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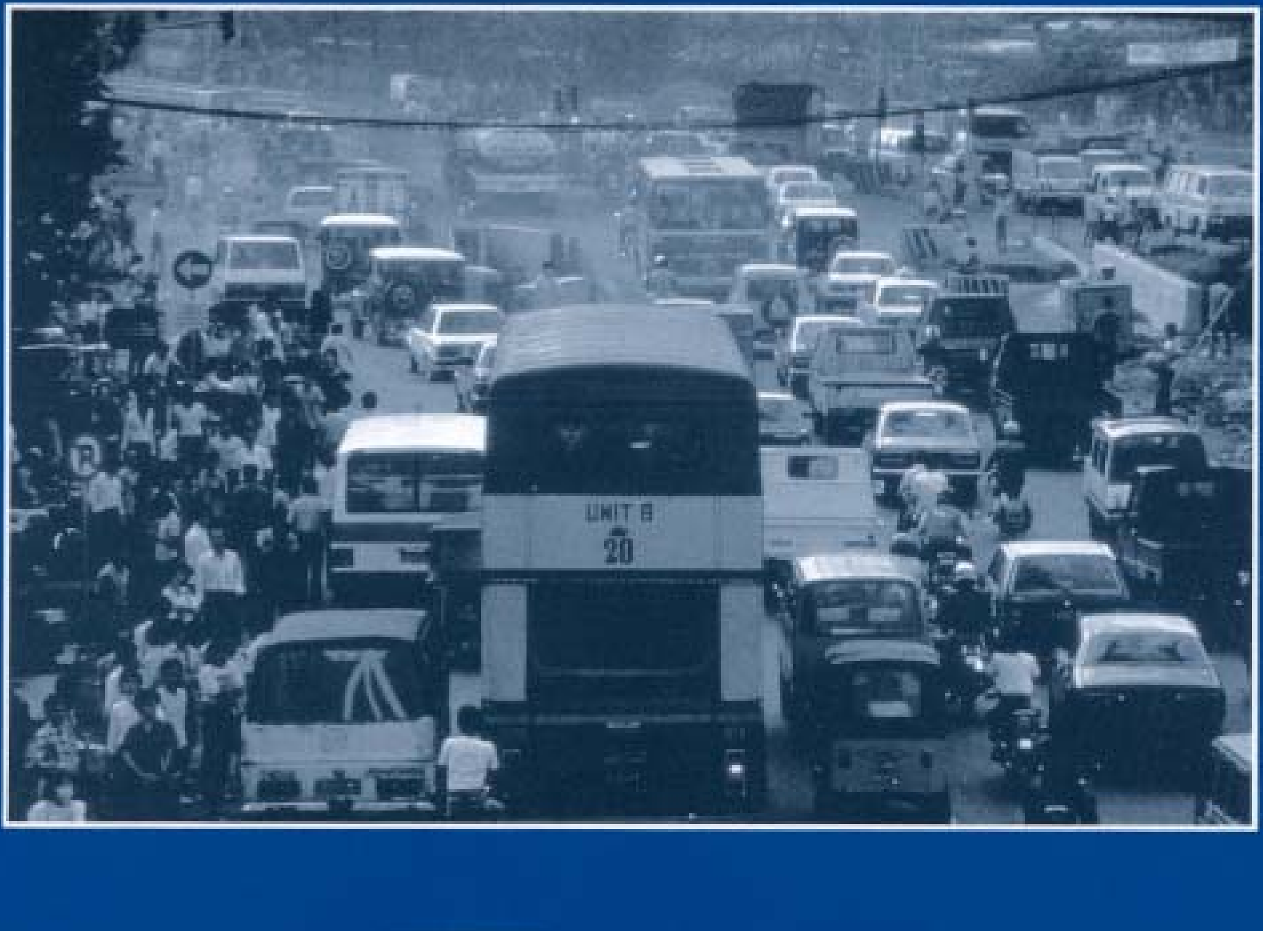
WORLD BANK TECHNICAL PAPER NO. 397
Pollution Management Series

Phasing Out Lead From Gasoline

Worldwide Experience and Policy Implications



Magda Lovei

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The World Bank
Washington, D.C.

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Foreword

Lead is one of the most toxic substances that large populations around the world are exposed to from the exhaust gases of vehicles and other sources. It is a treacherous poison: at lower levels of exposure, no obvious symptoms may occur, but children exposed to lead become less able to learn and build social contacts, becoming disadvantaged during their life. Adults breathing air contaminated with lead also suffer from hypertension and other cardiovascular problems.

The use of lead additives in gasoline has been one of the main contributors to the exposure of urban populations to lead. Children in developing countries may be particularly vulnerable to exposure because they spend a significant part of their time on the streets, and often lack proper nutrition that increases their susceptibility to lead poisoning.

Decisionmakers in an increasing number of countries have recognized that eliminating the use of lead additives in gasoline is a cost-effective way of reducing this threat. As a result, the phaseout of lead from gasoline has gained wide support. Much remains to be done, however, especially in countries where lead is still heavily used in gasoline, and rapid urbanization and motorization pose an increasing threat to exposed populations, especially urban children, the most vulnerable population group.

The phaseout of lead from gasoline makes good economic sense: relatively simple and inexpensive technical solutions are available to prevent large social damages. However, reviewing the experience of a number of countries with the phaseout of lead from gasoline, this report points out that lead phaseout is a complex issue that requires political commitment, cross-sectoral cooperation, incentive policies, and an understanding of consumers and the public.

The World Bank has been instrumental in raising political awareness of the problem and supporting national programs, regional initiatives, and the global phaseout of lead from gasoline.

Robert T. Watson
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Abstract

Human exposure to lead represents a serious environmental health problem in many urban areas. Based on a review of health and technical issues, this report points out that the phaseout of lead from gasoline is a desirable policy measure which can yield significant social benefits. Country experiences worldwide, however, indicate that political commitment, supporting policies, coordination among various sectors and stakeholders, and public understanding and support are necessary elements of successful lead phaseout. The report underlines the Word Bank's catalytic role in building government commitment, adopting appropriate policies, and facilitating the implementation of lead phaseout.

Acknowledgments

The author has greatly benefited from discussions during the *International Workshop on Phasing Lead Out of Gasoline* hosted by the Governments of the United States and Mexico in Washington, D. C., in March 1995, and the *International Conference on Heavy Metals and Unleaded Gasoline* hosted by the Government of the Slovak Republic in Banska Bystrica in September, 1995. The author is especially grateful to Richard Ackermann and Gordon Hughes for their guidance and comments in preparing the paper and to Andrew Steer for his support. She also wishes to thank Hans-Roland Lindgren and Eledoro Mayorga-Alba for their detailed technical review and comments, Amy Brooks for editorial, Sriyani Cumine for administrative assistance and Jim Cantrell for desktop publishing.

Abbreviations

ATECLP	Alliance to End Childhood Lead Poisoning
CEE	Central and Eastern Europe
CDC	Centers for Disease Control
COI	Cost of Illness
EAPCEE	Environmental Action Programme for Central and Eastern Europe
EDF	Environmental Defense Fund
ETBE	Ethyl Tertiary Butyl Ether
EU	European Union
FCC	Fluid Catalytic Cracking
HIC	High-Income Country
LIC	Low-Income Country
MIC	Middle-Income Country
MMT	Methyl-cyclopentedienyl Mangenese Tricarbonyl
MOENR	Ministry of the Environment and Natural Resources
MON	Motor Octane Number
MTBE	Methyl Tertiary Butyl Ether
NRDC	National Resources Defense Council
OECD	Organisation for Economic Co-operation and Development
OEM	Occupational and Environmental Medicine
RON	Research Octane Number
SEK	Swedish Krona
TAME	Tertiary Amyl Methyl Ether
U.S. EPA	United States Environmental Protection Agency
WTP	Willingness To Pay

Executive Summary

The phaseout of lead from gasoline is a complex issue which requires understanding the health impacts of lead, technical considerations and solutions, and the enabling policies and requirements for implementation.

Health Impacts of Leaded Gasoline

Lead is a cumulative neurotoxin that impairs the brain development of children. Studies have found a statistically significant connection between the exposure of people to lead and reductions in their intellectual performance measured by IQ: a *10 microgram per deciliter increase in blood lead was found to cause an approximately 2.5 point decrease in the IQ of exposed children*. Additionally, the exposure of adults to atmospheric lead has been connected to elevated blood pressure causing hypertension, heart attacks, and premature death. *No lower threshold of exposure exists under which the adverse effects of lead on children and adults cannot be detected.*

People are exposed to lead from a variety of sources. V*ehicular traffic is the largest source of lead exposure in many urban areas*, often accounting for more than 90 percent of all atmospheric emissions. Studies found that a 1 microgram per cubic meter atmospheric lead concentration may contribute to a 2.5-5.3 microgram per deciliter increase in the blood lead levels of the exposed population.

Highly significant relationships have been found between the use of lead additives in gasoline and the blood lead levels of exposed populations. Significant differences have been found, for example, between the blood lead levels of children living in areas with high traffic density, and the blood lead levels of those living in less congested suburbs. As a result, children in downtown areas may suffer a reduction of several IQ points. In some cases, IQ decrements of highly exposed children have been estimated to exceed 6 points.

Exposure to lead causes an economic loss to the society in various ways. The reduction of intellectual performance results in reduced productivity and losses in lifetime earnings; children with learning disabilities may require special assistance; adults with cardiovascular problems lose working days, suffer discomfort, require medical care, and may die prematurely. Although the value of the economic benefits of avoiding the health damage caused by the exposure to lead are country-specific, the magnitude of benefits estimated in the United States suggests that phasing out lead from gasoline is likely to produce substantial benefits in all countries.

Technical Issues

Lead additives in gasoline have been used since the 1930s to improve engine performance by increasing the octane rating of gasoline. Lead has also provided lubrication of the engine valve seats, allowing car manufacturers in the past to use low-grade soft metals. Due to the development of car technology, and the introduction of catalytic converters, however, most major manufacturers started to produce cars with hardened valves during the 1970s and 1980s. *As a result, the share of cars that require special lubrication is decreasing, and valve seat recession is becoming a diminishing concern in the lead phaseout process.*

Several tests have been carried out in the United States and Europe to assess the impacts of unleaded gasoline on old cars with soft valve seats. *These tests have failed to show significant recession of the soft valve seats under normal driving conditions*. They have also demonstrated that lead levels as low as 0.02-0.05 grams per liter of gasoline provided complete protection of engines even under severe driving conditions. Good engine maintenance was found to reduce potential engine damage. *Sufficient protection of sensitive engine valve seats can also be achieved by adding lubricants to unleaded gasoline*. The use of such lubricants has facilitated the total phaseout of leaded gasoline in several countries, including Austria, Sweden, the Slovak Republic, and Thailand.

The phaseout of leaded gasoline requires a capacity of refineries to produce gasoline components with relatively high octane rating. Modern conversion refineries have a wider range of technical alternatives to increase gasoline octane than less advanced skimming refineries. Such alternatives include the increasing utilization of alkylation, polymerization, and oxygenation processes.

Less advanced skimming refineries have a more limited choice of technical alternatives, such as increasing the severity of reforming, or adding octane-enhancing additives. Modernization investments, therefore, typically enhance the capacity of refineries to phase out lead. However, such investments may not be economical in many small and technically less advanced refineries, and phasing out lead should be part of a broader sector policy approach that assesses the economic viability and strategic alternatives of such refineries.

Other factors that influence the extent and costs of necessary refinery modification include existing spare octane capacity of refineries, the octane requirement of the vehicle fleet, and the price of gasoline additives. The cost of phasing out leaded gasoline, including investment costs and the incremental operating costs, has been estimated in the range of US$0.01-0.02 per liter of gasoline in the majority of refining capacity.

Worldwide Experience of Phasing Out Lead from Gasoline

Two main factors have contributed to a change in using lead additives in gasoline worldwide: the use of catalytic converters, requiring the introduction of unleaded fuels (because lead destroys the capacity of catalytic converters to reduce other pollutants); and increasing evidence and concern about the health impacts of lead, resulting in measures to reduce the lead content in gasoline. In some countries (for example, the United States), the introduction of catalytic converters was the driving force behind changing lead use in gasoline, reinforced by increasing public concern about the health impacts of lead. In other countries (for example, in Brazil, the Slovak Republic, Sweden, and Thailand), the phaseout of lead preceded the universal use of catalytic converters.

Historically, poorer countries have been more likely to use lead in gasoline. *However, government commitment and policies have played an important role in several middle- and low-income countries, including Brazil, Colombia, Nicaragua, the Slovak Republic, and Thailand, which have already achieved a total phaseout (some of them accomplished this very rapidly).* Other middle- and low-income countries, despite having the technical capacity, direct most of their unleaded gasoline production to export markets, due to limited domestic demand as a result of indifferent government policies and the lack of government commitment to address the problem of human exposure to lead. Meanwhile, many high-income countries have not yet phased out leaded gasoline.

Policy Implications

Large social benefits can be achieved by phasing out lead from gasoline. The technical solutions, which can be carried out at a modest cost, are relatively simple and well understood. Therefore, the removal of lead from gasoline is a highly cost-effective measure. In the United States, for example, the benefits of phasing out lead were estimated to outweigh the costs more than 10 times.

In the long run, the increasing use of new cars equipped with catalytic converters is likely to result in the worldwide phaseout of leaded gasoline. In the short run, however, a policy of phasing out lead from gasoline relying only on the replacement of old cars with new ones is likely to be ineffective, particularly when the car fleet has slow turnover rates and the use of catalytic converters is not considered an environ-

Six elements of effective phaseout of leaded gasoline

- Announce a clear lead phaseout schedule and deadlines;
- Fiscal incentives to create a price structure favor unleaded gasoline;
- Free market conditions or price incentives to ensure implementation of investments;
- Regulations to allow flexibility in implementation and optimal timing of investments (for example, lead trading—see box 10, p. 25);
- Consensus among affected stakeholders; and
- Public information, education, and training.

mental priority. *The achievement of rapid and significant health improvements requires the phaseout of lead independently from the adoption of catalytic converters.*

Governments can influence the composition of gasoline demand by creating price incentives in favor of unleaded gasoline. This can be achieved by differentiating existing gasoline taxes, or imposing a specific (lead) tax on leaded gasoline. Differentiated taxation has been very effective in influencing consumer behavior, thus facilitating the use of unleaded gasoline. *There is a positive relationship between the level of tax differentiation in favor of unleaded gasoline and its market share.*

The phaseout should be supported by direct regulations, such as fuel specifications limiting and ultimately prohibiting the use of lead and also restricting the presence of other harmful substances in gasoline. *In order to facilitate the planning of refinery investments, a step-by-step schedule of lead phaseout should be announced in advance.*

Under well-functioning free market systems, refineries are able to finance the capital costs of investment from commercial sources, and pass on the costs to their customers. In countries where ex-refinery prices are controlled by the state, refineries should be provided with incentives through the pricing system to carry out the necessary investments.

Implementing lead phaseout programs requires a broad consensus among the main stakeholders, and the understanding and acceptance of the program by the public. The government should establish a system of consultation between the ministries of environment, health, industry, transportation, finance, and trade, as well as representatives of the petroleum industry, car manufacturers, and gasoline distributors. Cooperation with NGOs can substantially increase the effectiveness of government efforts in public awareness building. Additionally, targeted training of auto mechanics and service station attendants should facilitate the promotion of proper fueling practices.

Chapter 1

Health Impacts of Leaded Gasoline

Lead has long been recognized as a neurotoxin that causes renal damage, neurological dysfunction, anemia, and at high doses, death. For a long time, medical attention concentrated on acute poisoning due to accidental and occupational exposures. Therefore, the adverse effects of lead at lower concentrations were not well understood until the 1970s, when scientific evidence showed that lead retarded the mental and physical development of children, causing reading and learning disabilities; changes in behavior, such as hyperactivity; reduced attention span; and hearing loss, even at low levels of exposure. Several studies (for example, Schwartz, 1988; Pocock et al., 1988) have also related increased blood pressure and hypertension in adults to elevated blood lead levels, which was shown to increase the risk of cardiovascular disease (Pirkle et al., 1985).

The effects of lead on children's behavior and intellectual performance may be captured by standardized intelligence tests measuring IQ. A highly significant association was found between lead exposure and the IQ of school-age children by several studies (for example, Needleman et al. 1979; Bellinger et al. 1992). According to a review of epidemiological studies (CDC, 1991), *a 10 microgram per deciliter (µg/dl) increase in blood lead (the best indicator of current exposure) can be associated with a 2.5 point decrease in the IQ of exposed children.* Additionally, prenatal exposure to lead has been demonstrated to produce toxic effects on the human fetus, resulting in reduced birth weight, disturbed mental development, spontaneous abortion, or premature birth at relatively low blood lead levels.

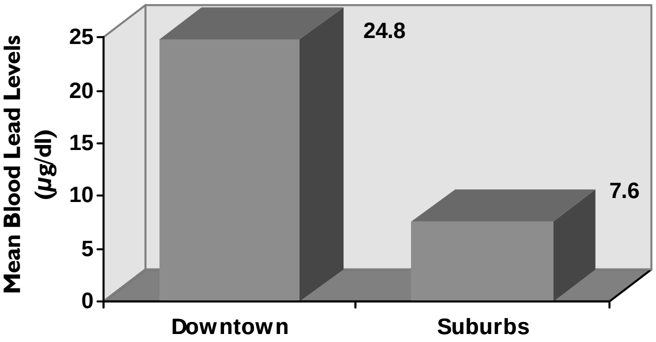
In response to increasing epidemiological evidence about the impacts of lead, the United States Centers for Disease Control (CDC) gradually lowered the level of lead in blood, over which medical intervention is necessary, from over 60 µg/dl before 1975 to 30 µg/dl in 1975; 25 µg/dl in 1985; and 10 µg/dl in 1991. Although 10 µg/dl is currently considered a limit for concern, *no threshold has been identified under which the adverse effects of lead on children or adults cannot be detected* (Schwartz, 1994b).

Ingestion is the main route of exposure to lead in children, who represent the highest risk group due to the high lead absorption rate of their digestive systems, their propensity to consume significant quantities of contaminated dust and soil, and the susceptibility of their nervous system to lead-induced disruptions. Adults are more susceptible to lead exposure through inhalation.

Human Exposure to Leaded Gasoline

The main sources of human exposure to lead include the use of leaded gasoline; industrial sources such as lead mining, smelting, and coal combustion; the use of lead-based paint; and lead-containing pipes in water supply systems. Additional sources may be food can solders, ceramic glazes, lead-containing batteries, and cosmetics. Due to the

Figure 1 The impact of traffic on the exposure of children to lead in Budapest, 1985



Source: Rudnai et al. 1990.

concern about the impacts of lead exposure, several countries have prohibited the use of many lead-containing products and took measures to abate the exposure from large point sources. *As a result, vehicular traffic, due to the use of leaded gasoline, remains the single largest source of environmental lead pollution in many urban areas, often accounting for over 90 percent of all lead emissions into the atmosphere.*[1]

The amount of lead additives used in gasoline, and the volume and patterns of traffic, have a strong influence on airborne lead concentrations. Average ambient lead concentrations in cities, therefore, are typically several times higher than in suburbs. In Jakarta, Indonesia, for example, 3.6 µg/m^3 lead concentrations were measured in a central location, and 0.3 µg/m^3 in a less congested district (Tri-Tugaswati, 1987). In Budapest, Hungary, the average concentrations of airborne lead in busy parts of the town exceeded those in suburbs by nearly 10 times (3.0 µg/m^3 versus 0.4–0.5 µg/m^3, respectively) in 1985 (Lovei and Levy, 1995). Extensive research in the United States also showed strong correlation between the reduction of lead in gasoline and the decline in ambient lead concentrations between 1972 and 1984. Similar effects were confirmed in Budapest, Hungary, where mean ambient lead concentrations declined from 3.0 µg/m^3 in 1985 to 0.6 µg/m^3 in 1993, as the lead content of gasoline was gradually reduced from 0.7 grams per liter (g/l) to 0.15 g/l.

Besides posing an immediate health risk through inhalation, vehicular lead emissions also accumulate in the soil, contaminate the drinking water, and enter the food chain, contributing to exposure through ingestion for long periods of time. Significantly higher lead levels of soil, for example, are typically measured near busy highways, rather than in areas not affected by traffic.

The impact of traffic-related exposures has been indicated in several countries by significant differences in blood lead levels among children living in high-traffic downtown areas, and those living in less congested suburbs. According to a study in Budapest (Rudnai, 1990), for example, 57 percent of tested children had blood lead levels over 20 µg/dl in downtown areas, and only 1.7 percent in the suburbs in 1985. The magnitude of difference in mean lead exposures (figure 1) may have caused as much as four IQ gradient decrements in exposed children in downtown areas (Lovei and Levy, 1995). In Manila, the Philippines, the ratio of children with higher than 20 µg/dl blood lead levels was 32.7 percent among sampled 6- to 14-year-old child street vendors, who are exposed to higher levels of traffic-related lead emissions, and 10.3 percent among other school children of the same age group (Hertzman, 1996; Subida, 1994; and Torres et al. 1991). *Mean* IQ decrements due to exposure to lead in Manila have been estimated at 2.2 in school kids, and 3.1 in child street vendors, while estimates of *maximum* IQ decrements in these population groups ranged from 4.5 to 6.4 gradients, respectively (Hertzman, 1996).

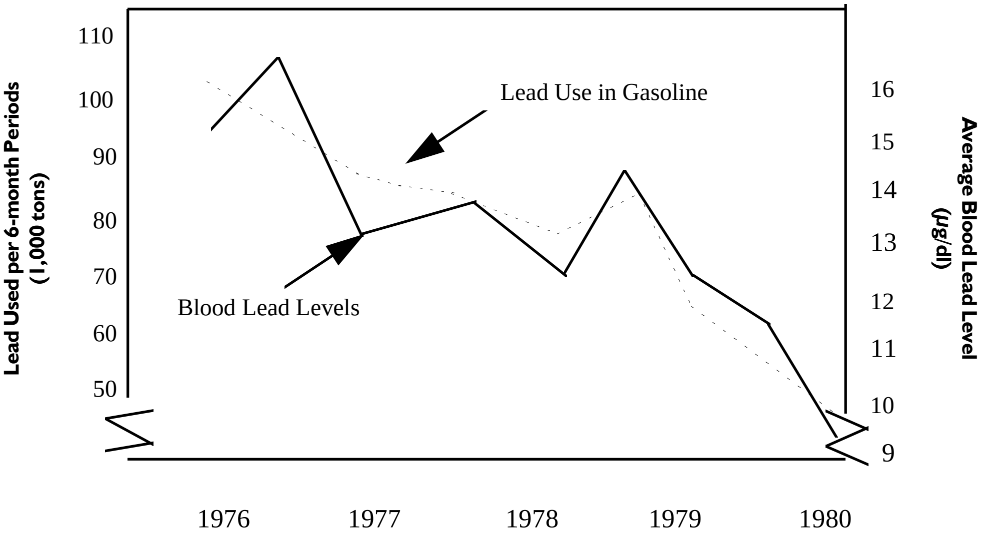
Based on a review of studies, the U.S. EPA (1985) concluded that a fairly consistent relationship between airborne lead concentrations and blood lead levels of exposed children could be established by a slope between 2.5 and 5.3. A recent analysis (Hayes et al., 1994) suggested that a 0.1 µg/m^3 decline in the mean air lead level predicted a decline of 0.56 µg/dl in the median blood level in children in the Chicago area, when the ambient air lead level was near 1.0 µg/m^3. Based on data from Hungary, Rudnai and Horvath (1994) found that a 1 µg/m^3 difference in the concentration of airborne lead was connected with a 1.2 µg/dl blood lead level in adults and 4.2 µg/dl in children, respectively. Ostro (1994) recommended that a slope of 3.9 be used for calculating the effects of lead in the ambient air on blood lead levels. *Established statistical relationships between ambient lead concentrations and blood lead levels, and between blood lead levels and children's IQ, suggest that a 1 mg/m^3 increase in ambient airborne lead concentrations can be connected to an approximately 1 IQ point mean decrement in exposed children.*

Based on a review of studies, Ostro (1994) has also estimated the relationship between ambient airborne lead levels and the cardiovascular impacts of lead on adults, including hypertension, heart attacks, and premature deaths. *A 1 µg/m^3 increase in ambient lead concentrations was estimated to cause 44,800 to 97,000 cases of hypertension per 1 million males between the ages of 20 and 70, 180 to 500 nonfatal heart attacks, and 200 to 650 premature deaths per 1 million males between the ages of 40 and 59.*

The use of lead additives in gasoline constitutes a unique environmental problem, causing long-term exposure of large populations to lead due to the very effective dispersion and accumulation of lead in the human environment. *Extensive studies carried out in the U.S. (Annest et al., 1983 and U.S. EPA, 1985) demonstrated a remarkably close relationship between changes in the lead use in gasoline and blood lead levels* (figure 2). Controlling for variables such as age, sex, urbanization, smoking, alcohol consumption, occupational exposure, dietary habits, regional differences, education, and income, it was found (U.S. EPA, 1985) that the use *of 100 metric tons of lead in gasoline per day was associated with a 2.1 µg/dl increase in the mean blood lead level of the U.S. population.*

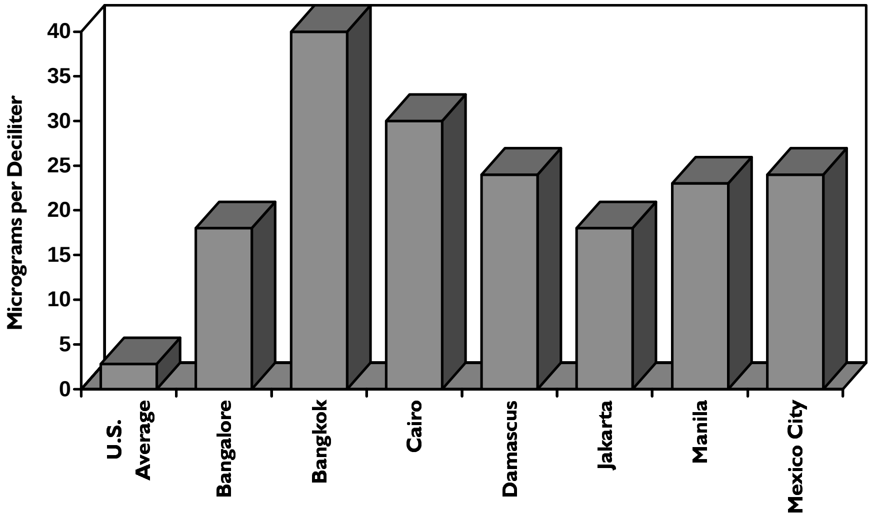
In many countries, evidence suggests that exposure to lead is one of the most serious environmental problems. Sample blood lead levels of urban populations, especially children, often reach alarmingly high levels (figure 3). It has been estimated (ATECLP and EDF, 1994) that among urban children in developing countries with no identified stationary source, 100 percent of those under 2 years of age, and over 80 percent of those between the ages of 3 and 5, had average blood lead levels greater than 10 µg/dl. Ingested lead is believed to be absorbed from the stomach more

Figure 2 Blood lead levels and the use of leaded gasoline in the United States, 1976-80



Source: U.S. EPA, 1985.

Figure 3 Average blood lead levels of sampled populations in selected cities, late 1980s–early 1990s



Note: The above figure only serves as illustration of blood lead levels occurring at various locations. The size, age group, sampling methods, year of sampling, and the representativeness of samples varied across countries. The results, therefore, cannot be interpreted as cross-country comparison of lead exposures.

Source: Bangalore, India, and Mexico City, Mexico: Khandekar, 1984; Bangkok, Thailand: Abt Associates, Inc. and Sobotka & Co., Inc., 1990; Cairo, Egypt: Chemonics International, 1994; Damascus, Syria: Othman, 1985; Jakarta, Indonesia: Tri-Tugaswati et al., 1987; Manila, the Philippines: Subida, 1994 and Torres et al. 1991.

effectively when the stomach is empty, and when diet lacks essential trace elements, such as iron, calcium, and zinc (ATECLP and EDF, 1994). *The population group most seriously affected by the exposure to lead, therefore, is likely to be the urban poor.*

It was estimated (Abt Associates and Sobotka & Co., 1990) that 30,000 to 70,000 children could suffer losses of 4 or more IQ points as a result of lead concentrations exceeding prevailing U.S. levels, about 400 to 800 adult men could suffer heart attacks and strokes, and 200 to 400 could die as a result of excessive exposures in the late 1980s in Bangkok, Thailand. In Cairo, Egypt, more than 800 infants may die annually due to their mother's exposure to lead, and more than 10,000 adults may die prematurely due to their exposure to lead (Chemonics International, 1994). Ostro (1994) estimated that more than 150 premature deaths, close to 200 cases of heart attacks, and an aggregate loss of 2 million IQ points decrement in children could be avoided by reducing ambient airborne lead levels to the WHO standard in Jakarta, Indonesia.

The Cost of Health Impacts

The exposure to lead causes an economic loss to people and societies in various ways. The cognitive damage caused by the exposure of children to lead influences their lifetime productivity and earning power. Barth et al. (1984) divided these impacts into the direct effects of lowered IQ on earnings; and indirect effects that influence the length of education, and participation in the work force. A review of studies indicated that, controlling for other factors, *a 1 point IQ reduction was associated with a 0.9 percent reduction in lifetime earnings.* Schwartz (1994a) estimated that the net present value[2] of benefits associated with a 1 µg/dl permanent reduction in mean blood lead levels amounted to $1,300 per child turning 6 years of age each year in the United States (1989 US$).

Children who suffer from learning disabilities as a result of lead exposure also may need special education or assistance. Bellinger et al. (1984), for example, concluded from an analysis of U. S. data that the number of children receiving daily assistance besides their regular school education is 17 percent higher among those with high exposure to lead, than those with low exposure.

Table 1 Annual health benefits of reducing the population's mean blood lead levels by 1 μg/dl in the United States

Source of Benefits	*Amount (millions US$)*
Children	
Medical Costs	189
Compensatory Education	481
Earnings Loss	5,060
Infant Mortality	1,140
Neonatal Care	67
Sub-total	*6,937*
Adults	
Medical Costs	
Hypertension	399
Heart Attacks	141
Strokes	39
Lost Wages	
Hypertension	50
Heart Attacks	67
Strokes	19
Mortality	9,900
Sub-total	*10,215*
Total	*17,152*

Source: Schwartz, 1994a.

Such costs have been estimated to amount to $3,320 per child with blood lead levels over 25 μg/dl in the United States in 1989 (Schwartz, 1994a).

Additionally, Schwartz (1994a) has pointed out that low birth weight and low gestational age caused by the exposure of mothers to lead were strong predictors of infant illnesses and infant mortality (causing about 380 deaths per year for the U.S. population)[2] and resulted in significant health costs of neonatal intensive care. He estimated the benefit of reduced infant mortality at $1.14 billion, and avoided infant health care costs at $67 million per year in the United States.

For adults, the costs associated with exposure to lead include (i) medical expenditures (physicians, drugs, and hospitalization) due to hypertension and strokes; (ii) lost workdays; (iii) other discomfort, restriction of nonwork activities, and pain; and (iv) the risk of premature death. Some of these costs (medical expenditures and lost workdays) may be calculated by the cost of illness (COI) approach that includes out-of-pocket expenses; others (discomfort, pain, and mortality) have to be estimated by indirect measures. Among these, contingent valuation methods and wage comparisons have been used to determine people's willingness to pay (WTP) for certain health benefits or the avoidance for health risks.

Ostro (1992) estimated the average cost of one emergency room visit at $258, one restricted activity day at $58, and one case of hypertension at $220 in the United States Schwartz (1994a) estimated the cost associated with a stroke at $30,000. Compensating wage studies and contingent valuation studies have valued a statistical life in the range of $1 - 10 million in the United States Schwartz (1994a) recommended calculating with the value of $3 million per statistical life as the best estimate of the willingness to pay to avoid excess mortality risk.

The economic benefits of avoided health impacts of exposure to lead are country-specific, depending on the cost of health care provision, cost of labor and capital, labor productivity, life expectancy, people's values about their health and life, and other factors. Schwartz (1994a) estimated, for example, that the health benefits of reducing the U.S. population's blood lead level by 1 µg/dl amounted to $17.2 billion annually (1989 US$) (table 1). This magnitude of benefits suggests that *phasing out lead from gasoline is likely to produce substantial benefits in other countries, as well.* Following parts of the paper will show that technical solutions to phasing out lead from gasoline are relatively simple and the costs are modest, making lead phaseout a particularly cost-effective policy measure. According to estimates, the benefits of phasing out leaded gasoline exceeded the costs more than 10 times in the United States (U.S. EPA, 1985). *Therefore, policies and measures that facilitate the phaseout program deserve high priority in every country.*

Notes

1. In some cases, industrial and other sources still pose a significant health threat. Comprehensive lead phaseout policies are, therefore, needed to address all sources of lead in these areas.
2. Based on the opportunity cost of capital approach, a 5 percent real discount rate (5 percent above the inflation rate), and a 1 percent annual growth rate of future real wages were assumed.

Chapter 2

Technical Issues

Two key areas of technical considerations should be reviewed: vehicle engine technology, and refinery technology.

Vehicle Engine Issues

The special property of lead to increase engine performance by preventing self-ignition(engine knock[1]) was discovered by Thomas Midgley, Jr. and Thomas A. Boyd at the General Motors Research Laboratory in 1921. Since one of the main characteristics of the spark-ignited engine (Otto engine) is its octane requirement[2] (the lowest octane of fuel necessary for the engine to avoid engine knock), lead additives (mixtures based on tetraethyl-lead and tetramethyl-lead) in gasoline provided a relatively easy solution to the early combustion problems of the Otto engine. By increasing the octane of gasoline, lead additives enabled auto manufacturers to produce more powerful (higher-compression) engines.[3] After the 1930s, the use of lead additives increased dramatically throughout the world, amounting to 375,000 tons annually by the early 1970s (Nriagu, 1990). Lead additives reached high concentrations in gasoline, in several countries (for example, Australia, Brazil, Greece, Indonesia, the United States) exceeding 0.8 gram per liter.

The invention of catalytic converters introduced significant changes to auto manufacturing, as well as to gasoline production. Catalytic converters were introduced in the 1970s to reduce the tailpipe emissions of hydrocarbons, carbon monoxide, nitrogen oxides, and other pollutants emitted with engine exhaust gases. Catalysts, however, required unleaded fuel in order to prevent lead, deposited on the catalyst material, from blocking the access of exhaust gases to the catalyst. Lead not only reduces the efficiency of the catalyst, but can destroy it. Unleaded gasoline, therefore, had to be introduced to supply cars equipped with catalytic converters.

Besides enhancing engine performance by increasing the octane rating of gasoline, lead also functions as lubricant of the exhaust valves, particularly the valve seats. In the past, the lubrication properties of lead allowed car manufacturers to use lower-grade metals on the engine valve seats. The introduction of catalytic converters, and the development of car technology, however, have resulted in a shift toward[3] the production of hardened valves by most major car manufacturers since the 1970s. In the United States, for example, most automobiles and light-duty trucks have had integrally hardened valve seats or inserts since 1971. In Europe, most auto manufacturers increased the hardness of valve seats produced since the 1970s, using cast iron inserts in aluminum heads and, more recently, induction-hardened iron or special alloy inserts (McArragher et al., 1993). As a result, *a decreasing share of the automobile fleets today have soft valve seats that require extra lubrication in the gasoline.*

In the European Union, for example, the percentage of car population with soft valve seats was estimated under 30 percent in 1993, forecasted to decrease to around 20 percent by 1997 (McArragher et al., 1993). The share of cars with soft valves may be higher in certain countries and country groups (for example, in Eastern Europe), where domestic car production switched to new technologies late, and the turnover of old vehicles is slow.

In connection with the lead phaseout program in the 1970s and 1980s, a large number of vehicles was tested in the United States to assess the impacts of unleaded gasoline on engines with soft valve seats[4] (Weaver, 1986). These tests demonstrated that recession of the valves only occurred in certain types of cars under severe driving conditions. In-use tests demonstrated much less impact on the valve seats than laboratory tests that created extreme driving conditions. Generally, vehicle speed was shown to be the most significant factor influencing the extent of valve seat recession, and good engine maintenance noticeably prevented engine wear. It was also pointed out that the amount of lead required to prevent valve recession of sensitive engines was much less (0.07 grams per gallon or about 0.02 g/l) than the amount allowed in previous regulations. *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* (Weaver, 1986).

Tests in Europe (McArragher et al., 1993) confirmed similar findings to those in the United States. They indicated that a concentration of 0.05 g/l lead provided complete protection to soft valve seats even under severe driving conditions, and lower levels (0.02 g/l) under moderate conditions. These levels are less than one-third of the lead level currently allowed by EU regulations (0.15 g/l). It was also pointed out that most tests carried out in the 1970s were applied to engines with softer valve seats than typical in current Western European car fleets, indicating an overestimation of the potential damage. Some car manufacturers, however, especially in Central and Eastern Europe, continued to use the earlier, softer metallurgy longer. For cars manufactured with this technology, therefore, test results carried out during the 1970s may provide a realistic assessment of valve seat recession.

Lead is not the only substance that can prevent the recession of soft valve seats. Various gasoline additives are available to substitute the lubrication function of lead if unleaded gasoline is used in cars with soft valve seats. Compounds based on sodium and potassium, for example, have been shown to provide sufficient protection against valve seat recession (McArragher et al. 1993). Such lubricating additives have been widely used in Western Europe. In Austria and Sweden, for example, where leaded gasoline has been completely phased out but old cars with soft valves are still running, special sodium naphthenate additives were introduced to prevent potential damage.[4] A similar approach was taken in Thailand and the Slovak

Box 1 Phaseout of leaded gasoline in the Slovak Republic

Lead was heavily used in Slovakia (part of former Czechoslovakia) until the 1980s. The lead content of gasoline was gradually reduced from over 0.7 g/l to 0.4 g/l in 1983; to 0.25 g/l in 1985; and 0.15 g/l in 1989, followed by the total phaseout by the end of 1994. *The market share of unleaded gasoline increased from 6 percent in 1992 to 100 percent in 1995.*

Besides health considerations about the impacts of lead, another — mainly supply-driven — factor contributed to the drastic change in the lead use in gasoline. As a result of a technical upgrade undertaken in response to increasing quality requirements of its export markets, Slovnaft, the only refinery of the Slovak Republic, developed an overcapacity in the production of high-octane gasoline components by the early 1990s. About 70 percent of the vehicle fleet in the country, however, consisted of cars designed to use leaded gasoline, manufactured with soft engine valve seats, and vehicle turnover was very slow. In order to resolve the disparity between supply and demand, Slovnaft developed a fuel additive that enabled all motorists to use unleaded gasoline by providing the necessary lubrication to the soft engine valves in old cars. The additive has been marketed, under the trade name ANABEX-99, as a universal fuel additive which can be used in cars with or without catalytic converters.

The total cost of phasing out lead from gasoline production, including the annualized investment cost of the new isomerization and lubricant production units, the development of new additive, and the increased operation cost of unleaded gasoline was estimated at US$0.02 per liter of gasoline.

Slovnaft used its control over the gasoline distribution network to market the new gasoline brands. A differentiated pricing policy in favor of unleaded gasoline and a strong public information campaign contributed to the success of the total lead phaseout program and the acceptance of new gasoline by consumers.

Republic, as well. In the Slovak Republic, leaded gasoline was completely phased out by the end of 1994, despite the fact that about 70 percent of the car park had soft valve seats (box 1). The cost of treating gasoline with a lubricating additive has been estimated at about US$0.003 per liter (Hirshfeld and Kolb, 1995b).[5]

Nor are the impacts of lead additives on vehicle engines all positive. Halogen acids[6] derived from lead salts cause increased corrosion, requiring more frequent muffler and spark plug replacement and oil change. Studies carried out after reducing the lead level of gasoline reported that reduced piston ring and cylinder-bore wear prevented engine failure and improved fuel economy (U.S. EPA, 1985). As a result of switching from leaded to unleaded gasoline, estimated maintenance savings in the range of US$0.003-0.024 per liter of gasoline were reported from Australia, Canada, and the United States (Walsh, 1995). *It was also pointed out that the incremental maintenance costs associated with leaded gasoline exceeded considerably the maintenance costs due to the recession of exhaust valves caused by the use of unleaded gasoline* (U.S. EPA, 1985).

Refinery Alternatives

Various technological options are available to enhance the octane of gasoline in the absence of lead by modifying the petroleum refining and blending process (box 2). The choice of options may be influenced by the technical specifications of refineries, environmental considerations and regulations, and the cost of alternatives.

Most refineries can be classified into two major groups: skimming and conversion refineries. Technically most simple skimming refineries (table 2) only perform crude distillation, treating, and blending,

Box 2 Refinery processes of gasoline production

To produce gasoline, refineries can rely on different types of production and blending processes requiring varying degrees of refinery complexity:

- **Atmospheric distillation** is a basic refinery process that separates crude oil into different oil product fractions:
  - ⇒ **Light naphthas:** low-octane (70-75 RON) gasoline components that can be blended straight into the gasoline or their octane number can be increased significantly by isomerization;
  - ⇒ **Heavy naphthas:** low-octane (35-55 RON) gasoline components used to feed the catalytic reforming unit;
- **Conversion:**
  - ⇒ **Fluid Catalytic Cracking** (FCC) upgrades lower-value heavy fuel oil into higher value lighter products such as FCC gasoline with 90-93 RON and refinery gases to be fed to alkylation or oxygenate production;
- **Upgrading processes** improve the octane of crude fractions:
  - ⇒ **Catalytic Reforming** increases the octane of heavy naphtha-gaining reformate with high octane (93-102 RON). The octane of reformates can be adjusted by the refiner. The potential of reforming depends on the "severity" (operating conditions, such as temperature and reaction time) of refinery operation. However, increasing reforming severity also increases the aromatic content of gasoline (increasing severity from 90 to 100 increases the aromatic content of reformate by about 15 percentage points), and reforming sensitivity (the difference between RON and MON);
  - ⇒ **Isomerization** increases the octane of light naphtha (to 85-90 RON) without increasing the aromatic content of gasoline;
  - ⇒ **Alkylation and Polymerization** are complementary to FCC, transforming FCC feedstock into high gasoline blending components (92-97 RON). However, polymerization increases the olefin content of gasoline; and
- **Oxygenation** represents blending with oxygenated blendstocks (for example, MTBE, ETBE, TAME, methanol, and ethanol with octane values up to 130 RON).[7] Oxygenates may be purchased as gasoline additives, or produced from purchased methanol and iso-butene produced by the FCC unit. Oxygenates are effective in reducing harmful emissions.

Table 2 Refinery alternatives and environmental impacts of replacing lead in gasoline

Alternatives to Replace Lead	*Skimming Refineries*	*Conversion Refineries*	*Environmental Effects*
Refining Process:			
Increase Reformer severity	●	●	
Increases aromatics			
Add: Reforming	●	●	Increases aromatics
Isomerization		●	Beneficial
Alkylation		●	Beneficial
Polymerization		●	Increases olefins
MTBE production		●	Beneficial
Blending:			
Purchased oxygenates (e.g., MTBE, ETBE, TAME, Methanol)	●	●	Beneficial
Octane-enhancing additives (e.g., MMT, DurAlt)	●	●	Beneficial
Butane	●	●	Increases volatility

Source: Hirschfeld and Kolb, 1995a.

while more advanced hydroskimming refineries also perform catalytic reforming for upgrading. Conversion refineries are technically more complex with cracking units (coking, thermal or fluid catalytic cracking), as well as isomerization, alkylation, and polymerzation capacity. Some of the modern conversion refineries, especially those situated in countries where cheap methane and butanes are available from wet gas processing in rich oil-producing areas, also have oxygenate production. *Worldwide, most refining capacity resides in conversion refineries that tend to be larger than hydroskimming refineries* (Hirschfeld and Kolb, 1995a). The octane-enhancing options available in these two refinery categories are different (table 2), also determining the quality and environmental effects of gasoline and the cost of substituting lead.

Modern, deep conversion refineries can substitute lead at a considerably lower cost than less advanced skimming refineries, due to a wider choice of technical alternatives—including alkylation, polymerization, and oxygenation—available in modern refineries to increase gasoline octane without lead. Additionally, the cost of refinery adjustment is also influenced by the (i) extent refining capacities are utilized and spare octane capacities exist; (ii) octane requirements of the vehicle fleet; and (iii) price of octane-enhancing gasoline additives.

The typical cost of phasing out leaded gasoline—including the annualized refinery investment costs amortized over the life of the investment, the incremental operating costs of producing gasoline without lead, and/or the cost of gasoline additives—has been estimated in the range of US$ 0.01–0.02 per liter (Abt Associates, 1996; Thomas, 1995; Hirshfeld and Kolb, 1995a and 1995b). The cost difference between the production of leaded (0.15 g/l) and unleaded gasoline in Germany, for example, was estimated at US$0.01 per liter (Thomas, 1995). Even in tech-nologically less developed skimming refineries, the cost of total phase-out of leaded gasoline has been estimated under US$0.03 per liter (Hirshfeld and Kolb, 1995a). In cases when excess refining capacity exists, the cost of the phaseout may be particularly low (box 3). *Each refinery, however, has a unique technical structure and set of alternatives to replace lead, and the costs of required investments and technical measures necessary to support the phaseout of lead should be evaluated on a case-by-case basis.*

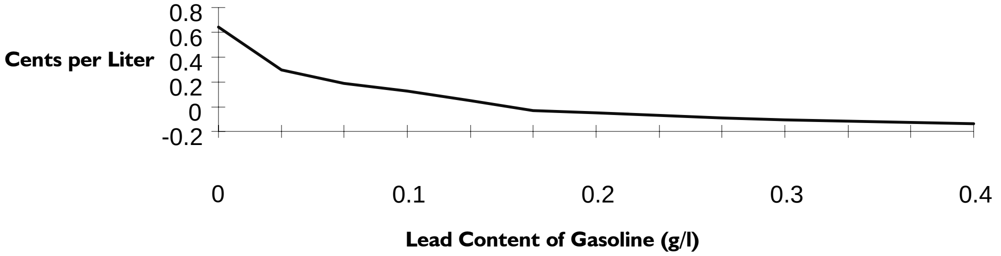
Refinery modernization investments necessary to reduce the lead content of gasoline often improve productivity and refining efficiency, and increase revenues. Therefore, only the investment costs directly

Box 3 Refinery optimization and the reduction of lead in gasoline may save money in Romania

Unlike many other Central and Eastern European countries that gradually reduced the maximum allowed concentration of lead in gasoline to the current European Union standard (0.15 g/l), Romania still allows lead concentrations of up to 0.6 g/l.

A recent study (Hirshfeld and Kolb, 1995b) of the technical feasibility of phasing out lead from gasoline in Romania has pointed out that the current technical capacity of Romanian refineries would not only allow the phaseout of lead without capital investments, but the first phase of lead reduction (moving from current levels of lead to 0.15 g/l), combined with refinery optimization measures, would even save money to the Romanian refinery sector. Refinery modeling demonstrated that the current use of lead was sub-optimal, and significant reduction in lead use would be justified by refinery economics alone, without taking into account the health benefits of such measure.

Figure 4 Incremental cost of lead reduction in Romania



associated with *accelerating* investments in refinery modernization, and changes in refinery configuration necessary to produce gasoline without lead, should be “charged” to the lead phaseout process. The proper method to assess the incremental costs due to the phaseout of lead is to compare *with* and *without project* scenarios. A recent study (Abt Associates, 1996), for example, pointed out that phasing out leaded gasoline at a hydroskimming refinery in the Russian Federation would cost between US$0.005 and US$0.02 per liter of gasoline (depending on technical solutions) if current production structure was maintained. However, due to changes in the refining sector, the refinery’s current product slate was expected to change in the near future. Taking this factor into account halved the estimated cost of lead phase-out.

While modernization investments of refineries typically improve the technical conditions to remove lead from gasoline, such investments should be economically justified. Many small skimming refineries (with refining capacities below 30 thousand barrels per day and lower) which were constructed to serve smaller markets in developing countries (for example, in Africa, Latin America, and the Caribbean), cannot achieve sufficient economies of scale to support and accommodate investments in capital-intensive modern conversion and upgrading units. The assessment of the economic viability and long-term outlook of these refineries may indicate that their closure (and the corresponding import of gasoline and other refined products) is more economical than keeping their operation running and injecting new investments. The best strategy of phasing out the use of lead in gasoline in these cases may be to import unleaded gasoline and high-octane gasoline components and additives for blending unleaded gasoline. It is unlikely that these small refineries can be made competitive. Many large oil refineries expanded their technical capacity and developed economies of scale in unleaded gasoline production leading to low world market prices for unleaded gasoline. On several markets, spot prices of unleaded gasoline are lower than the prices of leaded gasoline.

Some of the gasoline refining and blending processes increase the aromatic content of gasoline (benzene, toulene, xylene, and other polyaromatic hydrocarbons). Although the health impacts of increasing aromatic emissions attributed to the

Box 4 The Benzene Myth

Gasoline contains various harmful substances. One of them is benzene, a carcinogenic hydrocarbon that increases the risk of leukemia. The largest producer of tetra-ethyl lead (TEL), Octel, claims that unleaded gasoline should not be used in cars without catalytic converters, since unleaded gasoline contains more benzene then leaded, and without converters, the emission of benzene cannot be controlled. However, there are several weaknesses in this argument:

- The production of unleaded gasoline does not necessarily lead to significant increases in the benzene content of gasoline, since it can be controlled by various refining processes;
- Research has shown that personal activities, and pollution sources in homes, far outweigh the contribution of outdoor air to human exposure to benzene. The exposure of smokers, for example, exceeds the exposure of nonsmokers nearly 10 times. It was estimated that more than half of the nationwide exposure to benzene in the United States could be attributed to smoking (Wallace, 1989), and only 20 percent to traditional sources including traffic and industrial emissions; and
- Of all exposures originating from gasoline, leaded and unleaded, a significant share is attributed to the evaporation of gasoline in garages, during driving, and pumping gasoline. Such exposures are associated with gasoline used in cars with or without catalytic converters.

Additionally, the magnitude of health impacts caused by benzene exposure should be compared to those of lead exposures. It has been estimated (Tancrede et al., 1987; U.S. EPA, 1986) that the excess risk of leukemia associated with 70 years of exposure to 1 $\mu g/m^3$ airborne benzene was 4-8 x 10^{-6}. Based on emission estimates of 202 thousand tons of benzene annually in 1976, the U.S. EPA's Carcinogen Assessment Group estimated that 47 cases of deaths from leukemia could be attributed to the exposure to benzene from gasoline (U.S. EPA, 1985). For comparison, the annual number of deaths avoided by the reduction of lead in gasoline (only one of the positive health impacts of reducing lead), has been estimated between 4,000 and 5,000.

removal of lead from gasoline are smaller than those of lead emissions (box 4), the replacement of lead additives with other environmentally harmful substances should be avoided, and environ-mentally beneficial refining and blending processes should be selected. Isomerization and alkylation, for example, enhance the octane rating of gasoline without known adverse health effects. Oxygenates (additives that contain oxygen), including ethers such as methyl tertiary buthyl ether (MTBE) and ethyl tertiary buthyl ether (ETBE), and alcohols, such as ethanol and methanol, are also recommended alternatives to lead because they replace aromatics and also help fuels burn cleaner and more completely, thereby reducing the tailpipe emission of hydrocarbons, carbon monoxide, and various air toxins without significant adverse health impacts (*Box 5*). Other additives such as the manganese-based methyl-cyclopentedienyl manganese tricarbonyl (MMT) or glycol-based DurAlt are also known to increase gasoline octane. Concerns about the potential health impacts of using MMT, and requirements for the permanent use of DurAlt to be effective, however, have restricted the use of these additives.

Distribution Systems

The introduction of unleaded gasoline should be supported by a distribution infrastructure that allows for the separate storage, transportation, and sale of leaded and unleaded gasoline brands, and ensures that no contamination of unleaded gasoline occurs that may harm cars equipped with catalytic converters designed to use unleaded gasoline only.

In most countries, the introduction of unleaded gasoline may be carried out without significant changes in the distribution infrastructure. The reduced selection of leaded gasoline brands, for example, allows the use of the same number of storage tanks and pumps at retail stations during the introduction of a new unleaded gasoline brand. The distribution system can typically adjust to the replacement of one leaded gasoline brand by unleaded within three to four months.

Various methods have been also used at service stations to prevent misfueling and inform consumers

Box 5 Oxygenated gasoline and human health impacts

As part of a comprehensive strategy for reducing vehicular air pollution, the U.S. Clean Air Act Amendments of 1990 mandated the use of oxygenated fuels as a means of pollution prevention in areas of the country with high ambient atmospheric ozone and carbon monoxide concentrations. Oxygenated fuels—*oxyfuels* which are mixtures of traditional gasoline and oxygenates with maximum oxygen content of 2.5 percent by weight, and *reformulated gasolines* which are new blends with minimum 2 percent oxygen content by weight, maximum 1 percent benzene and 25 percent aromatic hydrocarbons content and no heavy metal additives—are expected to reduce the tailpipe emission of carbon monoxide, ozone-forming volatile organic compounds, benzene, nitrogen oxides, sulfur dioxide, and particulates.

Following the introduction of oxygenated fuels, public complaints emerged at some locations about adverse health effects—primarily mild headaches of short duration, eye and throat irritation, and cough—triggering a series of epidemiological surveys (for example, in New Jersey and Wisconsin) and controlled experimental chamber studies (conducted, for example, by the EPA, Yale University of Medicine, and the Swedish National Institute of Occupational Health). None of these studies found symptoms related to exposure to MTBE, the most heavily used oxygenate. Public complaints were found to be strongly associated, however, with the awareness of oxygenated gasoline influenced by adverse media coverage. It was also pointed out that health complaints about oxygenated gasoline may have been linked with MTBE's potent and unpleasant odor even at low concentrations. Some sensitive individuals and cigarette smokers were also more likely to have complaints.

The impacts of MTBE were also extensively studied in laboratory animal studies in the United States and Italy. The results of these studies indicate that MTBE has low toxicity with adverse effects occurring only at very high exposure levels. Although certain animals developed cancer at very high doses of exposure, the mechanism of cancer in animals appeared to be species-specific, and extrapolation to humans was considered inappropriate.

Based on intensive studies, an Occupational and Environmental Medicine report (OEM, 1996) concluded that "*reformulated gasoline and MTBE are no more harmful than the traditional gasolines they have replaced.*"

about the use of the different gasoline brands. In Japan, for example, pumps of the four types of gasoline brands on the market were distinguished by colored labels after unleaded brands were introduced. The use of gas pumps with different nozzle sizes for leaded and unleaded gasoline brands, designed to prevent misfueling, was originally introduced in Japan and the United States, and widely adopted by other countries later. *Experience has shown, however, that incentives provided through the gasoline pricing system are the most effective instrument to prevent intentional misfueling.*

Additionally, the gasoline taxation and pricing system should prevent the mis-management of the various gasoline brands. If a differentiated tax on leaded and unleaded gasoline brands is levied at the retail level, distributors who purchase gasoline at ex-refinery prices that reflect production costs only (lower prices for leaded than unleaded) will be encouraged to replace unleaded gasoline with leaded. While technical measures, for example, using colored dyes to differentiate leaded and unleaded brands, are available to limit such mismanagement, incentives through the pricing system—building the differ-entiated tax into the ex-refinery price—is a more effective way of prevention. Considering that most countries are importers of lead additives,[8] a *preferred way of preventing the mismanagement of the various gasoline brands and simultaneously creating incentives for refineries to switch to the production of unleaded gasoline, is the introduction of an environmental tax levied on the import of lead additives.* Incentive pricing, however, does not eliminate the need for quality control in the distribution system.

Notes

1. When the compression ratio (the degree of compression of fuel and air) is too high, part of the air-fuel mixture detonates and explodes (creating a knock) resulting in loss of power and overheating.
2. Gasoline octane values are measured in terms of *research octane number* (RON) and *motor octane number* (MON). RON measures performance at lower engine speeds, while MON measures it at higher speeds. In some countries (for example, the United States*), control octane number* (CON) is used by averaging RON and MON measures (R+M)/2.
3. Lead compounds are not the only additives used in gasoline. Additives have been widely used for various purposes including the inhibition of oxidation (aromatic amines and hindered phenols) and corrosion (carboxylic acids, amides, and amine salts); prevention of depositions in the carburetor (polybutene and polyether amines); improvement of water separation (polyglycol derivatives); and prevention of icing in the carburetor and fuel systems (surfactant, alcohol, and glycol) (Gibbs, 1990).
4. The number of vehicles affected was estimated to exceed 70 million (Schoonveld et al., 1986). These included mainly automobiles, heavy-duty trucks, agricultural equipment, and four-cycle marine engines manufactured prior to 1971.
5. Based on bulk blending of Lubrizol's Powershield 8164 additive at the recommended concentration of 0.7 g/l.
6. The formation of halogen acids is caused by the use of so-called lead scavengers (chlorinated hydrocarbons) that have been added to gasoline in order to avoid the excessive deposition of lead in the engine. (Scavengers react with lead and form volatile compounds that are vented out of the engine.)
7. MTBE: methyl tertiary butylether; ETBE: ethyl tertiary butyl ether; TAME: tertiary amyl methyl ether.
8. The only significant supplier of lead additives on international markets is the U.K.-based Associated Octel Company Ltd.

Chapter 3

Worldwide Experience of Phasing Out Lead from Gasoline

The worldwide history of lead use in gasoline can be divided into two main periods: the "the rise of lead" from the 1930s to the 1970s; and "the gradual removal of lead from gasoline" from the 1970s to the present time. Two main factors contributed to a change in the use of lead additives in gasoline, leading to the second period: (i) the development in car manufacturing technology that enabled manufacturers to equip their cars with catalytic converters, in response to growing environmental concerns about vehicular emissions; and (ii) the increasing concern about the health impacts of lead, in response to emerging new medical evidence. The first factor resulted in the introduction of unleaded gasoline to protect the catalytic converters, the second led to the gradual decrease in the lead content of gasoline to protect human health. Environmental authorities played a key role in initiating health studies, raising awareness of vehicular emission problems, and pressing for legislation to address these issues.

Countries around the world are at various stages of tackling the problem of human exposure to traffic-related lead emissions. Over 80 percent of countries among the heaviest lead users (with high lead content of gasoline and low market share of unleaded gasoline) are low-income countries (LICs),[1] while close to 70 percent of countries among low lead users (those who phased out leaded gasoline completely, or have low lead content in leaded gasoline and high market share of unleaded gasoline), are high-income countries (HICs) (table 3). *Although a connection can be detected between the income level of countries and their achievements in phasing out leaded gasoline, such achievements have also been strongly influenced by the political commitment of governments to tackle the problem, and policies designed to facilitate the lead phaseout process.*

High-Income Countries

Most HICs have decreased their vehicular lead emissions by reducing or eliminating the lead content of leaded gasoline, and introducing unleaded gasoline. Japan was one of the first countries that started to reduce the lead content of gasoline, responding to concerns about the widespread lead contamination of the atmosphere in Tokyo in 1970. As a result of rapid phaseout of lead from gasoline and the early introduction of catalytic converters that required increasing quantities of unleaded fuel, only 1-2 percent of gasoline contained lead by the early 1980s, and no leaded gasoline has been produced or used in Japan since 1986.

In Canada and the United States, the introduction of unleaded gasoline was initially driven by the intention of protecting the catalytic converters of new cars that were installed to reduce the tailpipe emissions of various pollutants. In this sense, *lead emission abatement was a byproduct of a complex environmental strategy that aimed to set strict vehicle emission standards.*

Table 3 Worldwide use of lead in gasoline

Maximum Allowed Lead in Gasoline	*Market Share of Unleaded Gasoline*		
	Low (0-30%)	*Medium* (30-70%)	*High* (70-100%)
Low (<0.15 g/l)	Bulgaria, Cyprus, Israel, Philippines, Spain	Brunei, France, Hungary, Ireland, Italy, Malaysia, Poland, Portugal, Singapore, Taiwan (China), United Kingdom	*Argentina, Austria, Belgium, Bermuda, Brazil, Canada, Colombia, Costa Rica, Denmark, El Salvador, Finland,* Germany, Guatemala, *Honduras,* Hong Kong, Iceland, *Japan,* Luxembourg, Netherlands, *Nicaragua,* Norway, *Slovak Republic, Sweden,* Switzerland, *Thailand, United States*
Medium (0.15-0.40 g/l)	Bahrain, Egypt, Iran, Ivory Coast, Jordan, Kenya, Lao PDR, Mauritania, Mauritius, Namibia, Paraguay, Qatar, Saudi Arabia, Sri Lanka, South Africa, Turkey, United Arab Emirates, Uruguay, Vietnam	Australia, Ecuador, Greece, Mexico, Russian Federation	
High (>0.40 g/l)	Algeria, Angola, Bangladesh, Benin, Botswana, Burkina Faso, Burundi, Cameroon, Chad, China, Croatia, Cuba, Ethiopia, Gabon, Ghana, India, Jamaica, Kuwait, Lebanon, Liberia, Libya, Madagascar, Malawi, Mali, New Zealand, Niger, Nigeria, Oman, Pakistan, Panama, Peru, Romania, Senegal, Syria, Venezuela, Yemen, Zimbabwe		

Note: Countries in italics have phased out lead completely.
Based on 1993–96 data.
Source: Alconsult, 1996; Octel, 1994; Walsh, 1996a; World Bank reports.

Growing public concern about the health effects of lead reenforced the process and, in addition to the market gains of unleaded gasoline, the lead content of leaded gasoline was also drastically reduced. By 1988, the total lead use in gasoline had been reduced to less than 1 percent of the amount used in the peak years in the 1970s in the United States (Walsh, 1996b). Leaded gasoline was completely phasedout by 1990 in Canada, and by 1996 in the United States.

In the European Union (EU), the regulation of lead levels in gasoline preceded the introduction of unleaded gasoline. While the lead content of gasoline has been regulated since the early 1980s, member countries could not agree until 1987 about equipping all new cars with catalytic converters

(Germany, the Netherlands, and Denmark have put significant pressure on the EU to take a stronger stand on vehicular emission control issues). Current EU regulation sets the maximum lead level of premium grade gasoline at 0.15 grams per liter. Some Western European countries took the initiative to reduce lead much faster than the EU legislation required. Austria, for example, banned lead in gasoline production in 1993. In Sweden, all gasoline became totally lead-free after 1994 (box 6).

Box 6 The Swedish experience with phasing out leaded gasoline

About 80 percent of total atmospheric lead emissions originated from traffic in the late 1980s in Sweden. Recognizing the danger of lead to human health, the Government of Sweden decided to accelerate the phaseout of lead in gasoline in three steps:

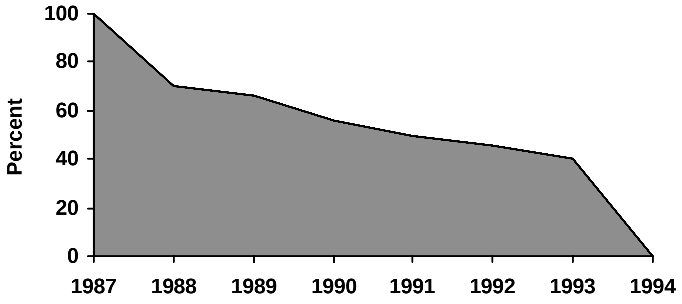
First, the lead content of gasoline was gradually reduced from 1.2 g/l in the 1970s to 0.8 g/l, 0.4 g/l, and 0.15 g/l.

Second, incentives for the production of unleaded gasoline were introduced by differentiated taxes on leaded and unleaded gasoline (the initial tax on unleaded gasoline was lowered by 0.10 SEK per liter in 1986). This measure was expected to level the difference in the production cost of leaded and unleaded gasoline. The initial tax difference, however, was too small to cover the additional investment cost of refinery conversion and the higher production costs of using new additives. The tax difference, therefore, was gradually increased. As a result of tax differentiation and the compulsory introduction of catalytic converters on all new cars from the 1988 model year, the market share of unleaded gasoline increased constantly. The presence of leaded gasoline on the market enabled the owners of older cars to occasionally purchase leaded gasoline, providing their engine had the lubrication necessary to avoid the recession of the soft valve seats of their engines.

In the final stage of the phaseout program, extensive market research preceded the introduction of a totally lead-free gasoline in 1992, which was intended to be used in older cars with soft valve seats. This gasoline contained a sodium additive, replacing the role of lead as lubricant. The tax difference between leaded and unleaded gasoline increased to 0.51 SEK in 1993, creating a 16 percent difference between the prices of leaded and unleaded gasoline. The market responded positively, and the company that first started the production of this unleaded gasoline brand gained significant competitive advantage. All gasoline producers soon followed suit. Since 1994, all gasoline sold in Sweden is unleaded.

The beneficial effects of gradual lead phase-out have been demonstrated. Stromberg et at (1995), have reported a clear statistical relation between the quantity of lead used annually in gasoline in Sweden (1637 tons in 1976, declining to 133 tons in 1993), and the blood lead levels of children with a two-year lag. The geometric mean blood lead levels of more than 2400 children tested in southern Sweden between 1978 and 1994 declined by approximately 60 percent during this time.

Figure 5 Declining market share of leaded gasoline in Sweden, 1987–94



Source: MOENR, 1994.

Box 7 The Brazilian experience with alternative fuels

Brazil achieved the total phaseout of leaded gasoline by 1991. Special circumstances and factors contributed to the approach the Brazilian government selected:

Brazil had become the world's leading sugar producer and exporter by the 16th century. As early as in the 1940s, ethanol produced from sugar canes was used as gasoline additive and blend. An accelerated program of using ethanol as automotive fuel was introduced in the 1970s, with the dual purpose of protecting the sugar industry from falling international sugar prices, and offering an alternative to the import of petroleum during the oil price shocks.

The distillery capacity of sugar mills was expanded followed by a second phase of the alcohol program including the establishment of new independent distilleries. The government supported the research of alcohol-fueled automobiles and the adoption of new technologies by the automobile industry. By the early 1980s, the majority of light vehicle production concentrated on alcohol-fueled cars. Domestic and foreign (Ford, Volkswagen) car manufacturers in Brazil modified their engine designs to adjust to the use of alcohol, allowing to utilize the advantages of alcohol over gasoline in terms of energy efficiency, smaller engine size and weight, and leaner air-fuel mixtures; and preventing the deterioration of vehicle durability due to higher corrosion.

In order to implement the alcohol program, the government provided subsidized loans to producers, and guaranteed markets for ethanol through government purchases at set prices. Additionally, the sales price of gasoline was set at levels that generated large revenues for the government and also encouraged consumers to purchase ethanol. Fuel pricing was one of the decisive factors in the increasing market share of ethanol fuel. When the Brazilian government began to narrow the gap between ethanol and gasoline prices and abolish subsidies to distilleries, a rapid drop of ethanol vehicle purchases followed, and consumer confidence was only regained by restored incentives.

While the Brazilian alcohol program is widely regarded as a success, the highly regulated nature of the government's policy and the use of heavy subsidies leave questions about the economic costs, and the replicability of the program in other countries.

Source: Geller, 1985.

Middle-Income Countries

While still significant amounts of lead can be found in gasoline in some high-income countries (for example, Australia, Kuwait), the use of lead has been completely phased out in a number of middle-income countries (MICs), including Brazil, Colombia, the Slovak Republic, and Thailand. In Brazil, for example, the use of ethanol (a byproduct of the sugar industry) as octane enhancer and alternative fuel was accelerated by government-sponsored programs from the mid-1970s in response to rising oil prices and declining sugar markets (box 7). As a result, the sale of ethanol vehicles significantly increased in Brazil, and leaded gasoline was completely phased out by 1993.

Several MICs (for example, Bulgaria, Hungary) have used differentiated taxation in favor of unleaded gasoline and other incentive measures, such as the compulsory introduction of catalytic converters on all new cars and differentiated duties levied on imported cars according to their pollution characteristics (or age as a proxy). As a result, the market share of unleaded gasoline has increased steadily in many of these countries (in Hungary, for example, it reached 50 percent by 1994).

In many other MICs (for example, Algeria, Iran, Libya, and Venezuela), however, unleaded gasoline has not been introduced to the domestic fuel market, and the use of gasoline with high lead content remains standard practice. The maximum allowed lead content of gasoline is often close to or exceeds 0.8 grams per liter (*Annex A*). Most of these MICs are petroleum-exporting countries with powerful state-owned oil companies and refineries that would possess the necessary technical capacity and resources to rapidly convert to unleaded gasoline production if government policies and regulations required such change.

Some MICs (for example, Tobago, Trinidad, and Venezuela) produce high-octane unleaded gasoline for export, and mainly leaded gasoline for domestic markets, as domestic regulations and demand do not require the use of unleaded gasoline. In some countries, differentiated policies have been applied for densely populated urban areas in order to target high-priority areas and, in some cases, to overcome temporary shortages in domestic unleaded gasoline supply. In Moscow and St. Petersburg, for example, only unleaded gasoline is allowed to be sold, while leaded gasoline is standard elsewhere in the Russian Federation. In Athens, the lead content of gasoline is lower than in the rest of Greece.

Low-Income Countries

The majority of LICs have not started to reduce the lead use in gasoline. On the contrary, the lead content of gasoline was increased significantly in several LICs during the 1970s and 1980s, for example, from 0.22 to 0.56 gram per liter in India, and from 0.58 to 0.84 gram per liter in Uganda. Several LICs (for example, China), however, have the technical capacity to produce unleaded gasoline, often used to produce for export. A few LICs, such as Honduras and Nicaragua, have recently banned the use of leaded gasoline.

Although the share of LICs in global automobile population and fuel consumption stays far behind the share of the rest of the world, their lead emissions represent a serious health concern due to the high lead content of gasoline; the outdated vehicle fleet and low fleet turnovers (10-15 years); and the increasing pace of urbanization and motorization. It is forecasted that by the year 2010, six of the mega-cities (Bombay, India; Lagos, Nigeria; Shanghai and Beijing, China; Karachi, Pakistan; Dhaka, Bangladesh; and Mexico City, Mexico) with populations more than 10 million people will be in LICs.

Additionally, at the same time when motor vehicle ownership has approached saturation levels in OECD countries indicated by the low annual growth rates of motor vehicle fleets (2 percent in the Uniated States and 3 percent in the United Kingdom between 1984 and 1988), vehicle fleets in developing countries have demonstrated high growth (30 percent in the Republic of Korea, 26 percent in Kenya, and 14 percent in China during the same time period) (Faiz, 1990), which is likely to continue. Without significant reforms, vehicular emissions are expected to cause significant health damage, especially in rapidly growing urban areas.

Note

1. Low-income countries are those in which 1993 GNP per capita was no more than $695, middle - income countries are those in which 1993 GNP per capita was more than $695 and less than $8,626, and high -income country groups are those in which 1993 GNP per capita was more than $8,626 (World Bank, 1994c).

Chapter 4

Policy Implications

Experience shows that if political commitment exists and the right policies are applied, a rapid and complete phaseout of leaded gasoline is possible. The process took less than 10 years in Austria, Colombia, the Slovak Republic, Thailand, and Sweden. The political commitment of governments is strongly influenced by their awareness and concern about the health impacts of leaded gasoline. Other factors may include (i) the presence, interests, and political influence of domestic auto manufacturers and oil refineries; (ii) the technical capabilities and competitive position of domestic oil refineries; (iii) external factors such as regulations of neighboring countries and the effects of tourism; and (iv) country-specific factors such as the availability of alternative fuels or additives. The selected policy approach has a significant impact on the cost-effectiveness of lead phaseout programs by influencing a change in consumer behavior, the pace of adjustments in gasoline production capacities, and the allocation of costs.

Historically, the use of catalytic converters has been the main driving force behind the introduction of unleaded gasoline, especially in high- income countries (HICs). Catalytic converters in properly maintained vehicles can very effectively reduce the tailpipe emissions of carbon monoxide, hydro-carbons, and nitrogen oxides, preventing the formation of ozone and photochemical smog, and contributing to improved air quality. In the long term, catalytic converters are likely to become significant means of addressing air quality problems in all urban cities of the world. Currently, however, about half of the car population world-wide does not have catalytic control devices, and the mandated use of such devices is only perceived as immediate priority in some cities and countries in the developing world where the exposure of large urban populations to vehicular emissions of smog and ozone precursors poses a significant health threat.

Additionally, policies that rely only on the increasing use of catalytic converters to reduce traffic-related lead exposures may be ineffective where the vehicle fleet is old, the retrofit of the old vehicles is economically not feasible, and the turnover of the vehicle fleet is slow (box 8). *In order to achieve rapid and significant health improvements by mitigating lead exposures, phasing out lead from gasoline should be carried out separately from the commitment to adopt catalytic converters.*

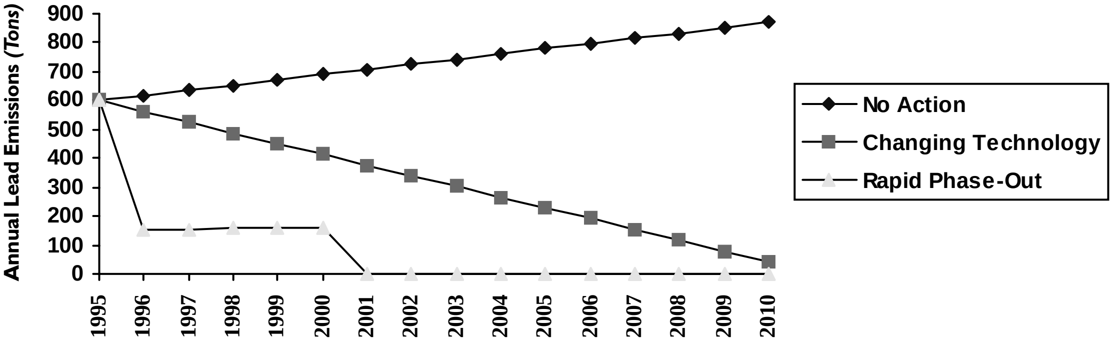
Gasoline Demand—The Role of Fiscal Incentives

During the interim period when unleaded and leaded gasoline brands are simultaneously offered, governments can very effectively influence the composition of gasoline demand by creating price incentives. *Differentiating existing tax rates, or imposing a specific environmental or lead tax on leaded gasoline are measures of corrective taxation, reflecting the differences in health damage caused by leaded and unleaded gasoline brands.*

Box 8 The impacts of various policy scenarios on vehicular lead emissions

A simple model has been used to demonstrate the impacts of various policy scenarios on vehicular emissions of lead. Basic assumptions of the model are: vehicle fleet initially consists of 1 million vehicles with average lifetime of 15 years, increasing by 30,000 vehicles annually; initial lead content of gasoline is 0.6 grams per liter (g/l); gasoline consumption is 1,000 liters per vehicle annually; and no catalytic converters are used.

Figure 6 Vehicular lead emissions under various policy scenarios *(tons)*

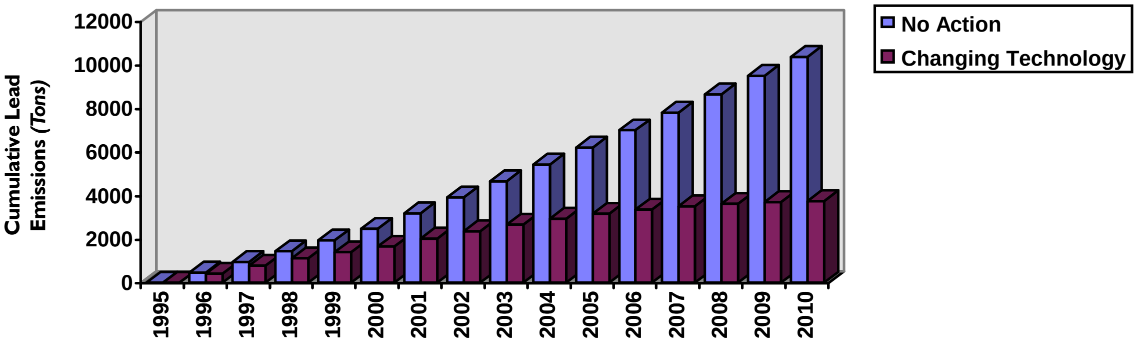


The impacts of three policy scenarios have been assessed on vehicular lead emissions:

- *No Action Scenario*: The lead content of gasoline remains unchanged, and catalytic converters are not introduced;
- *Changing Technology Scenario*: All new cars are equipped with catalytic converters, but the lead content of gasoline remains unchanged; and
- *Rapid Phaseout Scenario:* The lead content of gasoline is reduced from 0.6 g/l to 0 within 6 years.

As demonstrated in figure 6, the *Rapid Phaseout Scenario* results in a significant reduction in annual lead emissions. Figure 7 shows that rapid phaseout of the lead content of gasoline reduces the accumulation of lead in the environment by more than 6,600 tons compared to the scenario when only new cars use unleaded gasoline, while old ones still run on leaded fuel.

Figure 7 Cumulative additional lead emissions compared to the rapid phaseout scenario *(tons)*



Source: Author's calculations.

Incentive fiscal policies have been extensively used in several countries (figure 8). In Brazil, for example, retail price differentiation through taxation proved to be more effective to phase in cleaner fuels than government subsidies assuring the profitability of investments in alternative fuel production (Geller, 1985). Tax differentiation also resulted in significant gains in the market share of unleaded gasoline in several European countries (table 4), despite the slower initial penetration of catalytic converters. There is a clear connection between the level of tax differentiation in favor of unleaded gasoline and its market share (box 9).

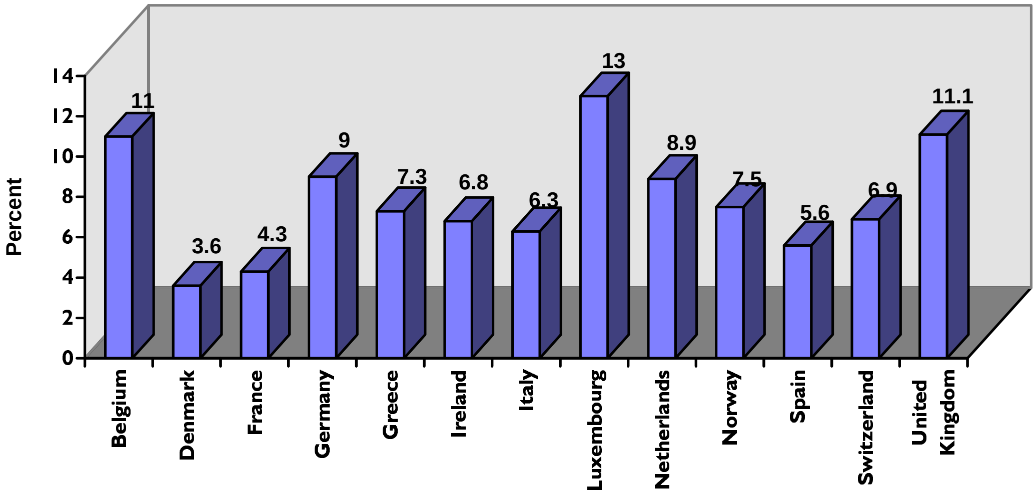
Gasoline taxation may be tailored to support national lead phaseout strategies. In most Western European countries, the initial small difference in the price of leaded and unleaded gasoline was gradually increased, for example, from 1.4 percent to 6.3 percent in Italy, from 6.9 to 11.1 percent in the United Kingdom, and from 1.8 percent to 9 percent in Germany. Widening the price difference before the total phaseout of leaded gasoline may increase the public acceptance of this measure, and smooth the transition. In Austria, for example, the price difference was drastically increased (from 4.2 percent to 9.1 percent between 1991 and 1992) before leaded gasoline was completely phased out in 1993. Sweden pursued similar policies before the total phaseout of all leaded gasoline in 1994 (box 6).

Tax differentiation reflected in gasoline prices in favor of unleaded gasoline not only increases demand for unleaded gasoline, but also reduces the risk of misfueling—the use of leaded gasoline in cars equipped with catalytic converters—that may destroy the converter. Without such tax policies, the effectiveness of costly vehicular emission control measures may be jeopardized. Charging higher prices for unleaded than for leaded gasoline has caused serious problems with intentional misfueling, for example, in the United States and Mexico, demanding significant administrative effort and costs to prevent such practice.

Gasoline Supply Adjustment—Direct Regulations, Market Incentives, and Timing

Direct regulations of the lead content of fuel are justified by the avoided high social costs associated with the use of leaded gasoline, and the need to prevent large future damages due to the accumulative nature of lead contamination. Direct regulations should also ensure that lead is not replaced by other environmentally harmful substances. *The introduction of fuel specifications that limit – and ultimately prohibit – the use of lead in gasoline*

Figure 8 Price difference in favor of unleaded gasoline in European countries, 1995
(Percent of leaded gasoline price)



Note: Based on data for the first three quarters of 1995 for Germany, the Netherlands, Switzerland, the United Kingdom; and the first two quarters of 1995 for Norway.
Source: IEA, 1995.

Table 4 Price difference and the market share of unleaded gasoline in selected European countries

Country	*Price Difference between Leaded and Unleaded Gasoline, 1990-93* (percent)*	*Market Share of Unleaded Gasoline, 1993 (percent)*
Belgium	6.5-11.2	57
Denmark	8.7-15.6**	76
Finland	8.4-15.5	70
France	2.4-6.5	41
Germany	8.2-13.3	89
Greece	6.0-9.7	23
Ireland	3.1-4.8	38
Italy	0-5.6	24
Luxembourg	4.5-16.5	69
Netherlands	4.5-9.2	75
Norway	7.9-10.9	50
Portugal	4.4-7.3	21
Spain	2.1-3.1	14
Switzerland	7.6-8.3	65
U.K.	6.9-9.5	53

* Expressed in percentage of leaded gasoline price, based on retail prices of 95 RON gasoline prices.
** Based on 92 RON gasoline prices.
Source: EDF, 1994; IEA, 1994. Octel, 1994.

Box 9 Determinants of the market share of unleaded gasoline in European countries: Multiple regression analysis

A multiple regression was calculated for 14 European countries using the average price difference between leaded and unleaded (95 RON) gasoline during 1990 and 1993 and the share of car population with soft valve seats in 1993 as independent variables, and the market share of unleaded gasoline in 1993 as a dependent variable (for detailed results, see *Annex B*). The results indicated that the price difference between leaded and unleaded gasoline, and the share of the car park with soft valve seats explain 78 percent of the variation in the market share of unleaded gasoline among these countries.

The following equation describes the relationship among the variables:

$$Y = 61.71 + 3.41X_1 - 1.19X_2$$

Where Y: Market share of unleaded gasoline in a given year;
X_1: Average price difference of leaded and unleaded (95 RON) gasoline during the given and previous two years (expressed as a percentage); and
X_2: Share of cars with soft valve seats in the given year.

According to the equation, a 1 percentage point increase in the average price difference of leaded and unleaded gasoline in a three-year period leads to a 3.4 percentage points increase in the market share of unleaded gasoline by the third year if the share of old cars with soft valve seats in the vehicle fleet does not change.

Source: Author's Calculations.

should be accompanied, therefore, by regulations of the aromatic and benzene content of gasoline in order to limit the potential adverse impacts of lead phaseout programs.

Optimal timing allows refineries to plan their new investments with consideration of lead phaseout requirements. In cases, however, when government policies change suddenly, or do not allow for proper planning of new investments, the timing of lead phaseout investments may become suboptimal. *Clear government policies and a firm lead phaseout schedule, therefore, are essential to ensure the cost-effective timing of refinery investments.* The knowledge of policy targets influences medium- and long-term production and investment planning at the micro level. When a regulatory target is set to phase out leaded gasoline completely within a relatively short period of time, refineries are likely to undertake investments and pursue technical solutions that differ significantly from investments in cases when only intermediate lead reduction levels are announced (intermediate lead reduction levels can often be achieved without capital investments, by using octane-enhancing additives).

Experience shows that direct regulations restricting the lead content of gasoline and clear deadlines for phaseout, combined with market-based policy incentives that influence the timing of refinery investments, allow flexibility in the adjustment of refineries, and lead to cost-effective solutions. This observation applies particularly to periods when the amount of lead in gasoline has to be significantly reduced. In the United States, for example, interrefinery trading and banking of lead credits accelerated the supply-side response to changing market demand and environmental regulations (box 10). However, such arrangements are not likely to be feasible in smaller domestic markets with a less diverse refining sector. In the EU, an agreement was reached to simultaneously reduce in all member countries the octane requirement of new engines from 98 RON to 95 RON, thereby allowing that the burden of technological adjustment be shared between car manufacturers and oil refineries.

The investments necessary to phase out lead often increase productivity and production efficiency, and improve the competitive position of refineries. Under well-functioning free market systems, refineries are usually able to finance the capital costs of investments from commercial sources, and pass the costs on to their customers in increased gasoline prices. In countries where petrochemical markets and prices are centrally controlled and foreign competition is restricted, governments should ensure that gasoline prices reach at least world market prices and provide sufficient incentives for refineries to carry out the switch to unleaded gasoline production. Liberalized foreign trade and free import of unleaded gasoline or gasoline additives also facilitate the adjustment of gasoline supply to the changing demand.

The success of a lead phaseout program ultimately depends on the way broader sector issues are addressed at the macro level. During the 1970s and early 1980s, the global trends of nationalization, strong government control, and increasing public

Box 10 Lead trading and banking in the United States

A lead trading and banking program was introduced in the United States to allow refineries greater flexibility in adjusting to regulations aimed at phasing out lead from gasoline. Lead credits were created on the basis of existing standards and current production levels. Interrefinery trading of lead credits was permitted in 1982, while banking of lead credits was initiated in 1985. Refineries with lower costs of adjustment in refining, storage, transportation, and distribution achieved higher than required lead reductions, earning credits that could be sold to refineries with higher adjustment costs, or banked against future reduction requirements.

An active market developed for lead credits. The U.S. EPA estimated that savings due to the trading program reached $228 million. The economic benefits of the phaseout program were estimated to exceed the costs more than 13 times. The monitoring of the lead content of gasoline, the enforcement of compliance, and an agreement about basic environmental goals were critical factors in the successful implementation of the program.

ownership characterized the petrochemical sector. This led to large operational inefficiencies that were protected by price distortions, subsidies, and foreign trade restrictions. By the late 1980s, it became clear that fundamental sector reforms were necessary. Since then, government policies have shown a general shift from central planning to the reliance on market forces with the aim of improving the economic performance of the petrochemical industry. The reduction of government intervention, elimination of price subsidies, decentralization of management control, and liberalization of trade led to a surge of petroleum enterprise restructuring and privatization in the last decade. Several of the large state oil companies have been either wholly or partially privatized, including YPF in Argentina, ORL in Israel, the Petroleum Authority of Thailand, and Petron in the Philippines. *Improving market conditions and sector restructuring measures are likely to enable and support the lead phaseout process.*

Consensus Building and Public Education

Although the technical process of phasing out lead from gasoline is simple and well understood, *implementing lead phaseout programs is a complex task that requires not only political commitment, but also a broad consensus among various stakeholders, and a wide understanding and acceptance of the public.* At the government level, cooperation of various agencies and ministries, including the ministries of energy, environment, finance, health, industry, transport, and trade, is necessary to agree on measures and policies. The involvement of interest groups (such as associations of car manufacturers and oil refineries), consumer groups (such as auto clubs), and nongovernment organizations concerned about environmental issues can facilitate the dialogue and national consensus. In Bulgaria, for example, an intergovernmental coordinating committee was recently established in order to coordinate among various stakeholders, and work out a national program to phase out leaded gasoline.

Several powerful stakeholders may be involved in the political consensus building process. Besides the oil refining sector, car manufacturers also often have a significant stake in the decisions about lead phaseout policies. In Europe, for example, significant opposition to the universal use of catalytic converters emerged among manufacturers of small cars. The introduction of unleaded gasoline was claimed to favor large vehicle manufacturers that developed hardened valve seat technology early on due to the requirements of their export markets. *A commitment of all vehicle manufacturers to produce vehicles that do not require special gasoline additives, therefore, represents a significant step toward the wide use and general acceptance of unleaded gasoline.* Car manufacturers can also support the phaseout of lead by endorsing in their consumer manuals and warranty the use of unleaded gasoline, and various gasoline additives used to replace lead in gasoline. The use of oxygenates, for example, has been widely endorsed by most large car manufacturers (box 11).

Many countries do not have their own vehicle manufacturing industry. As car technology develops and the use of catalytic converters becomes standard in many countries, most major car manufacturers utilize large economies of scale in producing vehicles equipped with catalytic converters. As a result, vehicle importers that require cars without converters may face higher prices than those buying cars with converters. According to U.S. car manufacturers, the extra cost of removing the catalytic converters and adjusting export vehicle engines to use leaded gasoline could be as costly as $500 per vehicle.

The role of broader environmental policies may be very significant in facilitating the phaseout of lead in gasoline. The taxation of sale, ownership, and import of vehicles according to their pollution characteristics, for example, is likely to accelerate the use of newer vehicles and those equipped with catalytic converters, increasing the demand for unleaded gasoline. Such measures typically require the coordination of environmental, import, and tax policies. The absence of coordination, improper import and tax policies, on the other hand, may slow down the lead phaseout process.

External factors such as tourism and the regional integration of environmental policies may also support the phaseout process. In some countries (for example, Hungary), unleaded gasoline has been introduced to supply the increasing number of Western European tourists visiting the country in

Box 11 Automobile manufacturers endorse the use of oxygenates

Several auto manufacturers have been recommending the use of oxygenates in gasoline due to their enhanced environmental qualities. Examples are:

Auto Manufacturer	*Regarding Gasoline Containing MTBE (by volume)*	*Regarding Gasoline Containing Ethanol (up to 10 volume %)*
BMW	Approved up to 15%	Recommended
Chrysler/Jeep/Eagle	Recommended	Recommended
Ford	Acceptable	Recommended
General Motors	Approved up to 15%	Acceptable
Honda	Approved up to 11%	Recommended
Mercedes-Benz	Approved up to 11%	Acceptable
Toyota	Approved up to 15%	Acceptable
Volvo	Approved up to 15%	Acceptable

Source: OFA, 1994.

cars that required unleaded fuel. Additionally, new and prospective members of the EU have adjusted their gasoline specifications to comply with EU regulations and standards. Similar measures have been adopted, for example, by Mexico under the North American Free Trade Agreement.

Government regulations concerning the lead content of gasoline, and incentive policies allowing refineries to adjust and consumers to change their fueling habits are more likely to succeed if consumers are informed. Information about the neurotoxic impacts of lead in gasoline, especially its impacts on the brain development of children, can be particularly powerful in influencing consumer behavior. Therefore, governments should launch public information campaigns and education programs that explain the danger of using leaded gasoline and the benefits of switching to unleaded.

Concerns about the feasibility of using unleaded gasoline in old cars without catalytic converters should also be addressed by public information. These concerns have been exaggerated without the support of practical or scientific proof, and there is a need to change the perception of the public. Motorists should be advised about the proper use of lubricating additives or the option of intermittent fueling depending on the selected lead phaseout strategy in a country.

Technical modifications of the engines (for example, the replacement of cast head material with hard valve seat inserts) reduce the sensitivity of old cars to the use of unleaded gasoline. Additionally, good car maintenance also reduces the potential adverse effects of unleaded gasoline on old vehicle engines. Therefore, targeted training of auto mechanics and service station attendants is an effective instrument to facilitate the adjustment and maintenance of cars equipped with engines not designed to use unleaded gasoline. Such training can also contribute to the dissemination of information to consumers about proper fueling practices.

Annex A

Worldwide Use of Lead in Gasoline

Table A.1 Indicators of lead use in gasoline
(1996 unless noted)

Countries	*Maximum lead content of leaded gasoline (gram per liter)*	*Market share of unleaded gasoline (percent)*
Africa		
Angola	0.77	0
Benin	0.84	0
Botswana	0.44	0
Burkina Faso	0.84	0
Burundi	0.84	0
Cameroon	0.84	0
Chad	0.84	0
Côte d'Ivoire	0.26	0
Ethiopia	0.76	0
Gabon	0.8	0
Ghana	0.63	0
Kenya	0.4	0
Liberia	0.77	0
Madagascar	0.8	0
Malawi	0.53	0
Mali	0.8	0
Mauritania	0.25	0
Mauritius	0.4	0
Mozambique	0.65	0
Namibia	0.4	0
Niger	0.65	0
Nigeria	0.66	0
Senegal	0.6	0
South Africa	0.4	12
Uganda	0.84	0
Zimbabwe	0.84	0

Asia		
Australia	0.25-0.45 (varies by states)	45 (1994)
Bangladesh	0.8	0
Brunei	0.11	43 (1993)
China	0.33	60
Hong Kong	0.15	80 (1995)
India	0.42	In 4 largest cities
Indonesia	0.45	<1, in Jakarta only (1995)
Japan	0	100
Korea, Rep. of	NA	83 (1992)
Lao PDR	0.4	0 (1993)
Malaysia	0.15	54 (1994)
New Zealand	NA	44 (1995)
Pakistan	0.42	0
Philippines	0.15	10
Singapore	0.15	60 (1994)
Sri Lanka	0.2	0 (1995)
Taiwan (China)	0.15	59 (1994)
Thailand	0.15	100
Vietnam	0.40	0
America & Caribbean		
Argentina	0	100
Bolivia	0	100
Bahamas	0.84	58 (1993)
Barbados	0.79	40 (1995)
Bermuda	0	100 (since 1990)
Bolivia	0	100 (since 1995)
Brazil	0	100 (since 1991)
Canada	0	100 (since 1990)
Chile	0.6	28
Colombia	0	100 (since 1990)
Costa Rica	0	100
Cuba	0.84	0 (1993)
Ecuador	0.50	24
Guatemala	0	100 (since 1991)
Jamaica	0.77	30
Mexico	0.26	56
Nicaragua	0	100
Panama	0.82	93
Paraguay	0.2	1
Peru	0.75	25
United States	0	100
Uruguay	No limit	6
Venezuela	0.85	0

North Africa & Middle East		
Algeria	0.63	0
Bahrain	0.4	0
Egypt	0.8	Introduced recently
Iran	0.19	0
Iraq	0.6	0
Israel	0.15	10 (1994)
Jordan	0.3	0
Kuwait	0.53	0
Lebanon	0.84	0
Libya	0.8	0
Morocco	0.5	0.4 (1992)
Oman	0.62	0
Qatar	0.4	0
Saudi Arabia	0.4	0
Syria	0.4	0
Tunisia	0.5	0
UAE	0.4	0
Yemen	0.45	0
Western Europe		
Austria	0	100 (since 1993)
Belgium	0.15	74
Denmark	0	100
Finland	0	100
France	0.15	62
Germany	0.15	97
Greece	0.4 (0.15 in Athens)	33 (1995)
Iceland	0.15	85
Ireland	0.15	65
Italy	0.15	44
Luxembourg	0.15	82
Netherlands	0.15	86
Norway	0.15	98
Portugal	0.4	39
Spain	0.4	23
Sweden	0	100 (since 1994)
Switzerland	0.15	87
Turkey	0.4	18
United Kingdom	0.15	67
Central & Eastern Europe		
Bulgaria	0.15	5
Croatia	0.6	30
Czech Republic	0.15	55
Hungary	0.15	64
Moldova	0.4	0
Poland	0.15	70
Romania	0.6	6
Russian Federation	0.6	50
Slovak Republic	0	100 (since 1995)

Note: NA = not available.

Sources: Alconsult, 1996; EDF, 1994; IEA, 1996; NRDC, 1994; OAPEC, 1996; Octel, 1994; Walsh, 1996; World Bank reports; personal communication with Government officials.

Annex B

Determinants of the Market Share of Unleaded Gasoline in European Countries: Data and Results of a Multiple Regression

Table B.1 Regression input data

	Average price difference of leaded and unleaded (95 RON) gasoline, 1990-93, (percent) X_1	*Share of car population with soft valve seats, 1993 (percent)* X_2	*Market share of unleaded gasoline, 1993 (percent)* Y
Spain	2.6	41	14
Italy	3.5	43	24
Ireland	3.9	37	38
France	4.5	44	41
Portugal	6.5	36	21
Netherlands	7.1	25	75
Greece	7.6	42	23
Switzerland	7.9	14	65
United Kingdom	8.2	36	53
Belgium	9.4	25	57
Finland	11.7	24	70
Luxembourg	12.0	23	69
Denmark	13.4	31	76

Source: EDF, 1994; McArragher et al., 1993; Octel, 1994.

Table B.2 Regression statistics

Multiple R	0.884862849
T Square	0.782982262
Adjusted R Square	0.743524491
Standard Error	12.25860964
Observations	14.0

Source: Author's calculations.

Table B.3 Analysis of variance

	df	*SS*	*MS*	*F*	*Signif. F*
Regression	1	5963.919959	2981.95998	19.84355	0.0002242
Residual	12	1653.008612	150.2735102		
Total	13	6516.928571			

	Coefficients	*Standard Error*	*t Stat.*	*P Value*
Intercept	61.71050033	23.27676605	2.651162975	0.02254
X Variable 1	3.407831912	1.266421163	2.690915165	0.020995
X Variable 2	-1.191643145	0.477921812	-2.49338514	0.029855

Source: Author's calculations.

Annex C

The World Bank's Role in the Global Phaseout of Leaded Gasoline

Lead phaseout programs require the cooperation of several government agencies. Based on its multisectoral expertise, the World Bank is well positioned to play a catalytic role by assisting governments to (i) determine the priority assigned to the reduction of lead exposures; (ii) design and adopt appropriate policies to support the phaseout of leaded gasoline; and (iii) facilitate the implementation of these policies.

Phasing out leaded gasoline typically requires capital investments in refineries. Ideally, these investments should be commercially funded, however, that is not always the case. Investors are frequently deterred by the perceived risk of changing government policies. The World Bank can facilitate private financing and reduce the perceived risk in these cases through direct lending and guarantees. The Bank can also assist countries in facilitating the reform of the petrochemical sector through structural adjustment loans and policy advice.

Due to the World Bank's credibility, Bank lending covering part of the investment cost frequently attracts other investors. In Thailand, for example, less than one-third of the investment cost of refinery investments were financed by the Bank. Internally generated cash and commercial financing sources covered the remaining costs (box C.3).

The use of World Bank guarantees is another way of facilitating private participation in oil refinery investments. Such guarantees are mainly used in cases when governments remain involved in the sector even after privatization takes place. Government involvement may include regulation (for example, fuel specification) that affects the operation of private enterprises in the sector, or the provision of inputs and/or the sale of outputs. Due to the Bank's position to influence government policies, the Bank is well suited to provide guarantees against the consequences of government regulations and policies that the private sector is not expected to absorb. Since "government performance risk" is an important deterrent for private investors, the reduction of this risk facilitates commercial financing.

Box C.1 Setting priorities: Addressing the lead issue in Bank reports

Several Bank reports have assisted policymakers with pointing out the importance of addressing vehicular lead emissions as a high environmental priority:

In *Indonesia*, where the number of motorized vehicles more than doubled during the 1980s, and about one-third of the vehicles are concentrated in urban areas, vehicle emissions constitute the main source of air pollution in cities. A Bank study (Ostro, 1994) suggested that reducing ambient lead concentrations to WHO standards could prevent more than 60,000 cases of hypertension, close to 70 cases of heart attacks, and almost 60 cases of premature mortality annually in Jakarta. The public health costs of lead pollution in Jakarta were estimated between US$40 million and 97 million in 1990 and, as part of a comprehensive urban environmental program, lead phaseout measures were recommended (World Bank, 1994a).

The *Philippines Environmental Sector Study* (World Bank, 1993) assessed the economic costs and benefits of addressing various environmental problems, and gave high priority to phasing out leaded gasoline. The study suggested that lead levels of 0.6 g/l for premium gasoline and 0.3 g/l for regular gasoline be drastically reduced, and unleaded gasoline introduced.

In *Thailand*, the exposure of the rapidly growing urban population to lead emissions has been identified as one of the most serious health problems associated with environmental pollution. Bank reports (World Bank, 1992a, 1994b) pointed out that almost all lead emissions originated from motor vehicles, and estimated that vehicular lead emissions increased by an average rate of 9 percent between 1982 and 1992. The average blood lead levels of tested populations reportedly reached about 15-27 µg/dl in Thailand, and 40 µg/dl in Bangkok.

The sector study on *Transport Sector Air Quality Management in the Mexico City Metropolitan Area* (World Bank, 1992b) pointed out the population's high exposure to lead, indicating that traffic was one of the contributing sources. Changes in gasoline pricing policies (higher prices for unleaded gasoline caused problems with misfueling) were suggested in order to provide incentives for consumers to buy unleaded gasoline.

The *Middle East and North Africa Environmental Strategy* (Hertzman, 1995), prepared with the assistance of the Bank, estimated that about 80-90 percent of lead emissions originated from the use of leaded gasoline in the countries of North Africa and the Middle East. The report noted the high toll of lead exposures on children's intellectual development (for example, a more than 4 average IQ point loss in Cairo), premature deaths, and heart attacks. The study called for the phaseout of lead from gasoline as a cost-effective measure.

A Bank study dealing with environmental health problems (World Bank, 1994c) in *Central and Eastern Europe* (CEE), and the *Environmental Action Programme for Central and Eastern Europe* (World Bank and OECD, 1993) pointed out the priority of tackling lead emissions from stationary and mobile sources in the region. The contribution of vehicular transport to elevated blood lead levels of the inhabitants of several cities has been highlighted in these reports. Follow-up studies managed by the Bank (Lovei and Levy, 1995; and Hirshfeld and Kolb, 1995) assessed the impacts of lead phaseout measures on human health, and the feasibility and costs of reducing lead in gasoline, highlighting the advantages and cost-effectiveness of these measures.

Box C.2 Raising awareness and political commitment: International support and regional programs

The World Bank has actively supported governments and environmental and other organizations in their efforts to phaseout lead from gasoline: The *International Workshop on Phasing Lead Out of Gasoline* hosted by the Governments of the United States and Mexico held in Washington, D.C., March 14-15, 1995, was co-sponsoerd by the World Bank. It was the first large international gathering devoted exclusively to addressing the complex issues related to the removal of lead from gasoline. Countries from around the world gathered and shared their views, experiences and achievements.

The U.N. Commission for Sustainable Development discussed and formally endorsed the results of the International Workshop in a meeting on *The Global Phaseout of Leaded Gasoline* on April 12, 1995, in New York, urging countries to develop action programs to meet this goal.

The *International Conference on Heavy Metals and Unleaded Gasoline* hosted by the Government of the Slovak Republic on September 7-8, 1995, in Banska Bystrica, Slovak Republic, addressed issues of the hazards of heavy metals and practical measures to phase out lead from gasoline in Central and Eastern Europe.

A regional program to phase out lead from gasoline was initiated by the Government of Bulgaria during the *Central and Eastern European Environment Ministers' Conference* on October 23-30, 1995, in Sofia, Bulgaria ("Sofia Initiatives"). The Bank contributed to the conference with several publications and studies on this issue.

The Committee on Euorpean Policy of the UN Economic Commission for Europe (U.N.-ECE) initiated the preparation of a pan-European strategy to phase out lead from gasoline. In order to support this work, a *Task Force to Phaseout Lead in Gasoline* was established on the initiative of the Danish Ministry of Environment.

During the *Summit of the Americas Intergovernmental Technical Experts Meeting on the Partnership for Pollution Prevention* on November 6-8, 1995, in San Juan, Puerto Rico, the Bank initiated a joint program with several other agencies and organizations (including the Pan-American Health Organization, U.S. EPA, U.S. Department of Energy, Inter-American Development Bank, the Canadian CIDA, and the Organization of American States), to support the preparation of National Plans for the phaseout of leaded gasoline in Latin America and the Caribbean.

During the *U.N. Conference on Human Settlements* (*Habitat II*) held in Istanbul, Turkey, on June 3-14, 1996, the World Bank issued a statement calling for the global phaseout of leaded gasoline, urging countries worldwide to make a political commitment and take steps to accelerate the elimination of lead from gasoline.

Box C.3 Supporting the implementation of lead phaseout: The example of Thailand

In response to evidence showing the serious health impacts of lead and other vehicular emissions in the late 1980s, the Government of Thailand became strongly committed to addressing the problem.

The Bank provided support to improve air quality as part of its lending for the road sector *(Third and Fourth Highway Sector Projects* in 1990 and 1992a) by assisting the Government of Thailand to strengthen regulatory institutions, build up an ambient air monitoring network, set ambient standards, vehicle emission and fuel standards, and introduce vehicle emission testing. The Bank was involved in an extensive dialogue with the Thai government about the formulation and implementation of cost-effective policies for air quality improvement, and providing analytical support and financing for the government's Action Plan to reduce air pollution. In addition, the Bank worked closely with the key agencies involved in developing the government's clean fuel standards.

The Thai government adopted a rapid phaseout strategy: in 1990, the maximum lead content in gasoline was set at 0.4 grams per liter; in May 1991, unleaded gasoline was introduced; in September 1992, the maximum lead content in all gasoline was lowered to 0.15 grams per liter; and by the end of 1995, the use of lead in gasoline was banned altogether.

Government regulations to eliminate lead and to reduce the aromatic and benzene content and vapor pressure of gasoline were part of a comprehensive program that required changes in the three refineries of the country. After a successful restructuring of the Bangchak Petroleum Refinery (*Bangchak Oil Refinery Restructuring Project,* World Bank, 1985) that enhanced production efficiency and facilitated the partial privatization of the refinery, the Bank has provided financing for the *Clean Fuels and Environmental Improvement Project* (World Bank, 1995b) to meet the government's fuel quality requirements. The deregulation of oil prices, and removal of restrictions for private sector investments in the refinery sector in 1992, facilitated the rapid adjustment of refineries to changing conditions.

The fuel reformulation program of the Thai government has been very effective and resulted in significant reductions in lead emissions. About a year after its introduction, unleaded gasoline increased its market share to about 18 percent, and within four years, vehicular lead emissions were eliminated.

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