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Existing In Use Vehicles

The Key to Short Term Reductions in Mobile Source Emissions

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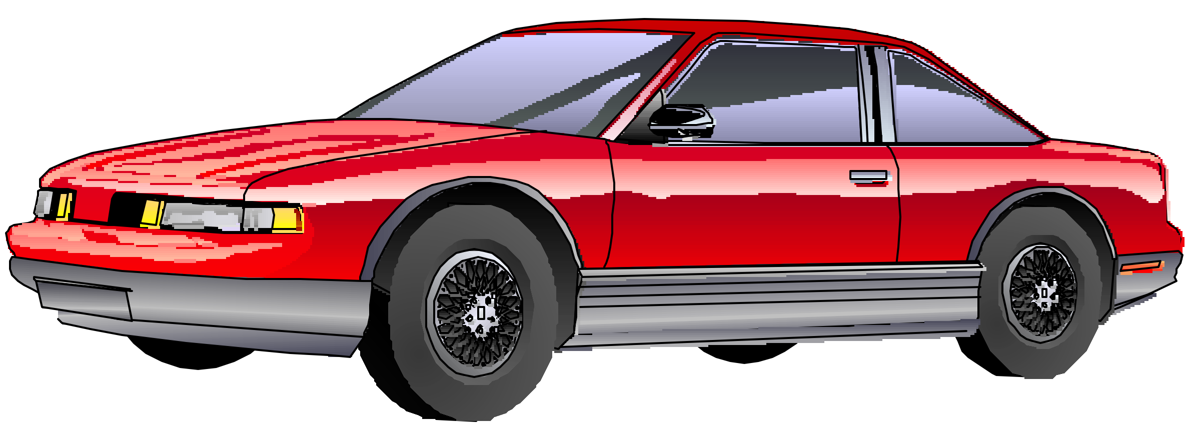


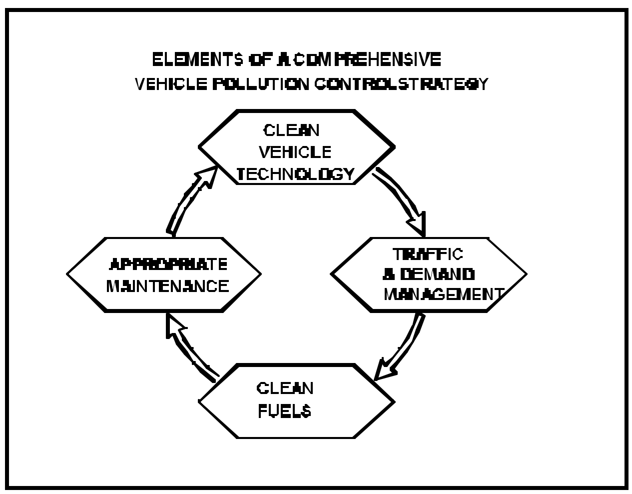
1. Background and Introduction

Over the past 50 years, the world's vehicle population has grown fifteen-fold, now exceeding 700 million units and will soon reach 1 billion. Most of these 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 these vehicles have brought many advantages -- increased mobility and flexibility for millions of people, more jobs, and enhanced many aspects of the 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. 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 will usually require a comprehensive strategy. Generally, the goal of a motor vehicle pollution control program is to reduce emissions from motor vehicles in-use to the degree reasonably necessary to achieve healthy air quality as rapidly as possible or, failing that for reasons of impracticality, to the limits of effective technological, economic, and social feasibility. Achievement of this goal generally requires emissions standards for new vehicles, clean fuels, programs designed to assure that vehicles are maintained in a manner which minimizes their emissions and traffic and demand management and constraints. These emission reduction goals should be achieved in the least costly manner.

Many countries around the world have made substantial progress in introducing advanced technologies on new vehicles. However, vehicles introduced before tight standards went into affect 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 existing, in use, higher polluting 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)
- Alternative Fuel Conversions

Each of these approaches will be discussed in the following sections.

2. Inspection and Maintenance (I/M) Program

a. What it Is

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 assure their repair.

For countries with only minimal if any controls on vehicles, a simple I/M program 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 program requires minimal capital investment and resources.

As vehicle technology advances, more sophisticated test procedures may be necessary including loaded mode tests which use a dynamometer to simulate the work which 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 NOx, 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.

b. Actual Experience - The British Colombia Program

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) <u>and</u> the oxides of nitrogen (NOX) using the acceleration simulation mode (ASM) test, which is a loaded mode test simulating vehicle acceleration. The inspection also included an idle test and an anti tampering check to further assure that high emitting vehicles were identified and repaired.

	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

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

Based on the audit results, overall emissions were reduced by approximately 20% for HC, 24% for CO and 2.7% for NOX.[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 was resulting 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 be receiving waivers even though their emissions are excessive, i.e., they exceed either 10% CO, 2,000 ppm HC or 4,000 ppm NOx. 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 indicates that many vehicles are repaired sufficiently that they remain low emitting. For example, almost 53,000 vehicles which failed the test the first year were repaired well enough to pass the following year.

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 NOX.

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.

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 all increase the overall benefits significantly.

3. Vehicle Retrofit

a. What It Is

Another approach to cleaning up older cars with 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 production. Retrofit programs can be mandatory or voluntary with both positive and negative inducements.

b. Actual Experience - Germany

Germany conducted a voluntary retrofit program using tax credits as an incentive during the 1980s. A vehicle which 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 tax credit offset about 50% of the installation cost to the consumer. The converters used in this program were typically the original vehicle manufacturer's converter used 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 and according to the German Umweltbundesamt has been very successful, especially for closed lop controlled vehicles.

c. Non Car Retrofit Programs - London Buses

While the focus of this paper is on older passenger cars, there have been some retrofit programs on buses and trucks which can provide useful insights into effective programs. For example, 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 which was typical at that time (about 0.2 Wt. % sulfur) and a CRT system and 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 with the naturally aspirated engines that exist in these older buses that the mix of NOX and PM is not appropriate for the CRT system to function correctly; this system has been found in Sweden to work very well with turbocharged engines.

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

Based on these very good results, no visible smoke and reductions of PM, CO, HC and NOX, 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 and based on laboratory testing of 2 buses the emissions performance only deteriorated by about 10%. Based on this, additional buses are being fitted with oxidation catalysts and operated on city diesel.

4. An Accelerated Retirement (Scrappage) Program

a. What It Is

Accelerated vehicle retirement (scrappage) programs encourage or require vehicle owners to voluntarily retire their vehicles sooner than they would have otherwise.

b. Actual Experience - British Columbia

A voluntary pilot demonstration program began in April, 1996, with a target of removing 1,000 vehicles in the Lower Mainland and 100 vehicles in Victoria. An evaluation was recently sponsored by the Scrap-It Program Steering Committee.[5] 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.

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.

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 below. The emissions of the scrapped vehicles are much greater than the emissions of any of the

5/"Evaluation of the Scrap-It Pilot Program", August 1997 incentives, resulting in reductions that are similar for all three incentives.

Emissions Reductions (Tons per 1000 Vehicles over remaining life)

Incentive	HC	CO	NOX	HC+NOX	HC+NOX+(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 below. Note that the dollar values for individual pollutants (HC, CO, and NOX) assume that the entire cost of the program is applied to the reductions of only that emission type.

Cost Effectiveness by Pollutant

Incentive	Cost-Effectiveness ($/ton)				
	HC Only	CO Only	NOx Only	HC+NOX	HC+NOX+(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

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

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 1000 vehicles for the three incentives. Cost effectiveness was on average $130 per ton 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 (PM10 and PM2.5) 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. The cost-effectiveness of Scrap-It is similar to the cost-effectiveness of the AirCare I/M program.

5. Alternative Fuels Conversion

a. What It Is

Alternative fuels include methanol (made from natural gas, coal or biomass) ethanol (made from grain), vegetable oils, compressed natural gas (CNG) mainly composed of methane, liquefied petroleum gas (LPG) composed of propane, 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 the alternative fuel.

b. Natural Gas

Because natural gas is mostly methane, natural gas vehicles (NGVs) have lower exhaust 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. NOX 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 NOX 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-NOX technology used in stationary natural gas engines, and typically an oxidation catalyst as well. They are capable of achieving very low levels of NOX, particulate, and other emissions (less than 2.0 g/BHP-hr NOX and 0.03 g/BHP-hr particulate with high efficiency, high power output, and (it is anticipated) long life. For example, 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 recent years in California.

c. Liquefied Petroleum Gas (LPG)

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. 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. 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.

6. Conclusions and Recommendations

The situation and circumstances regarding high emitting in use vehicles differ significantly among different countries. However, it appears that many countries could benefit from an increased focus on control strategies addressing these vehicles.

a. Conclusions Regarding I/M

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

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

C 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.

b. Conclusion 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. It appears extremely difficult to institute a successful retrofit program unless a good I/M program is also in place.

c. 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.

< 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 that are already in use

or scheduled to be used. These programs can also achieve significant gasoline savings as a byproduct. 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.

< 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; In a scrappage program confined to limited areas, will the owners of the scrapped cars replace them primarily with cars of more recent vintage, with better fuel economy and lower emissions, or will they "import" older cars from outside the program area, sharply reducing emission benefits and fuel savings?

< Another option for removing polluting vehicles from the fleet that policymakers might consider is to insist that vehicles failing well run 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.

d. 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 will depend on the relative costs of the conventional and the alternative fuel.

7. Beijing - An Example of a Successful Program

Over the past decade, NOx concentrations within the Second Ring Road, i.e., the city center, increased from 99 $\mu g/m^3$ in 1986 to 205 $\mu g/m^3$ in 1997, more than doubling in a decade. CO and NOx concentrations on the urban trunk traffic roads and interchanges exceed national environmental quality standards all year round[6] and recent data indicates that standards for ozone, formed by the photochemical reaction of NO_x and HC, have been exceeded in several places during the last decade.

Since the amount of coal burning has remained stable for many years while the vehicle population has grown from 300,000 vehicles to 1.4 million, Beijing local authorities attribute the increases to vehicular emissions.[7]

6/"Urban Transport and Environment in Beijing", Beijing Municipal Environment Protection Bureau, Beijing Municipal Public Security and Traffic Administration Bureau, and Beijing Urban Planning, Design and Research Academy, January 15, 1999.

7/"Urban Transport and Environment in Beijing", Beijing Municipal Environment Protection Bureau, Beijing Municipal Public Security and Traffic Administration Bureau, and Beijing Urban Planning, Design and Research Academy, January 15, 1999.

Beijing has begun to move aggressively to address this growing problem:

- In July, 1998, the sale of leaded gasoline was stopped
- the Euro 1 auto standards were phased in as of January 1, 1999, one year ahead of the national schedule.
- Beijing will implement more stringent exhaust standards (Euro 1) for both HDGE[8] and HDDE starting January 1, 2000.

As important these measures are, however, they will require many years to have their full impact. Therefore, in order to accelerate the progress toward clean air Beijing has taken several additional steps, including:

- all 1995-1998 domestically produced cars sold in Beijing must be retrofitted with a vehicle manufacturer developed kit designed to meet the Euro 1 standards by the end of 1999.
- About 15,000 vehicles have been converted to CNG or dual fuel at this time and it is expected that this will exceed 17,000 by the end of the year. Diesel to CNG conversions are estimated to result in about 10 to 20% less NOx, and gasoline to LPG conversions are estimated to result in about 40% less CO and HC.
- BEPB is actively pursuing loaded emission testing capability for the I/M program
- Vehicles which have accumulated more than 500,000 km in use are forced into retirement in Beijing; approximately 58,000 vehicles, mainly taxis, have been scrapped to date.

These measures have already begun to reverse the trend toward higher pollution levels and are expected to move forward substantially the date when clean air can be breathed in Beijing.

8/Since all heavy duty engines in Europe are diesel, the gasoline fueled engine standards will be the US 1982 requirements.