to cite one well studied example, these reductions occur in a well run program.

- Centralized programs are more likely to achieve substantial reductions because they tend to have better quality control, are easier to enforce, and can more cost effectively used more sophisticated test procedures. In Mexico City where both types of programs were run in parallel, it was concluded that decentralized programs were more corrupt and less effective.

12.2 Conclusions Regarding Retrofit Programs

- Real world experience indicates that retrofit programs can be very successful, especially if they are focused on specific vehicle categories. A combination of tax incentives coupled with restrictions on the use of non-retrofitted vehicles has worked well in stimulating successful retrofit programs.

- Catalysts retrofit programs require careful planning, dependable unleaded fuel supplies, and effective oversight of the equipment suppliers, installation facilities, and vehicle operators. Programs should include retrofit of closed-loop engine management systems for best catalyst durability and emission benefit.

- If the decision is made to proceed with a retrofit program, public education and effective enforcement are essential.

- Finally, an incentive must be established to bring about a significant number of actual retrofits. The incentive can be either in the form of mandatory requirements or economic incentives such as tax credits. It appears extremely difficult to institute a successful retrofit program unless a good I/M program is also in place.

12.3 Conclusions Regarding Accelerated Retirement Programs

- Analysis indicates that early retirement programs for older vehicles can exhibit a wide range of outcomes, depending on both the structure of the programs and the values of a number of key variables that are very uncertain.

- It is quite likely that a carefully designed early retirement program, targeted at areas that exceed air quality standards, can achieve environmental benefits at costs equal to or lower than those of other emissions-reduction options already in use or scheduled to be used. These programs can also achieve significant gasoline savings. Another byproduct of the programs is likely to be a positive impact on fleet safety, primarily because of the improved safety design of newer cars and the likelihood that the brakes and other safety systems on the vehicles retired will be in worse condition than those on the replacement vehicles.

- An important side effect of a very large early retirement program will be to increase the demand for, and raise the prices of, the remaining cars in the fleet, because many of the former owners of the retired vehicles seek to purchase replacement vehicles. This will adversely affect lower income vehicle buyers just entering the car market. On the other hand, the money used to purchase the vehicles will go directly to former owners of retired vehicles, many of whom may be expected to be of lower income.

- The actual benefits of a scrappage program depend critically on assumptions. For example, one cannot be sure what types of vehicles will be attracted to a large-scale scrappage program, particularly their emissions levels and the extent to which they would have been ready for retirement anyway, or else would have been kept operative but used much less than average vehicles. If the assumed values for the emissions and remaining lifetimes of the vehicles in the program are too high (or too low), then the estimated benefits will be overstated (or understated).

- Estimated net benefits also depend on assumptions about the nature of replacement vehicles for those that are scrapped, and the nature of resulting changes in the existing fleet in the area affected by the scrappage program. It is unclear whether the "vehicle miles lost" by scrapping cars before their normal retirement dates will be made up by increased driving of the remaining fleet or whether these miles will be made up in large part by increased sales and use of new vehicles. Another uncertainty is the degree to which in a scrappage program confined to limited areas, owners of the scrapped cars replace them primarily with cars of more recent vintage or a "import" older cars from outside the program area.

- Past emissions testing programs have demonstrated wide variations in emissions performance among older vehicles of the same model type and vintage, probably because of different maintenance regimes as well as the random nature of failures of emission control systems. Policymakers concerned about obtaining a better benefit/cost ratio from a scrappage program might wish to examine options that tie participation in such a program to emissions performance. For example, scrappage bonuses might be offered only to vehicles that failed scheduled emissions tests in an I/M program, or that were identified as high polluters by remote sensing.

- Another option for removing polluting vehicles from the fleet that policymakers might consider is to insist that vehicles failing I/M emission tests be removed from service if they cannot be repaired. More effective I/M programs will reduce the incremental emissions benefits of a vehicle retirement program by removing the highest emission (and highest net benefit) vehicles from the fleet.

- Still another option is to vary the size of the bonus (or the magnitude of the corporate incentive, e.g., emission credit) according to some measure of the potential emissions benefits. The measure could be based on previous emissions experience with different engine classes, data on average remaining lifetime and average emissions of different vintages, etc. Given an accurate basis for estimating emissions and lifetimes, this approach would yield an improvement in the cost-effectiveness of the program. However, there may be important concerns here about the availability of adequate data, especially about remaining lifetime.

12.4 Conclusions Regarding Alternative Fuels

- Some alternative fuels do offer the potential for large, cost-effective reductions in pollutant emissions in specific cases. Care is necessary in evaluating the air-quality claims for alternative fuels, however - in many cases, the same or even greater emission reduction could be obtained with a conventional fuel, through the use of a more advanced emission control system. Which approach is the more cost-effective depends on the relative costs of the conventional and the alternative fuel.

12.5 Conclusions Regarding Used Imports

- Imported used vehicles or engines remain a serious problem in many countries. Three primary approaches have emerged:
- Require imports to pass a stringent emissions requirement as a condition of registration,
- Ban imports of used vehicles or engines, or
- Place a high tax on imported used vehicles or engines.

12.6 Mechanical Impact of Unleaded Gasoline on Engines

- The potentially detrimental effects of eliminating leaded gasoline appear to have been greatly exaggerated in the public mind, while the potentially beneficial effects have been understated or ignored. The present widespread public alarm over the effects of this change has little foundation in fact.

12.7 Environmental Impact of Unleaded Gasoline

- Gasoline is inherently toxic. Some of the lead substitutes can increase this toxicity. For example, the increased use of benzene and other aromatics has led to concern over human exposure to benzene. In order to maximize the health benefits of unleaded petrol use in vehicles without catalysts, it is prudent to assure that acceptable alternatives are used.

- Research completed to date suggests that oxygenates, at levels that exist in reformulated gasoline, pose no greater health risk than the gasoline they are replacing. As part of the total cleaner gasoline formulation, they help decrease vehicle emissions.

13. Appendix A : Health and Environmental Concerns from Vehicle Emissions

Cars, trucks, motorcycles, scooters and buses emit significant quantities of carbon monoxide, hydrocarbons, nitrogen oxides and fine particles. Where leaded gasoline is used, vehicles are also a significant source of lead in urban air. This Appendix reviews some of the consequences of these pollutants.

13.1 - Photochemical Oxidants (Ozone)

Ground-level ozone is the prime ingredient of smog, the pollution that blankets many areas during the summer.[1] Short-term exposures (1-3 hours) to high ambient ozone concentrations have been linked to increased hospital admissions and emergency room visits for respiratory problems. Repeated exposures to ozone can exacerbate symptoms and the frequency of episodes for people with respiratory diseases such as asthma. Other health effects attributed to short term exposures include significant decreases in lung function and increased respiratory symptoms such as chest pain and cough. These effects are generally associated with moderate or heavy exercise or exertion. Those most at risk include children who are active outdoors during the summer, outdoor workers, and people with pre-existing respiratory diseases. In addition, long-term exposures to ozone may cause irreversible changes in the lungs, which can lead to chronic aging of the lungs or chronic respiratory disease.

Ambient ozone also affects crop yield, forest growth, and the durability of materials. Because ground-level ozone interferes with the ability of a plant to produce and store food, plants become more susceptible to disease, insect attack, harsh weather and other environmental stresses. Ozone chemically attacks elastomers (natural rubber and certain synthetic polymers), textile fibers and dyes, and, to a lesser extent, paints. For example, elastomers become brittle and crack, and dyes fade after exposure to ozone.

Ozone is also an effective greenhouse gas, both in the stratosphere and the troposphere.[2] That is, ozone absorbs infrared radiation emitting from the earth, captures it before it escapes into space, and re-emits a portion of it back toward the earth's surface. The specific role of ozone in climate change is very complex and not yet well understood. Ozone concentrations in the atmosphere vary spatially, both regionally and vertically, and are most significant in urban areas where precursor gases are abundant. This variability makes assessment of global, long-term trends difficult.

Ozone is not emitted directly into the atmosphere, but is formed by a reaction of VOC and NO_x in the presence of heat and sunlight. Ground-level ozone forms readily in the atmosphere, usually during hot summer weather. VOCs are emitted from a variety of sources, including motor vehicles, chemical plants, refineries, factories, consumer and commercial products, and other industrial sources. VOCs are also emitted by natural sources such as vegetation. NO_x is emitted from motor vehicles, power plants and other source of combustion. Changing weather patterns contribute to yearly differences in ozone concentrations and differences from city to city. Ozone can also be transported into an area from pollution sources found hundreds of miles upwind.

The U.S. EPA recently tightened the air quality standard for ozone from 0.12 parts per million measured over one hour to 0.08 parts per million measured over eight hours, with the average fourth highest concentration over a three-year period determining whether an area is out of compliance. The updated standard recognizes the current scientific view that exposure to ozone levels at and below the current standard causes significant adverse health effects in children and in healthy adults engaged in outdoor activities.

13.2 - Particulate (PM)

Particulate matter is the general term for the mixture of solid particles and liquid droplets found in the air. Particulate matter includes dust, dirt, soot, smoke, and liquid droplets that are directly emitted into the air from natural and manmade sources, such as windblown dust, motor vehicles, construction sites, factories, and fires. Particles are also formed in the atmosphere by condensation or the transformation of emitted gases such as sulfur dioxide, nitrogen oxides, and volatile organic compounds.

Scientific studies show a link between particulate matter (alone or in combination with other pollutants in the air) and a series of health effects. Studies of human populations and laboratory studies of animals and humans have established linkages to major human health impacts including breathing and respiratory symptoms; aggravation of existing respiratory and cardiovascular disease; alterations in the body's defense systems against foreign materials; damage to lung tissue; carcinogenesis, and premature mortality.

PM also causes damage to materials and soiling; it is a major cause of substantial visibility impairment in many parts of the U.S.

Motor vehicle particle emissions and the particles formed by the transformation of motor vehicle gaseous emissions tend to be in the fine particle range. Fine particles (those less than 2.5 micrometers in diameter) are of health concern because they easily reach the deepest recesses of the lungs. Scientific studies have linked fine particles (alone or in combination with other air pollutants) with a series of significant health problems, including premature death; respiratory related hospital admissions and emergency room visits; aggravated

1/Ozone occurs naturally in the stratosphere and provides a protective layer high above the earth.

2/Intergovernmental Panel on Climate Change (IPCC), Working Group I, «Climate Change 1992 - The Supplementary Report to the IPCC Scientific Assessment,» supplement to:

Intergovernmental Panel on Climate Change (IPCC), Working Group I, «Policymakers Summary of the Scientific Assessment of Climate Change», Fourth Draft, 25 May 1990.

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.

As with ozone, the U.S. EPA recently tightened the air quality standards for particulates. The standard for coarse particles (10 microns or less) remains essentially unchanged, while a new standard for fine particles (2.5 microns or less) was set at an annual limit of 15 micrograms per cubic meter and a 24-hour limit of 65 micrograms per cubic meter.

Some particles have been found to be more hazardous than others. For example, the California Air Resources Board (ARB) is evaluating diesel exhaust as a candidate toxic air contaminant under the State's air toxics identification program. To evaluate whether or not diesel exhaust causes cancer, the OEHHA reviewed all controlled animal and mutagenicity studies as well as studies of worker populations exposed to diesel exhaust. In the last decade, seven studies on rats have demonstrated that exposure to diesel exhaust through inhalation causes cancer. In each of these studies, rats were exposed to concentrations of diesel exhaust greater than 2.5 mg/m^3 (2,500 $\mu g/m^3$) and were observed for periods longer than 24 months.

The report also analyzed over 30 human studies concerning lung cancer risk and workplace exposure to diesel exhaust. Workers who were exposed to diesel exhaust were more likely than others to develop lung cancer. The consistent results are unlikely to be due to chance, confounding, or bias, according to CARB.

The report concludes 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.

13.3 - Lead

Over the past century, a range of clinical, epidemiological and toxicological studies have continued to define the nature of lead toxicity, to identify young children as a critically susceptible population, and to investigate mechanisms of action of lead toxicity. A full discussion of lead toxicity, clinical manifestations and mechanisms of action can be found in the 1995 **Environmental Health Criteria Document for Lead**, published by the International Program on Chemical Safety (IPCS). In summary, lead affects many organs and organ systems in the human body with subcellular changes and neurodevelopmental effects appearing to be the most sensitive. The most substantial evidence from cross sectional and prospective studies of populations with lead levels generally below 25 µg/deciliter of blood relates to decrements in intelligence quotient (IQ).

As noted by the IPCS, existing epidemiological studies do not provide definitive evidence of a threshold. Below the range of about 10 - 15 µg/deciliter of blood, the effects of confounding variables and limits in the precision in analytical and psychometric measurements increase the uncertainty attached to any estimate of effect. There is, however, some evidence of an association below this range. Animal studies provide support for a causal relationship between lead and nervous system effects, reporting deficits in cognitive functions at lead levels as low as 11-15 µg/deciliter of blood which can persist well beyond the termination of lead exposure. Other effects that may occur include:

impaired sensory motor function

impaired renal function

increased blood pressure

some but not all epidemiological studies show a dose dependent association of pre-term delivery and some indices of fetal growth and maturation at blood lead levels of 15 µg/deciliter or more.

Lead and its compounds may enter the environment during mining, smelting, processing, use, recycling or disposal. In countries where leaded gasoline is still used, the major air emission is from mobile and stationary combustion of gasoline. Areas in the vicinity of lead mines and smelters are subject to high levels of air emissions.

Airborne lead can be deposited on soil and water, thus reaching humans through the food chain and in drinking water. Atmospheric lead is also a major source of lead in household dust.

Because of the concerns highlighted above, a global consensus has emerged to phase out the use of lead in gasoline.[3]

In December 1994, at the Summit of the Americas, heads of state from a number of countries pledged to develop national action plans for the phase out of leaded gasoline in the Western Hemisphere[4], and in May 1996, the World Bank called for a global phase out of leaded gasoline and offered to help countries design feasible phase out schedules and incentive frameworks.

A key recommendation of the Third "Environment for Europe" Ministerial Conference held in Sofia, Bulgaria in October 1995 called for the reduction and ultimate phase out of lead in gasoline.

In June 1996, the second United Nations Conference on Human Settlements, called Habitat II, included the elimination of lead from gasoline as a goal in its agenda.

In May 1997, environmental ministers from the Group of Seven plus Russia endorsed the phase out of leaded gasoline in the

3/US Environmental Protection Agency (US EPA) (1986) Ambient Air Quality Criteria Document for Lead. Research Triangle Park NC: EPA ORD; US Centers for Disease Control (CDC) (1991) Preventing Lead Poisoning in Young children. Atlanta: US DHHS, October 1991; Howson C and Hernandez Avila M (1996) Lead in the Americas. Washington: NAS Press; International Program on Chemical Safety (IPCS) (1995) Environmental Health Criteria Document: Lead. Geneva: IPCS, WHO; National Research Council (NRC) (1993). Measuring Lead exposures in Infants, Children and Other Sensitive Populations. Washington: NAS Press.

4/"Reducing Health Risks Worldwide - EPA's International Lead Risk Reduction Program", March 1998

"1997 Declaration of Environmental Leaders of the Eight on Children's Environmental Health."

13.4 - Lead Scavengers

While lead additives improve gasoline octane quality, they also cause many problems with vehicles. Notable among these is the build up of deposits in the combustion chamber and on spark plugs, which cause durability problems. To relieve these problems, lead scavengers are also added to gasoline to increase the volatility of the lead combustion by-products so they are exhausted from the vehicle. These scavengers are still used with leaded gasoline.

Ultimately, a significant portion of these additives is emitted from vehicles. This is important because a number of lead scavengers, most notably ethylene dibromide, have been found to be carcinogenic in animals and have been identified as potential human carcinogens by the National Cancer Institute.[1] Their removal along with the removal of lead may result in significant benefits to health.

13.5 - Carbon Monoxide (CO)

Carbon monoxide (CO) is a tasteless, odorless, and colorless gas produced by the incomplete combustion of carbon-based fuels. CO enters the bloodstream through the lungs and reduces the delivery of oxygen to the body's organs and tissues. The health threat from CO is most serious for those who suffer from cardiovascular disease, particularly those with angina or peripheral vascular disease. Healthy individuals also are affected, but only at higher levels. Exposure to elevated CO levels is associated with impairment of visual perception, work capacity, manual dexterity, learning ability and performance of complex tasks.

13.6 - Nitrogen Oxides (NO_x)

NO_x emissions produce a wide variety of health and welfare effects. Nitrogen dioxide can irritate the lungs and lower resistance to respiratory infection (such as influenza). NO_x emissions are an important precursor to acid rain and may affect both terrestrial and aquatic ecosystems. Atmospheric deposition of nitrogen leads to excess nutrient enrichment problems ("eutrophication"), which can produce multiple adverse effects on water quality and the aquatic environment, including increased nuisance and toxic algal blooms, excessive phytoplankton growth, low or no dissolved oxygen in bottom waters, and reduced sunlight causing losses in submerged aquatic vegetation critical for healthy ecosystems. Nitrogen dioxide and airborne nitrate also contribute to pollutant haze, which impairs visibility and can reduce residential property values and revenues from tourism.

13.7 - Other Toxics

The 1990 Clean Air Act (CAA) directed the U.S. 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 is 720 cancer cases in the U.S. For all years, 1,3-butadiene is responsible for the majority of the predicted cancer incidence, ranging from 58 to 72 percent of the total motor vehicle toxics risk. This is due to the high unit risk of 1,3-butadiene. Gasoline and diesel particulate matter, which are considered to represent motor vehicle polycyclic organic matter (POM), are roughly equal contributors to the risk. The combined risk from gasoline and diesel particulate matter ranges from 16 to 28 percent of the total, depending on the year examined. Benzene is responsible for roughly 10 percent of the total for all years. The aldehydes, predominately formaldehyde, are responsible for roughly four percent of the total for all years.

A variety of studies have found that in individual metropolitan areas, mobile sources are one of the most important and possibly <u>the</u> most important source category in terms of contributions to health risks associated with air toxics. For example, according to the US EPA, mobile sources are responsible for almost 60% of the air pollution related cancer cases in the U.S. per year.

13.8 - Climate Change

Beyond direct adverse health effects, there are other concerns with vehicle emissions. Among these is global warming caused by the so-called 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 60^0 F (33 ^{0}C) colder, and life as we know it would not be possible.

Over the past century, however, human activities have increased atmospheric concentrations of naturally occurring greenhouse gases and added new and very powerful 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, Ms. Gro Harlem Brundtland, has termed this overheating.

Recent events have heightened this concern. In late November 1995, Working Group 1 of the Intergovernmental Panel on Climate Change concluded that "the balance of evidence suggests that there is a discernible human influence on global climate."

5/ "Automotive Emissions of Ethylene Dibromide", Sigsby, et al, Society of Automotive Engineers, #820786

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✔ **Chemicals (Geneva)**, which promotes sustainable development by catalysing global actions and building national capacities for the sound management of chemicals and the improvement of chemical safety world-wide, with a priority on Persistent Organic Pollutants (POPs) and Prior Informed Consent (PIC, jointly with FAO)

✔ **Energy and OzonAction (Paris)**, which supports the phase-out of ozone depleting substances in developing countries and countries with economies in transition, and promotes good management practices and use of energy, with a focus on atmospheric impacts. The UNEP/ Collaborating Centre on Energy and Environment supports the work of the Unit.

✔ **Economics and Trade (Geneva)**, which promotes the use and application of assessment and incentive tools for environmental policy and helps improve the understanding of linkages between trade and environment and the role of financial institutions in promoting sustainable development.

UNEP TIE activities focus on raising awareness, improving the transfer of information, building capacity, fostering technology cooperation, partnerships and transfer, improving understanding of environmental impacts of trade issues, promoting integration of environmental considerations into economic policies, and catalysing global chemical safety.

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ABOUT THE OECD'S ENVIRONMENTAL HEALTH AND SAFETY PROGRAMME

The Organisation for Economic Co-operation and Development (OECD) is an intergovernmental organisation consisting of 29 democratic countries with industrialised market economies in Europe, Asia, North America and the Pacific. Founded in 1960, the OECD promotes: economic growth, employment and social welfare in OECD countries; free trade between OECD countries, as well as with non-members; and sound economic growth in non-member countries. The OECD has programmes of work in the following areas: General economic policy; Statistics; International trade; Development co-operation; Science, technology and industry; Financial, fiscal and enterprise affairs; Energy; Food, agriculture and fisheries; Education, employment, labour and social affairs; Territorial development; Public management; Transport; and Environment. The later includes the OECD Environmental Health and Safety Programme.

What is OECD's Environmental Health and Safety Programme? Following concern over widespread contamination and accompanying adverse effects, coupled with the need for international co-operation, the OECD established this Programme in 1971 to undertake work on the safety of chemicals. Today, the 29 Member countries and the OECD Secretariat work together to develop and co-ordinate environmental health and safety activities on an international basis. Such activities include harmonising chemical testing and hazard assessment procedures; harmonization of classification and labelling; developing principles for Good Laboratory Practice; co-operating on the investigation of existing chemicals (high production volume chemicals); work on Pollutant Release and Transfer Registers (PRTRs), as well as sharing and exploring possible co-operative activities on risk management from chemicals. In addition, the EHS Programme also conducts work on pesticides, chemical accidents, waste management, biotechnology and food safety.

The principal objectives of the Environmental Health and Safety Programme are to: assist OECD Member countries' efforts to protect human health and the environment through improving chemical, biotechnology, and pesticide safety; making policies more transparent and efficient; and preventing unnecessary distortions in the trade of these products.

The major products of the EHS Programme are: test guidelines, Good Laboratory Practice, the system of mutual acceptance of industrial chemical testing data, hazard/risk assessment methods, initial assessment reports on high production volume chemicals, risk management monographs, consensus documents on products derived through modern biotechnology, guidance documents on preventing chemical accidents; material to facilitate the exchange of pesticide assessment reports; and a system to effectively control the transfrontier movement of hazardous wastes.

Much of this information is available free of charge to the public through the EHS web site:
http://www.oecd.org/ehs/

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