The Case for Banning Lead in Gasoline

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Manufacturers of Emission Controls Association
1660 L Street, NW ❖ Suite 1100 ❖ Washington, DC 20036 ❖ tel: (202) 296-4797 ❖ fax: (202) 331-1388

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Preface

Leaded gasoline presents a serious inherited public health problem thrust upon the leaders of this generation. This paper makes the health, technical, economic, and moral case for those leaders to act to ban leaded gasoline. The paper focuses on the following points:

- *Airborne lead is a cumulative neurotoxin inhaled and ingested by humans, adversely affecting the mental and physical health of children, and causing elevated blood pressure, hypertension, and other cardiovascular conditions in adults.*

- *Unleaded gasoline, known as a clean fuel, makes economic sense as it improves engine and component durability and reduces maintenance costs.*

- *Those supplying lead for gasoline argue that unleaded gasoline contributes to valve wear and higher benzene emissions and, therefore, justifies the continued use of leaded gasoline. Countries that have eliminated lead in gasoline have considered and rejected these arguments.*

- *There is economic justification to switching immediately to 100% unleaded gasoline. China, India, Vietnam, and Central American countries successfully implemented this approach.*

Unleaded gasoline is now used in much of the world, but leaded gasoline still remains in many populous world countries and major world cities. Eighty percent of airborne lead comes from combustion of leaded gasoline, and airborne lead is found responsible for adversely affecting the mental and physical development of children. Many countries, putting health costs into the equation, have realized economic benefits from the conversion to unleaded gasoline.

0.0 EXECUTIVE SUMMARY

0.1 Effects of Leaded and Unleaded Gasoline on Human Health

A number of highly respected health studies have confirmed the serious health threat posed by leaded gasoline, even at very low levels. Lead is a cumulative neurotoxin that adversely affects the mental and physical development of children and causes elevated blood pressure, hypertension, and other cardiovascular conditions in adults.

Studies have conclusively correlated levels of lead in gasoline to elevated lead blood levels and have found that decreasing lead in gasoline causes blood lead levels to fall.

The introduction of unleaded gasoline, and subsequent decrease in blood lead levels, have a significant economic value, primarily in the form of avoided health care costs and wage losses due to lower intelligence and illness. For instance, one study concluded that a one microgram per deciliter reduction in blood lead level for one year's cohort of children (all children born in the same year) translated to a gain of approximately US $6.9 billion.

0.2 Effects of Unleaded and Leaded Gasoline on Vehicle Components

Unleaded gasoline is a clean fuel that does not produce the typical leaded gasoline corrosive compounds. The vehicles' maintenance savings from unleaded gasoline use significantly outweigh any potential negative side effects, such as valve wear, if any, on a few older susceptible pre-1980 engines.

Estimates of leaded gasoline vehicle maintenance costs range around US $0.189 per gallon (US $0.05 per liter) of gasoline. The components formed in leaded fuel combustion are corrosive and harm engines, spark plugs, and exhaust systems. Conversely, unleaded gasoline extends spark plug life from 6,000 miles to above 50,000 miles, extends oil change intervals by a factor of two to four and results in less engine and exhaust system corrosion. Engine life was predicted to be increased by 50%. In fact, engine life achieved in actual road use with unleaded gasoline is frequently above 200,000 miles and sometimes, in applications like taxis, above 400,000 miles. Leaded gasoline, even in trace amounts, deactivates the catalytic converter used for emissions control. Additives used to prevent the accumulation of lead in the combustion chamber cause lead to stick to active catalyst sites, deactivating them.

0.3 Options for the Elimination of Leaded Gasoline

Approach #1:

Immediate, 100 percent conversion from leaded gasoline to unleaded gasoline. This is the most cost effective and health effective approach. It avoids the huge cost of an additional gasoline distribution system because the existing gasoline station tanks and pumps are used and achieves elimination of ambient lead in the shortest time. This approach was taken by China starting in 1997. China took the 100 percent conversion approach city by city, starting with Beijing, and province by province so that in two years the entire country was practically lead-free. In India, the city of Delhi converted to 100 percent unleaded gasoline in September 1998 and followed the same approach as China – now India is also completely lead-free. El Salvador went from over 90 percent leaded gasoline in 1995 to 100 percent unleaded gasoline in 1996 – all Central American countries are now 100% lead-free. Finally, after one year of preparation, Vietnam switched to 100 percent unleaded gasoline on July 1, 2001. This relatively new but proven approach appears perfect for remaining countries now using leaded gasoline and considering its cessation. It is especially attractive for African countries that import 'pre-owned vehicles' that are already equipped with functioning emission control systems.

Approach #2:

Rapid phase-out of leaded gasoline by incrementally reducing lead concentrations from higher to lower levels, followed by the introduction of unleaded gasoline and then the banning of lead. This gives more time for refinery upgrade, but requires a very expensive dual distribution infrastructure for a period of time and takes four to six years to obtain zero lead levels. This approach was taken by Thailand. In retrospect, Thailand officials indicated that a 100 percent lead-phase out would have been the better approach for their country.

Approach #3:

Phase-in unleaded gasoline to coincide with introduction of new vehicles designed for that fuel, and **phase-out** leaded gasoline as older vehicles are retired. The United States and Canada used this approach, but it took 20 years, which is too long. Catalytic converters were a new technology and time was needed to establish the effectiveness of this technology. Also, the impact of using unleaded gasoline on vehicles designed to operate on leaded gasoline needed to be assessed. Neither of these factors is relevant today. The effectiveness of catalyst technology is proven and, as is discussed in more detail below, using unleaded gasoline in vehicles previously operated on leaded gasoline lead is not an issue today.

0.4 Issues and Solutions Concerning Unleaded Gasoline Use

Excessive valve wear of older engine designs is still cited as a reason to maintain a leaded gasoline supply. (Note: valve wear also occurs with leaded gasoline). Actual experience with using unleaded gasoline in older vehicles demonstrates this argument is both faulty and misleading. No such in-use engine problem has ever occurred with U. S. older design engines operated on unleaded gasoline. The reason for this is that U.S. engines designed for leaded gasoline required valve rotation of approximately 6-rpm to avoid accumulation of lead deposits on the valve seating surfaces. For instance, many such older engines used unleaded gasoline marketed by Amoco since the 1940s without valve seat problems and enjoyed all the advantages of unleaded gasoline. Valve wear also has not occurred in China, India, Vietnam or Thailand where all older design engines are now operating with unleaded gasoline. Valve wear did not occur in any of the Central or South American countries that have switched over from leaded to all unleaded gasoline. One Japanese carmaker did encounter valve recession concurrent with the introduction of unleaded gasoline in Japan in the mid-1970s. The reason was that this engine maker incorporated an advanced engine design change from 6-rpm to 12-rpm valve rotation almost concurrently with introduction of unleaded gasoline in Japan. Once discovered, the engine valve rotation was returned to 6-rpm and there was no longer any problem. Such mid-1970 Japanese automaker model engines are mostly retired. U.S. manufacturers installed Stellite valve seats [31] on all engines since 1971, thus greatly improving resistance to valve wear. Other manufacturers followed this engine design improvement. Although valve rotation was introduced to remove valve seat lead deposits, it could be considered as unnecessary with unleaded gasoline. However, engine designers have found that a certain amount of valve rotation without excessive wear is beneficial to maintain optimal valve closure.

Octane enhancement is also not a problem. Many efficient refinery procedures exist that can cost-effectively increase the octane rating of gasoline without using lead.

Benzene emissions are to be avoided – the concern is that some refinery processes used to increase the octane rating of unleaded fuel might cause increases in emissions of the aromatic gases. However, many cost-effective refinery techniques exist that increase the octane number without increasing benzene emissions. Oxygenated hydrocarbon additives such as ETBE are an effective octane additive*. In fact, the World-Wide Fuel Charter [25] has set benzene specification limits for all four categories of gasoline. Many countries are adopting these recommendations. Furthermore, vehicles equipped with catalytic converters destroy 90 to 95% of benzene and other aromatics in the exhaust stream.

*Note: Metal based octane enhancer additives should not be used. One such additive, called MMT, has raised concerns among health experts and its combustion products interfere with catalytic emission control devices, shorten sparkplug life and has been found to have a negative effect on fuel economy (see discussion at Part 4.3.2).

0.5 Costs of Producing and Using Unleaded Gasoline

The most significant costs incurred in removing lead from gasoline are the cost of alternate octane values and modifying refinery production facilities. Estimated costs of eliminating leaded gasoline range widely from less than $0.005 per gallon to $0.076 per gallon. One study considered a majority of refineries and estimated a modest range of only US $0.038-0.076 per gallon (US $0.01-0.02 per liter) of gasoline and where the associated refinery upgrade cost pays for itself in a short period through increases in productivity and efficiency.

0.6 Worldwide Experience with Regulating Lead

Countries around the world are at various stages of tackling the problem of human exposure to lead emissions (See Appendix I). In 1996. The World Health Organization had called for a lead ban by 2001. Progress has been made. Unfortunately, over 100 countries in some areas in the world still utilize this fuel despite indisputable evidence confirming that lead in gasoline jeopardizes children's health and negatively impacts engine life. The United States began to phase out leaded gasoline in 1970 and it took 20 years to completely eliminate it. Since 1975, many countries have introduced unleaded gasoline, including Japan, Canada, Mexico, Central and South America, all of Western Europe, Korea, Australia, China, Thailand, Vietnam, the Philippines and Taiwan. In the United States, health concerns of leaded gasoline peaked about the same time as the need to clean up pollution from automobiles. In other countries, the regulation of lead levels in gasoline because of health concerns preceded the widespread use of catalytic converters to clean up automobile exhaust pollution.

The 3rd edition of World-Wide Fuel Charter (WWFC), December 2002, included a key change for all gasoline fuel specification categories, calling for the elimination lead in fuel worldwide to avoid potential health risks and damage to catalysts. Automakers and engine manufacturers around the world support efforts to end the use of lead in gasoline [25].

In 2001, seventeen Sub-Saharan African countries signed a resolution known as the 'Dakar Accord' agreeing to the cessation of leaded gasoline in their respective countries by 2005.

At the World Summit for Sustainable Development held in South Africa during August-September 2002, a Clean Fuels and Vehicles Partnership was formed. One goal of the partnership is to end leaded gasoline in the world by 2005. Signatories to the global partnership include the United Nations Environment Program (UNEP), the United Nations Department of Social and Economic Affairs, Canada, Chile, the Central American Commission on Environment and Development (Costa Rica, Panama, Nicaragua, El Salvador, Honduras, Guatemala, and Belize), Italy, Mexico, Netherlands, South Africa, the United States and China. About 15 industry and non-governmental organizations have also joined the partnership.

0.7 Conclusions

The ban of leaded gasoline provides immediate and significant human health benefits and reduced vehicle maintenance costs. The recommended and most effective policy approach in working towards the removal of lead in gasoline is an **immediate 100 percent conversion** to unleaded gasoline. If that is not possible, the more costly rapid **phase-out-of-lead** approach can be used. All issues raised by lead supporters have easy and cost effective solutions and are vastly outweighed by the well-documented health and vehicle-related benefits. Each country needs to formulate a plan for banning leaded gasoline that reflects the needs and recommendations of its parent/teacher groups as well as of those of health organizations, industry and international partnership coalitions. Protection of children's mental development is paramount and dictates the approach all countries must take. Leaded gasoline must be eliminated with all possible speed.

1.0 INTRODUCTION

In those countries where leaded gasoline is still widely utilized, it is the primary source of human lead exposure. Leaded gasoline produces airborne lead compounds that are inhaled and ingested resulting in a steady accumulation of lead within the body. Many nations have switched to unleaded gasoline and have avoided this serious situation. However, other nations still use leaded gasoline as the main fuel for the spark-ignited engines used in passenger cars, light-duty trucks, two-wheeled vehicles, and off-road SI engines used in materials handling equipment as well as lawn and garden equipment. Consequently, the people of these nations suffer unnecessary and serious health effects. Leaded gasoline has serious negative effects on health and the environment. The accumulation of lead in the body, known as the human lead burden, has been found to pose a significant risk to humans even at very low levels. The major source of human lead accumulation in developing countries was found to be airborne lead, 90 percent of which comes from leaded gasoline [12]. The World Health Organization has determined that over a billion humans still suffer health problems due to this source of lead and has called for the complete elimination of leaded gasoline. Lead in gasoline also severely limits exhaust emissions control options because it completely destroys the effectiveness of catalytic converters, the most commonly used exhaust emissions control system. For both reasons, a growing number of nations around the world have moved, or are moving, to completely eliminate lead in gasoline. Although the negative impact on health and emissions control is well known, leaded gasoline is still widely used in a number of countries worldwide. Leaded gasoline remains a transportation fuel partly because several easy and cost effective ways to quickly switch to unleaded gasoline are not fully understood and because the Tetraethyl Lead (TEL) industry, which makes billions of dollars in profits from selling lead for use in gasoline, continues to actively promote its use.

This paper presents the case for quickly and cost-effectively eliminating lead in gasoline for all countries still using leaded fuel. Lead impairs children's intellectual development and hurts their chances to compete in the ever-expanding global economy. Nations rely on the next generation of children for their future, and by harming children, the use of leaded gasoline puts future economic and social advancement in jeopardy. MECA considers protection of children's health, welfare, and intellectual development <u>the most important reason</u> to remove lead from gasoline.

By contrast, opposing arguments stating that lead is necessary to protect old automobile engines are grossly exaggerated. Even for these old engines, the overall cost benefits of lead elimination are positive. The argument that benzene emissions will increase if unleaded gasoline is used for old vehicles is equally flawed. A quick and complete ban on lead in gasoline for all nations still utilizing leaded gasoline is the most beneficial and cost-effective course of action.

Since the introduction of unleaded gasoline in the United States, airborne lead has been reduced by more than 95% – a major achievement in air quality improvement.

A growing number of countries have or are moving rapidly towards 100 percent unleaded fuel. (See Table 1). Indeed, great progress has been made in the last five years as a growing number of countries are replacing leaded gasoline with unleaded gasoline (see Table 2). Unfortunately, a significant number of countries still use gasoline with lead added (see Table 3).

Table 1
Unleaded Gasoline Sales Only

North America	Caribbean Sea	Central America
Bermuda	Antigua	Belize
Canada	Barbuda	Costa Rica
Mexico	Bahamas	El Salvador
United States	Dominican Republic	Guatemala
	Haiti	Honduras
	Jamaica	Nicaragua
South America	Puerto Rico	Panama
	Saba	
Argentina	St. Eustasius	
Bolivia	Trinidad & Tobago	Africa
Brazil	U.S. Virgin Islands	
Colombia		Egypt
Ecuador		Malawi
Paraguay	Europe	Western Sahara
	Austria	
Asia	Belgium	Middle East
	Czech Republic	
Bangladesh	Denmark	Bahrain
Bhutan	Finland	Georgia
Brunei	France	Israel
China (People's Republic of)	Germany	Kuwait
Hong Kong	Great Britain	Oman
India	Hungary	Saudi Arabia
Japan	Iceland	Syria
Kazakhstan (Republic of)	Ireland	United Arab Emirates
Macau	Liechtenstein	
Malaysia	Luxemburg	
Mongolia	Monaco	Indian Ocean
Nepal	Netherlands	
Pakistan (Islamic Republic of)	Norway	Madagascar
Philippines	Poland	
Singapore	Portugal	
South Korea	Slovakia	Pacific Ocean
Sri Lanka	Sweden	
Taiwan	Switzerland	Australia
Tajikistan		Guam
Thailand		New Zealand
Vietnam (Socialist Republic of)		Tasmania

Table 2
Leaded Gasoline Being Replaced By Unleaded Gasoline

South America	Europe	Africa
Chile	Albania	South Africa
Cuba	Andorra	
French Guiana	Belarus	
Guyana	Bosnia & Herzegovina	Asia
Peru	Bulgaria	
Suriname	Croatia	Kyrgyzstan (Republic of)
Uruguay	Estonia	Turkmenistan
Venezuela	Greece	Uzbekistan (Republic of)
	Italy	
	Latvia	
	Lithuania	Middle East
	Macedonia	
	Malta	Armenia
	Moldova	Azerbaijan (Republic of)
	Romania	Cyprus
	Russia	Gaza Strip
	San Marino	Qatar
	Spain	Turkey
	Slovenia	West Bank
	Ukraine	
	Vatican	
	Yugoslavia	

Table 3
Mainly Leaded Gasoline

Africa	Africa Cont'd	Asia
Algeria	Madagascar	Afghanistan (Islamic State of)
Angola	Mali	Indonesia (Republic of)
Benin	Mauritania	Kampuchea (Cambodia)
Botswana	Mauritius	Laos
Burkina Faso	Mayotte (Fr.)	
Burundi	Morocco	
Cameroon	Mozambique	Middle East
Cape Verde	Namibia	
Central African Republic	Niger	Iran
Chad	Nigeria	Iraq
Comoros	Reunion (Fr.)	Jordan
Congo	Rwanda	Lebanon
Cote d'Ivoire	Sao Tome and Principe	Syria
Democratic Rep. of the Congo	Senegal	Yemen
Djibouti	Seychelles	
Equatorial Guinea	Sierra Leone	
Eritrea	Somalia	Indian Ocean
Ethiopia	Sudan	
Gabon	Swaziland	Madagascar
Gambia	Tanzania	
Ghana	Togo	
Guinea	Tunisia	
Guinea-Bissau	Uganda	
Kenya	Western Sahara	
Lesotho	Zambia	
Liberia		
Libya		

2.0 ADVERSE IMPACTS OF LEADED GASOLINE VS. THE POSITIVE IMPACTS OF UNLEADED GASOLINE

2.1 Adverse Health Effects of Lead

The adverse health effects of exposure to lead have been known for centuries. When lead was introduced in gasoline in the late 1920s, the knowledge of the lead exposure health risks sparked a growing concern among scientists and others. The subsequent health risk studies were one of the primary reasons the United States decided to switch to unleaded gasoline in 1970.

Since then, many highly respected scientific studies have confirmed the seriousness of the threat posed by lead. These studies have reported several significant health threats resulting from both low and high blood lead levels, including neurodevelopmental effects in children and increased blood pressure and related cardiovascular conditions in adults [3]. Lead has also been identified as a possible carcinogen. Of these three effects, health experts view the neurodevelopmental effects of lead exposure to unborn children and small children as the most significant public health hazard [3].

Worldwide, a large number of health and government agencies, including the World Health Organization, the U.S. Environmental Protection Agency, the International Agency for Research on Cancer, and the California Air Resources Board (which in April 1997 identified inorganic lead as a toxic air contaminant), have determined that lead poses a serious health hazard [3]. The scientific evidence and concern for health risks posed by lead have caused a growing number of countries to ban lead in gasoline (see Table 1 above).

2.1.1 Measuring Lead Levels in Humans

Human lead levels are measured by an analysis of teeth, bone, and/or blood. Teeth and bone are cumulative indicators of lead exposure. Cumulative indicators show the degree to which a person has been exposed throughout his or her life. In the case of teeth, lead concentrates in tooth dentine. Needleman [14] and others have studied dentine lead levels by analyzing shed children's baby teeth.

Measurement of blood lead levels, or the concentration of lead in blood (measured in micrograms per deciliter, µg/dL), is more representative of recent exposure (within the past 3 months), while simultaneously indicating cumulative exposure (since some lead is mobilized in the blood from bone and other storage areas) [3]. A study by Billick found that blood lead increased and decreased with the seasonal use of leaded gasoline [2].

2.1.2 Neurodevelopmental Effects in Children

Studies have shown the adverse neurodevelopmental effects lead exposure has on children. Some have concluded that children with elevated levels of lead accumulated in their baby teeth, even with relatively low levels of lead in their blood, experience more behavioral problems, lower intelligence quotients (IQ), and more concentration problems than their counterparts without significant lead accumulation [14, 23]. One study found that children with prenatal umbilical-cord blood lead levels at or above 10 µg/dL consistently scored lower on standard intelligence tests than those with lower levels of lead [3].

Several factors make children more susceptible to lead exposure than adults:

- Children easily assimilate lead in the stomach, resulting in greater distribution levels throughout the body.
- Children possess greater metabolic rates, resulting in a higher intake of lead through food.
- Children have greater neurological sensitivity.
- Children have a higher breathing frequency through the mouth and tend to be more active which translates to greater volumes of air (with airborne lead) inhaled during the course of a day.
- Children have a higher hand-to-mouth frequency resulting in higher ingestion rates of lead deposited on various surfaces.

These inherent characteristics of children require that special attention be given to the potential of child lead exposure.

Economically disadvantaged children are highly susceptible to lead exposure. Often they reside in urban areas where the general population has higher than average lead exposure levels and play in places where nearby road traffic emits high levels of airborne lead. Poorer children are also likely to have diets deficient in lead-suppressing minerals, such as calcium and iron, which makes them more vulnerable to lead exposure [3].

2.1.3 Relationship between Leaded Gasoline and Blood Lead Levels

Studies from the mid-1970s to the present have shown the relationship between decreases in airborne lead levels and blood lead levels in humans. Scientists recognize these two trends and are confident that they are significantly correlated.

The U.S. Center for Disease Control (CDC) used evidence from two cross-sectional surveys, versions of the National Health and Nutritional Examination Survey (NHANES), to investigate the distribution of blood lead levels in the U.S. population. The results showed a 78% decline in blood lead levels for persons aged one to 74 years of age in the 10 years between the surveys. Data from the NHANES II survey, conducted between 1976 and 1980, suggests that approximately 88.2% of children aged one to five exhibited a blood lead level greater than or equal to 10 µg/dL during this period. Subsequently, NHANES III reported that only 8.9% of the same age group showed such high blood lead levels between 1988 and 1991. Similar declines were found in other subgroups determined by race, ethnic background, gender, urban status, and socio-economic levels.

This substantial reduction in overall blood lead levels in the U.S. coincided with a decline in lead exposure from environmental sources, most notably from the reduction of lead in gasoline. The amount of lead used in gasoline decreased 99.8% nationally between 1976 and 1990. In addition, food and soft drink cans containing lead solder diminished from 47% of cans in 1980 to 0.85% in 1990.

The highly significant correlation between blood lead levels and the amount of lead used in gasoline led the NHANES II and III authors to conclude that lead in gasoline was most likely the largest determinant of blood lead levels during the entire survey period and that leaded gasoline phase-out probably resulted in the decreased blood levels detected in the latter survey [3]. This conclusion is reinforced by experiences in California between 1976 and 1980 when average ambient air lead levels decreased 30-fold, precipitating a 37% drop in average blood lead levels during the same period.

2.2 Economic Health Benefits of Unleaded Gasoline Use

The "human costs" of lead poisoning are enormous and well documented. But there are also significant adverse economic impacts from human exposure to lead in gasoline. Thus, banning lead in gasoline will not only have an enormous positive impact on public health, it will result in enormous savings in terms of avoiding lost earnings and health care costs.

In 1994 Professor Joel Schwartz of the Harvard School of Public Health quantified the economic health benefits of reduced lead exposure in the U.S. Schwartz related lead exposure to lowered IQ and then related lower IQ to earnings lost over a human life span. He estimated that a 1 μg/dL reduction in blood lead level for children born in the same year translated to a gain of approximately US $6.9 billion, the majority of which is attributed to avoiding lost future earnings ($5.060 billion) [17]. A summary of Dr. Schwartz's estimate is shown in Table 4.

Table 4.
Annual Health Benefits of Reducing Mean Blood Level by 1 µg/dL in the Population of the U.S.

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

The table above shows the breakdown of the implied economic health benefits (in 1989 US$) related to lead exposure reductions for both children and adults as determined by Schwartz [12].

A 1995 report by Dr. David Salkever of the Johns Hopkins School of Hygiene and Public Health asserted that Dr. Schwartz's estimations were significantly conservative in relating earnings to the marginal productivity of labor in the market. Salkever estimated that earnings losses averted by a 1 µg/dL reduction in blood lead level in children were approximately 50% greater than Schwartz's estimation of $5.060 billion [16] and that such benefits would only continue to grow as education and cognitive skills become increasingly more important in our economy.

Another study estimated the health costs to society in economic terms, based solely upon the effects of lower IQ's in children, might be as high as 45 cents per gallon or $45 billion dollars annually [18b].

Human lead burden is directly related to increased blood pressure. A similar relationship exists between high blood pressure and the costs associated with strokes, heart attacks, and deaths attributed to increased blood pressure. In this case, it was estimated that a 1 µg/dL reduction in blood lead level is valued at approximately US $57 per year per person [18b].

2.3 Adverse Impact of Lead on Emission Control Equipment

Leaded gasoline has many negative effects on both vehicle parts and emission control equipment. The nature of the chemical components resulting from the combustion of leaded gasoline cause high engine wear, short spark plug life, corrosive wear of the exhaust system, and high maintenance costs. Leaded gasoline also deactivates the catalytic converter. Alternative non-catalytic methods of exhaust emissions control that are compatible with leaded fuel are fuel inefficient, resulting in a 30% decrease in fuel economy, and cannot achieve the same low emission levels of catalyst-equipped vehicles.

2.3.1 Catalytic Converter

The effects of leaded gasoline on engines and catalytic converters have been studied for many years. Research has confirmed that lead in fuel rapidly deactivates the performance of the catalytic converter [4]. At lead levels of 0.125 grams per liter (g/l) or greater, the deactivation occurs after only a few tankfuls. Even trace lead levels (less than 0.003 g/gal (0.0008 g/l)) in unleaded gasoline will cause lead poisoning of the catalyst and will negatively influence its performance in an automotive catalytic converter. Gasoline with zero residual lead provides the most flexibility in catalyst design and the greatest potential to utilize the most cost-effective catalyst materials [4]. Consequently, the United States Federal Code of Regulations do not allow the addition of lead compounds at the refinery to gasoline that will be sold as "unleaded." The maximum lead specification for unleaded gasoline is 0.014 g/l (0.05 g/gal), but this maximum does not reflect the lead level of actual commercial gasoline sold at the pump. In the United States, lead in commercial gasoline has approached zero (non-detectable limits) for several years.

2.3.1.1 Lead Deactivation of the Catalyst

Ford Motor Company published the definitive study on the mechanism by which leaded fuel poisons a catalyst [7]. Tetraethyl lead (TEL), mixed with ethylene dibromide (EDB) or ethylene dichloride (EDC), is a gasoline octane additive. EDB, the most common mixture agent, is added to minimize lead compound accumulation within the combustion chamber, on the spark plugs, and on the valve seats by providing, upon combustion, a compound that reacts with lead to form the volatile lead bromide. Gaseous lead bromide is exhausted with other gases into the exhaust system and diffuses to the active catalyst sites. It finds the active catalyst sites, adsorbs on these sites and remains there as solid lead compounds – thereby deactivating the catalyst site for further reactions. This phenomenon is known as lead poisoning. The Ford scientists analyzed lead poisoned catalysts and found lead concentrations only on the precious metal catalyst sites. No lead was found associated with the aluminum oxide and other base metal oxides used to disperse the precious metal throughout the catalyst support. Ford scientists also found that various precious metals were affected differently by lead. Platinum (Pt) was slightly more resistant to lead poisoning because it is somewhat protected by sulfur in the fuel. Pt oxidizes sulfur dioxide to sulfur trioxide and then reacts with lead compounds to form lead sulfate which is not a catalyst poison. The protection is short lived, however, as additional lead sulfate clogs up the site area and eventually renders the area inactive. Nevertheless, Pt is the prefered catalytic material for initial catalyst formulations in catalytic converters used directly after the switch to unleaded gasoline. The Ford researchers also studied palladium and rhodium, which are even more strongly poisoned by leaded gasoline.

2.3.1.2 Lead Deactivation Occurs Rapidly

One tank of leaded gasoline causes a rapid decline in catalyst performance, which increases emissions significantly. A return to unleaded gasoline will return some of the lost catalyst performance. However, a permanent decline in catalyst performance will occur with steady use of unleaded gasoline. For example, in 1983 the U.S. EPA tested five vehicles, some equipped with oxidation catalysts and others with three-way catalysts. EPA researchers refueled each vehicle ten times with gasoline containing 0.28 g/l of lead [13]. For the five vehicles in the study, emission levels were reported to steadily increase with each fueling such that when the vehicle was refueled with unleaded gasoline after having been fueled with 10 tankfuls of leaded gasoline, hydrocarbon (HC) emissions were over four times the original levels and carbon monoxide (CO) emissions were nearly three times the original levels. For the three-way catalytic converter-equipped vehicles, NOx emissions nearly doubled. EPA reported that most deactivation occurred with four tankfuls of leaded gasoline. HC and CO emissions continued to increase with further fueling but not at the same rate [4].

2.3.2 Oxygen Sensor

Leaded gasoline poisons the exhaust gas oxygen (EGO) sensor functions. EGO sensors are the key part of the modern fuel injection systems that control the fuel/air mixture to the perfect mixture (stoichiometric) needed for the three-way catalyst emission control system. Direct association of lead compounds with precious metals that had been observed in laboratory studies on catalyst support materials were also observed within zirconia exhaust-gas oxygen (EGO) sensors using electron microprobe and Auger electron spectroscopy [7]. After exposure of the zirconia EGO sensor at 730°C to combustion products from iso-octane containing 1.5 g Pb/gal, microscopic analysis indicated that the lead species were found directly associated with the platinum electrode surface, but not detected on the outer porous spinel barrier coating of the sensor. Thus, lead deactivation of catalyst supports and platinum electrodes in oxygen sensors are similar in that the halide-containing lead species specifically seek out precious metal surfaces that provide a catalytic site for dissociation, resulting in lead deposits on the precious metal surface.

2.4 The Benefits of Unleaded Gasoline to Vehicle Maintenance

The use of unleaded gasoline considerably reduces the vehicle maintenance costs incurred with leaded fuel use. Unleaded gasoline is a clean fuel with less corrosive products of combustion than leaded gasoline. Consumers benefit from maintenance savings and fewer engine and exhaust system repairs due to corrosion. The additives EDC and EDB, needed in leaded gasoline, form corrosive acids upon combustion [18a]. They cause corrosion to engine parts, more frequent oil changes, and the replacement of spark plugs, mufflers and exhaust pipes. Conversely, unleaded gasoline extends spark plug life from 6,000 miles to over 50,000 miles, and extends oil change intervals by a factor of 2 to 4. Reduced engine corrosion was predicted to improve engine life by an additional 50% [5]. In actual on-road service, an engine life of 200,000 miles is common and sometimes 400,000 miles is achieved in commercial vehicles like taxis. As a result of switching to unleaded fuel, several nations, including Australia, Canada, and the U.S., have reported maintenance savings in the range of US $0.189 per gallon (US $0.05 per liter) of gasoline [23]. The economic benefit in terms of savings in vehicle maintenance costs alone justifies the removal of lead from gasoline [18b]. Along with health benefits, the arguments become even more compelling.

3.0 OPTIONS FOR BANNING LEADED GASOLINE

There are three proven approaches a country can take to eliminate leaded gasoline. One choice, recently used by China, India, and Vietnam, as well as Central and South American countries, is **immediate, 100 percent conversion** of all gasoline from leaded to unleaded. China started switching individual cities to 100 percent unleaded gasoline in June 1997, then entire provinces, and now is completely lead free. The city of Delhi, India, switched to 100 percent unleaded in September 1998 and then other cities and the rest of the country so that India is now completely lead free. Vietnam switched to unleaded gasoline as of July 1, 2001. Thailand began a second type of approach in 1990, known as the **rapid phase-out** approach by incrementally reducing gasoline lead concentrations. Thailand introduced two grades of unleaded gasoline in 1991 and 1993 and then subsequently phased out leaded gasoline in 1996. In retrospect, Thailand officials feel they should have moved more rapidly to phase-out lead. The United States, Canada, Japan, and Western Europe chose the third approach, which was to **phase-in** unleaded gasoline coinciding with the introduction of new vehicles designed for unleaded fuel and to **phase-out** unleaded gasoline as older vehicles were retired. This latter process is the most expensive approach and needlessly prolongs the serious health effects of lead in the environment.

The **immediate, 100 percent conversion** from leaded to unleaded gasoline appears to offer the most cost effective benefits as it most swiftly eliminates the negative health effects, avoids dual refinery and distribution system costs, and reduces vehicle maintenance costs. This approach gives realistic consideration to health needs and actual vehicle usage and is responsive to the protection of children's mental development. However, it requires a means to replace the equivalent octane value of the TEL removed. Options are discussed in Section 4.3.

3.1 Approach #1: Immediate Conversion of All Gasoline to Unleaded Gasoline

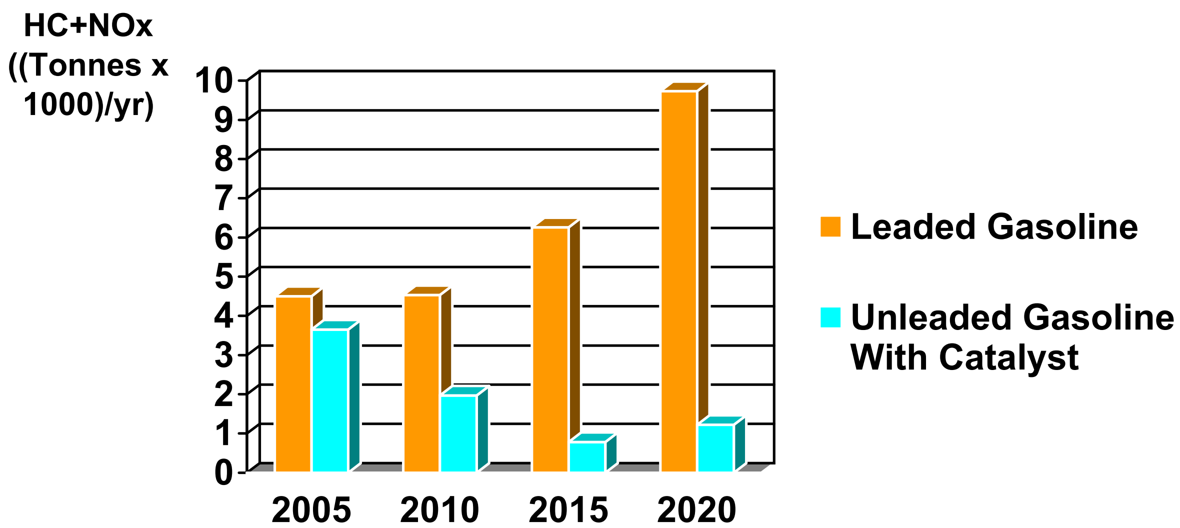
The **immediate, 100 percent conversion** from leaded gasoline to unleaded gasoline is a fast and attractive option. Ambient air lead concentrations are quickly reduced to zero. The source of negative lead health effects is quickly and effectively eliminated. Because unleaded gasoline completely replaces leaded gasoline, and since it is distributed through the existing leaded fuel system, countries avoid the complications and the costs of building a new distribution system with two separate pumps and storage tanks at the gasoline station and maintaining a dual fuel distribution system. Residual leaded gasoline in tanks and pipelines will be diluted to near zero after several refill replacements of the gasoline station storage tank. Older vehicles will also benefit from decreased maintenance costs because of increased spark plug and longer exhaust system and engine life. Since there is only unleaded gasoline, the unnecessary handling costs, and the potential for misfueling and lead contamination of unleaded gasoline, which can undermine the performance of the catalytic converter, are not even considerations. This approach also simplifies a nation's tax structure for on- and off-road fuels.

Some countries import 'pre-owned' light-duty gasoline-fueled vehicles designed for unleaded gasoline with Stellite valve seats and already equipped with fully functional exhaust emission control systems. These vehicles require unleaded gasoline so that the existing emissions control systems continue to remain functional. Leaded gasoline will quickly destroy them. The immediate switch of all gasoline to unleaded gasoline is an ideal approach for this situation. For purposes of appreciating the benefits of the **immediate, 100 percent conversion** approach for such a situation, Figure 1 presents a hypothetical example based on the following assumptions:

- Unleaded gasoline is available January 1, 2005
- In 2005, the light-duty vehicle (LDV) fleet is 100,000 vehicles
- Sales on new LDVs is 10,000 vehicles in 2005 and it this figure grows at a rate of 1.08% annually
- The baseline emission levels of vehicles fueled with leaded gasoline are: 1.5 g/mi hydrocarbon (HC), 2.5 g/mi oxides of nitrogen (NOx), and 16 g/mi carbon monoxide (CO).

Based on these assumptions, it is estimated that nationwide light-duty vehicle exhaust emissions will be reduced by approximately 50% in 5 years and to 90% in 12 years. Lead emissions will be reduced by above 90% in just one year.

Figure 1. Unleaded Gasoline for Imported Pre-Owned Light-Duty Vehicles with Emission Control Catalysts Will Avoid Huge Amounts of Pollution



Assumptions: 1. Unleaded Available Jan. 1, 2005
2. 2005 LDV Fleet of 100,000
3. LDV Sales of 10,000/yr @1.08 Growth; Scrap 10,000 LDV/yr; Life of 10 yrs
4. Baseline Leaded Gasoline Emissions of 1.5 g/mi HC, 2.5 g/mi NOx, 16 g/mi CO

China, India, Vietnam and the Philippines, as well as Central and South American countries (see Section 6.0) have completed the **immediate, 100 percent conversion** approach. There have been no reported difficulties or reported engine failures. As a result of the immediate elimination of lead in gasoline, measured ambient lead levels were dramatically reduced.

The **immediate, 100 percent conversion** approach requires a means of octane replacement. If imported octane is required this can be later phased out when the internal refinery system is upgraded.

3.2 Approach #2: Rapid Phase-out of Leaded Gasoline

The **rapid phase-out** approach is characterized by a transition period of four to six years from leaded to unleaded gasoline, during which concentrations of TEL in leaded gasoline are rapidly reduced, followed by the introduction of unleaded gasoline, and finally the ban of all leaded gasoline.

The **rapid phase-out** approach requires separate gasoline distribution systems and separate refinery storage facilities for each product. Some countries using this approach have added a valve seat wear prevention additive to unleaded gasoline, but whether preventive additives are actually needed is debatable. In fact, Thailand planned to use the additive but found it was not needed and decided to by-pass this step. Lead contamination of unleaded gasoline and the potential for misfueling are the major problems with this approach until leaded gasoline is finally banned. An effective measure to avoid the latter is to mandate leaded gasoline pump prices to be one or two cents per gallon higher than unleaded gasoline.

As previously stated, Thailand took the **rapid phase-out** approach starting in 1990. Figure 2 illustrates the effectiveness in reducing lead emissions with regard to the number of years over which a rapid phase-out occurs.

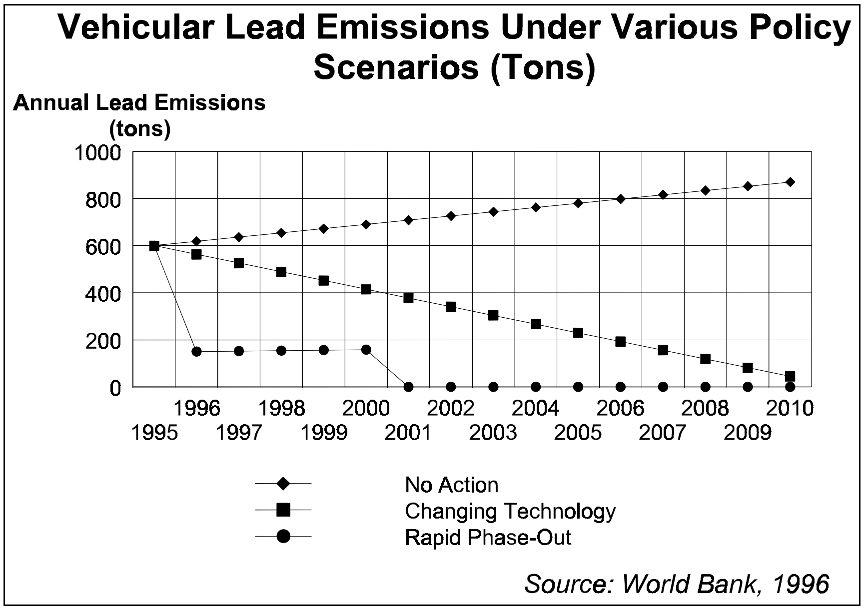


Figure 2. Annual lead emissions are reduced and eliminated far more quickly under rapid phase-out than under other policy scenarios.

It was found that some Thailand motorists used unleaded gasoline in older vehicles which contributed to the effectiveness of the program. These motorists also obtained the economic benefits of unleaded gasoline without any reported negative effects.

3.3 Approach #3: Phase-in, Phase-out

The **phase-in, phase-out** approach requires the maintenance of a dual distribution system for many years. New vehicles are designed for unleaded fuel, and as older vehicles are retired, the demand for leaded fuel diminishes. Finally, leaded fuel is banned. The United States, Canada, Australia, Japan and many European countries took this approach.

Since ambient lead in the air is now near zero in the U.S., the approach is considered successful. It took nearly 20 years for the complete transition, however, which was unnecessarily long. Most experts agree that, in retrospect, the better approach is to ban lead completely or to require a rapid phase-out.

A price differential policy with respect to leaded and unleaded gasoline pump price is critical to the success of Approach #2 and #3 programs. An effective measure is to mandate leaded gasoline pump prices to be $0.01 to $0.03 per gallon higher than unleaded gasoline. In the United States there was no such policy when unleaded gasoline was introduced. As a result, owners of older vehicles (without catalytic converters) tended to use leaded gasoline when the pump price was lower, although some did choose to use unleaded gasoline and realized reduced maintenance costs and improved engine life. Of greater concern was that some motorists altered the gasoline tank filler on the new model catalyst-equipped vehicles to accept lower pump price leaded gasoline thereby deactivating the emission control system, resulting in a tenfold increase in pollution. To avoid this negative incentive a policy dictating a slightly higher leaded gasoline pump price has been effective. See Sweden (Section 6.3).

3.4 All Groups Affected by the Lead Issue Should Be Consulted

National governments are not the only entities to have a proper role in the process to eliminate leaded gasoline. The involvement of parents and teachers, as well as health and environmental organizations, fuel manufacturers, and vehicle manufacturers, are all crucial to successfully eliminate lead from gasoline, and to subsequently protect public health, particularly children's physical and mental development. The demand for lead elimination is peaking throughout the rest of the world. Parents want a healthy environment for their children. Similarly, teachers want healthy and alert students that can achieve their maximum potential. A public education and awareness program has been found to be essential to avoid misunderstanding and provide for a smooth transition. Through collaboration, these groups can achieve widespread support for and understanding of the importance of banning leaded gasoline.

Though the refinery industry has its economic limitations, it has had over 30 years of forewarning that lead poses serious health risks and must be eliminated from gasoline. It is very important to have a reasonable and timely plan to balance the concerns and interests of all parties. The forewarning period has been more than sufficient – it is time to act.

4.0 ISSUES AND SOLUTIONS CONCERNING UNLEADED GASOLINE USE

The overwhelming benefits of unleaded gasoline are undisputed. The lead additive industry, however claims: 1) that engine valve wear with unleaded gasoline will occur, 2) that benzene emissions will increase if unleaded gasoline is used by older vehicles, 3) that gasoline octane replacements will be more costly, and 4) that unleaded gasoline will result in loss of engine thermal efficiency and fuel economy. As the discussion below reveals, these claims are either inaccurate, overstated, or can be addressed. While there are costs associated with eliminating the use of lead in gasoline, ***the costs incurred are far outweighed by the overwhelming health and economic benefits of unleaded gasoline, especially with regard to children's mental health.***

Since the 1920s, lead has been added to gasoline to increase its octane rating and reduce engine knock. Knock is a measure of how sensitive the fuel/air mixture is to engine pre-ignition. By reducing knock tendency (raising octane rating), engines could be designed for more power. Many gasoline fuel octane enhancers exist. Among the first of these, tetraethlylead (TEL) has been used as an octane additive for over 50 years. Ethylene dibromide (EDB) or ethylene dichloride (EDC) is also added to prevent accumulation of lead deposits within the combustion chamber and sparkplugs. Most of the lead is removed as volatile lead bromide or chloride. Nevertheless, some lead compounds still remain within the engine, on sparkplugs and on valve seats. Engines had to be designed to scrape off lead deposits on valve seats.

To prevent the accumulation of lead on the valve seats, the valves were designed to rotate a few degrees per revolution [8]. This approach caused a certain amount of valve wear that had been considered acceptable in former times. Another factor is the aggressive chemical corrosive effect of ethylene dibromide (EDB) or ethylene dichloride (EDC) combustion products. Corrosion of spark plug electrodes is evident after a few thousand miles. Spark plug replacement is necessary in about 6,000 miles as progressively declining combustion quality reaches intolerable levels resulting in higher specific fuel consumption. Corrosion is also progressive and increasingly evident throughout the engine including the valve seats. Iron particles caused by these aggressive chemicals build up in the lubrication oil causing on-going engine wear. This is diminished, but not overcome, by total base number* (TBN) lubricant oil additives and frequent oil changes [18a].

Subsequently, in the early 1970s, engines were redesigned again for unleaded gasoline. Stellite valve seat inserts were introduced, further improving resistance to valve wear. Note: Stellite seats were of a high Co/Cr alloys with > 300 Brinnell hardness rating and provided higher temperature resistance, chemical/cavitation corrosion resistance, and anti-galling features [31]. Some engine dynamometer studies concluded that certain older engines would be susceptible to valve seat wear if operated on unleaded gasoline. Other studies agreed that this did occur on a limited number of older engines, **but only at high engine speeds and loads and only after operating at those conditions for extended periods in engine dynamometer studies**.

*Base Additives to neutralize the acidic combustion compounds.

However, once unleaded gasoline was introduced throughout the United States, older vehicles that used it did not experience valve wear problems. In fact there was a history of unleaded gasoline use in the United States. A brand of AMOCO premium unleaded gasoline was marketed as a clean gasoline fuel in parts of the U.S. since the 1940s. Vehicles that used this fuel experienced benefits of longer sparkplug, exhaust system and engine life and most importantly did not have valve wear problems. Also, many vehicles were converted successfully to LPG fuel (an unleaded fuel) throughout the world without incurring excessive valve wear.

Proponents of leaded gasoline say that an increase in aromatic hydrocarbon emissions, especially benzene, may result from older vehicles' emissions using unleaded gasoline. They argue refinery methods, which yield low aromatic compounds, may not be available, are undesirable, or prohibitively expensive. Practical solutions exist, however, to address this issue (see Section 4.3.1). Recognizing the need to reduce benzene in gasoline, the proposed World-Wide Fuel Charter recommends an unleaded gasoline benzene content specification of 5% maximum for Category 1 gasoline, 2.5% for Category 2 and 1% for Categories 3 and 4 [Ref. 25].

One of the reasons lead was added to gasoline was to lower unit cost and to increase the fuel octane rating. Potential cost increases are an issue when switching to unleaded gasoline, but today there are many overall cost effective methods to increase the octane number of unleaded gasoline. Also, as noted earlier, there are economic health and vehicle maintenance factors that positively offset higher-octane cost, if any.

The TEL industry claimed better thermal efficiency with leaded gasoline. Yet in actual use unleaded gasoline is directly linked to major improvements in fuel economy and engine power. With the introduction of unleaded gasoline in the United States for use in 1975 model year vehicles, the average fuel economy of passenger cars increased from 13.5 miles per gallon to ~27.5 miles per gallon. One of the primary contributors to the overall gain in fuel economy was the re-tuning of the engine for unleaded gasoline and the fact that optimal ignition efficiency (due to non-fouling and longer effective spark plug life) is maintained for extended periods. This also improved engine power and performance. Another primary contributor to the improved fuel economy was the development of the "stoichiometric" engine – an accomplishment that gave additional increases in power and about 8 to 10% improved fuel economy as well as superior emissions control. These technical advances could not have been achieved with the use of leaded gasoline [18a, 19]. Thus, the TEL industries predictions of lower fuel economy and power losses with unleaded gasoline did not occur.

4.1 Impact on Existing Fleets

Time is an additional positive mitigating factor to the strong case outlined above that unleaded gasoline will not cause problems to older vehicle engines. Very few older vehicles (pre-1971 U.S., pre-1975 Japanese, and pre-1980 European remain in the existing vehicle fleets throughout the world. Of these, the few susceptible vehicles are even smaller in number. The TEL industry argument, if even credible, has waned to such an extent as to be negligible. Stellite valve seats have been installed on all U.S. vehicles since 1971. Japan introduced them in 1975. European automobile manufacturers followed soon thereafter. All fleets in every country consist mostly of those with Stellite valve seats or equivalent.

One example to consider would be the existing fleets of Venezuela, Cuba and other Caribbean island nations where leaded gasoline is still permitted. Venezuela and Caribbean island nations have post-1970 modern fleets and therefore engines with Stellite valve seats. Cuba reportedly has many pre-1970 vehicles still operating. However, even these older vehicle engines would not be expected to have any problems with unleaded gasoline since those vintage light-duty vehicles are of US origin (a design that never had a problem). Any newer Russian vehicles would also not have problems [see the Vietnam experience [Section 6.3]. Yet the TEL industry continues to argue that these vehicle populations would have major engine problems. The example of the Thailand study [21] and experience of China, India and Vietnam supports this view [see Section 6.3] and proves otherwise.

In any case, a nation can still opt to protect the few existing, more susceptible older vehicles with the older design valve seats and the high valve rotation design that are operating in their country by advising restricted operation of such vehicles to speeds of 100km/h or less or adopting an unleaded gasoline specification containing non-lead anti-valve wear additives (see Section 6.3 Sweden). Although Thailand planned to use non-lead anti-wear additives, it has been reported that it did not when Thailand found that such additives were not needed.

4.1.1 Issue of Valve Wear

What is engine valve wear and why is it important to engine life? Valves are designed to allow inflow of the fresh air/fuel mixture and outflow of the exhaust gases and to seal off the combustion chamber during combustion and gas expansion phases of the engine cycle. Valves are designed to rotate a few degrees with each revolution of the engine to assure a smooth closure surface and to scrape off lead deposits. This slight movement of the valve face on the valve seat causes a small degree of valve wear that increases with engine age. Excessive valve wear would result in valve recession and perhaps the escape of exhaust gases and resultant engine power loss. It should also be noted that valve wear does occur with leaded gasoline. In the past it was considered acceptable maintenance to repair and resurface valve surfaces after 50,000 to 100,000 miles of vehicle service. Today, modern unleaded gasoline spark-ignited (SI) engines with Stellite valve seats operate with minor valve wear, if any, for 250,000 to above 400,000 miles on high-speed modern highways.

Valve seat hardness and valve rotation design affect valve wear significantly. Since the early 1970s in the United States and a few years later in other countries, modern engines have been constructed with Stellite valve seat inserts [31]. These valve seat inserts are constructed of metals with hardness rating greater than 300 Brinnell Hardness Value, superior scuff resistance, and higher temperature and corrosion resistance [1]. Such inserts are heat-shrunk into place. Older engines have valve seats constructed of metals with lower hardness value. Older engines can be re-built with Stellite valve seat inserts.

As stated earlier, valve rotation was introduced to scrape off detrimental lead deposits on the valve seat. Lead deposits on the valve mating surfaces are claimed by the TEL industry to have some high temperature lubricating properties, which minimize progressive valve wear in spite of the aggressive corrosive nature of TEL/EDB combustion products. Since unleaded gasoline would not have the same lead-containing materials on the mating valve surfaces they have advanced concern that valve wear would be severe in older engines without Stellite valve seats.

Fortunately, the incidence of excessive valve wear with unleaded gasoline in actual on-road use is much less of a problem than anticipated – sufficiently so as to be almost non-existent. In actual vehicle use it has rarely been found. Studies have shown that it can occur only in older susceptible engines, specifically certain mid-1970s Toyota engines [1], when operated continuously at high speeds and load and does not occur when operated below 100 km/hour. Authors note: It is suspected by the authors that the susceptible engines referred to above are those with higher than normal valve rotation designs. Also, alternate fuel additives have been developed that are now proven in actual use which completely protect the susceptible older engines using unleaded gasoline from valve wear even under extreme engine operating conditions (see Section 6.3 Thailand and Sweden).

A curious contradiction exists – on one hand the TEL industry has successfully promoted high concentrations of TEL, yet on the other hand only small amounts are reported necessary for valve seat protection of older valve seats. One study found the amount of lead required to minimize valve wear in susceptible engines to be 0.05 g/liter, which is much less than the amount of lead formerly used in the United States in leaded gasoline (which was about 3 g/gallon in 1970) [12]. Thus, if valve wear was the sole concern, only a small amount of lead would be necessary to avoid it rather than necessitating the use of gasoline with a high lead content. Countries currently using very high lead content gasoline (0.4 to 0.8 grams/liter) should take note of the above contradiction.

4.1.2 Minimizing Factors

In light of several studies on valve wear, the nature of older vehicle operation, characterized by fewer miles driven, lower speeds, and lower load operation than newer vehicles, reduces the likelihood that the few older vehicles equipped with non-Stellite valve seats would be adversely affected by using unleaded gasoline. Due respect has to be given to the fact that valve wear or other alleged problems did not occur in China, India, Vietnam or Central American countries when they switched to 100% unleaded gasoline thereby subjecting the entire vehicle population to unleaded gasoline. Studies have determined that valve seat wear is only encountered on certain older engines when operated at higher vehicle speeds and that normal driving speeds do not cause valve wear. If need be, to further reduce the chance of valve wear, valve wear protection additives can be made available to older vehicles [11].

4.1.2.1 Nature of Older Vehicle Operation

Engine design and operating parameters, such as engine speed and load, affect the degree to which an engine experiences valve wear. An engine design with high rotating valve speed coupled with non-Stellite valve seats is considered to be the most susceptible to excessive valve wear. For leaded gasoline engines, a slight rotating valve design was incorporated into engines (U.S. designs commonly rotated at 6 RPM at specific engine conditions) in order to remove lead deposits. In the early 1970s, one Japanese automobile manufacturer increased their valve rotation to about twice this value. Vehicles in Japan with this engine design experienced valve wear problems when fueled with unleaded gasoline. After studying the problem, Japanese engineers returned to the original valve rotation speed and installed Stellite valve seats [29, 30]. After the redesign, the valve wear problem no longer existed. Other Japanese auto manufacturers did not encounter this problem.

Honda has stated that all its engines are designed for unleaded gasoline and would not experience excessive valve wear with unleaded gasoline. The valve rotation of U.S. engines has remained relatively constant and U.S. vehicles have not encountered in-use valve wear problems [6]. When Thailand realized it was necessary to ban lead in gasoline, it conducted extensive studies of its on-road vehicle fleet to determine the effect of unleaded gasoline on various vehicle models. First, a screening program was necessary in order to identify which older vehicles were susceptible to valve wear. In the case of older engines, the results were mixed. For instance, the 1979 Mitsubishi and 1974 Datsun had hardened valve seats whereas the 1982 Mazda and 1977 Opel had non-hardened seats, yet none of these engines experienced above normal valve wear even when operating at high speeds (130 km/h for 15,000 km). However, a 1974 Toyota with non-hardened valve seats did experience high measurable wear. Subsequent screening revealed that a 1976 Toyota experienced above normal valve wear and a 1977 Toyota did not when operating as described above. Authors note: These differences are suspected to be caused by different valve rotation designs for the respective Toyota engines. In tests run on several selected susceptible vehicles at more normal speeds of 100 km/hour continuously for distances between 3000 and 12,000 km, it was found that unleaded gasoline did not cause unusual valve wear on any valve seats. When susceptible vehicles were run at higher speeds (120 km/h), valve wear was measured [1]. Thailand estimated that the number of on-road vehicles possessing non-hardened valve seats was about 10% of the fleet and that these numbers would decline in the future. The information gathered prompted the government to go ahead with their lead ban program [1].

These studies suggest that vehicles with non-hardened valve seats will unlikely be adversely affected by using unleaded gasoline because older vehicles probably will not normally be operated at high speeds or loads for an extended time. Public information programs will be helpful in this respect.

In certain countries, engines are routinely rebuilt when they wear out in a process that includes cylinder re-boring, refitting with cylinder sleeves, turning bearing surfaces, replacing pistons, and other items. During this rebuild process, valve seats can be replaced by shrink fitting them in place in the engine head. Therefore, valve wear, should it occur in some small number of engines, can be either repaired or rebuilt with Stellite seats.

The conclusion has been drawn, through many similar studies that concern for valve seat recession has been substantially exaggerated [11]. The use of unleaded fuel has also introduced benefits such as improved fuel economy [5]. Most importantly, overall maintenance costs savings realized from unleaded gasoline compared to leaded gasoline use considerably exceed any potential exhaust valve replacement costs, if any, that may be encountered with unleaded gasoline [5].

4.1.2.2 Valve Wear Protection Additives

Several anti-valve wear protection additives (VWPA) have been formulated for unleaded gasoline. Sodium or potassium-based alkenyl sulfonate or napthenate VWPA may be used. Phosphorus-based VWPA is not recommended for catalyst-equipped vehicles [1]. The sodium- and potassium-based additives have been used in Europe for many years and have not been reported to negatively affect catalytic converter performance.

The effectiveness of such additives in preventing valve seat wear was recently studied in Thailand [1]. The tests were run on an engine dynamometer at very high RPM and load. Under these conditions, the effects on susceptible engines using unleaded fuel without the additives were compared to those engines using unleaded fuel with the additives. The optimum treat rate, or the optimal concentration of additive in the fuel, that prevented excessive valve wear for extreme driving conditions in vehicles with non-hardened valve seats was determined. Results showed that under the most severe operating conditions (exhaust temperature of 650°C), VWPA additives were highly effective in preventing valve wear of susceptible engines at specific optimum treat rates [1]. However, as noted above, Thailand considered and planned using the additives but did not do so because it was found not to be needed.

4.2 Benzene Emissions

Benzene emissions are to be avoided. Benzene is a common aromatic hydrocarbon compound found in gasoline and is listed as a toxic air contaminant as it has been identified as a carcinogen that increases the risk of leukemia. The lead industry argument concerns benzene emissions from older vehicles without catalytic converters. Vehicles equipped with catalytic converters destroy 90 to 95 percent of aromatics and benzene in the exhaust stream. Thus, even lower emissions of these compounds result from an unleaded gasoline-fueled catalytic converter equipped vehicle than a car burning leaded gasoline with no converter.

Unleaded gasoline incorporates a variety of non-lead octane improver components to achieve octane rating. Several choices are available. These include certain oil refining processes, or non-lead high-octane additives. Some refining methods increase the benzene content of gasoline. Therefore, there is a risk that benzene emissions could increase depending on the refinery method used to increase the octane number of unleaded gasoline. However, as done in the U.S., petroleum refinery processes are chosen to limit the benzene and aromatic content [18b] and non-lead organic octane additives are used.

If, for some reason, a country is forced to balance health effects trade-offs between removal of leaded gasoline or situations where benzene emissions would be temporarily increased, it is leaded gasoline that has the greatest health concern. Health studies clearly suggest that the adverse health effects of lead exposure far outweigh those resulting from potential increases in benzene emissions. For example, the U.S. EPA's Carcinogen Assessment Group in 1976 estimated that benzene emissions from automobiles accounted for 47 cases of leukemia per year in the U.S. This is compared to 5,000 deaths, 6,000 first-time strokes and heart attacks per year due to lead in gasoline for white males aged 40 to 59 years [18b]. Although benzene emissions are undesirable, the effects of emissions from leaded gasoline are undoubtedly more severe. The choices are: 1) lead can be removed from gasoline in such a way as not to increase benzene emissions; 2) if a benzene concentration increase is unavoidable then there will be an increase in benzene evaporative emissions from older vehicles – this can be offset and overcome in one to two years as new vehicles equipped with catalytic converters and evaporative recovery systems replace older vehicles; and 3) once unleaded gasoline is introduced, many high mileage all-day-use vehicles can be retrofitted with a catalytic converter and/or an evaporative recovery system. Such retrofitted vehicles provide immediate benzene emission control within large cities.

4.3 Octane Enhancement

Numerous technological processes, other than the use of lead additives, are available to improve the octane rating of gasoline. They vary with the refinery technical specifications, environmental regulation considerations, cost, and health effects [11].

4.3.1 Refiner Options for Increasing Octane Rating

Refining processes for gasoline may be classified into two major groups: hydroskimming refineries and conversion refineries. The more simple hydroskimming refineries are capable of processes that include crude distillation, treating, blending, and upgrading processes. Technically advanced conversion refineries that modify the crude oil fractions to gasoline components via processes such as catalytic reforming and fluid catalytic cracking are more common. Conversion refineries also have isomerization, alkylation, and polymerization capacity and may include oxygenate production. Procedures may be combined with upgrading processes in order to enhance the octane number. A brief description of each process is listed in Table 5 below [11].

Table 5
Upgrading Processes for Octane Enhancement

Process	**Description**
Catalytic Reforming	Increase in octane of heavy naphtha containing reformates which are high in octane (93-102 RON). Magnitude of increase is at the discretion of the refiner. The "severity" of the operation determines the potential of reforming; however an increase in severity normally includes an increase in the aromatic content of gasoline.
Isomerization	Increase in octane of light naphtha (to 85-90 RON) without an increase in the aromatic content of gasoline.
Alkylation and Polymerization	Normally performed in conjunction with fluid catalytic cracking (FCC), which is a process that converts heavy fuel oil into a lighter product with greater value, such as gasoline at 90-93 RON. These processes take end-products of FCC and transform them into high value gasoline blending components (92-97 RON). Polymerization tends to increase gasoline olefin content.
Oxygenation	Blending of gasoline with oxygenated compounds such as ethyl tertiary butyl ether (ETBE), methanol, and ethanol which contain high octane values (up to 115 RON). Effective in reducing harmful CO emissions.
Blending	Mixing of blendstocks and additives that can increase octane (by 1-2 values) to produce finished products to meet desired specifications.

4.3.2 Health and Other Concerns of Alternative Octane Enhancement Processes

Some refining processes, serving as alternatives to lead additives, increase the aromatic content of gasoline. Benzene emissions are of less concern than lead emissions, but environmentally beneficial blending processes still should be used to minimize aromatic emissions. Isomerization and alkylation enhance octane in gasoline increasing benzene. Oxygenation, producing additives such as ETBE, also is a favorable refinery option because it replaces aromatics and aids in the complete combustion of fuel, resulting in cleaner tailpipe emissions [11].

The manganese additive MMT is not recommended for octane enhancement because combustion products have health concerns [27] and have been found to have negative effects on emission control systems [9], [25], [26].

MECA has a long history dating back to the 1970s in advising against the use of the MMT gasoline additive because of its negative effects on catalysts in emissions control systems. While this paper focuses on the issue of banning lead in gasoline, it is critical that MMT does not replace TEL in gasoline.

Since gasoline fuel is widely used throughout the world on light-duty vehicles, the exhaust emissions have the potential to affect almost all humans, and plants and animals as well. Manganese compounds can be toxic to humans when inhaled [27]. In 1999 a study by the American Medical Association's Council on Scientific Affairs concluded that there is insufficient information to determine the risks of MMT and recommended that research be carried out before the widespread introduction of MMT into the gasoline supply [27]. The Alliance To End Childhood Lead Poisoning in their background paper and policy statement titled "Don't Repeat The Leaded Gasoline Experiment: Keep MMT Out Of Gasoline" has advised countries to apply the precautionary principle to MMT use – "countries should resist introducing MMT and any other ash-forming additives until definitive studies carried out by disinterested parties have proven their safety".

The negative effects of MMT products of combustion on emission control system performance have long been known. Under normal engine operation, MMT products of combustion were found to cause a decrease in hydrocarbon performance of former catalyst formulations and some improvement in NOx performance. MMT products of combustion are not gaseous in nature so that these solids will eventually coat and clog the surfaces of catalysts and oxygen sensors with solid debris and thereby limit transfer of the pollutant gases to the active catalyst sites resulting in decreased catalyst and oxygen sensor performance. High engine speed and load causes higher exhaust temperatures so that the solid particles are glassy in nature and stick to catalyst surfaces sealing entrances to the porous catalyst interior preventing mass transfer thus causing a decline in catalyst performance.

A recent 2-year study of 50 vehicles (10 models x 2 pairs of each model with and without MMT – Part 1 followed by 10 vehicles – Part II) by the Alliance Automobile Manufacturers, the Association of International Automobile Manufacturers, and The Canadian Vehicle Manufacturers' Association essentially confirmed the above and found additional negative effects of MMT after 50,000 mile accumulation [26]**.** Conclusions of the study are as follows:

- Increases fleet HC and CO emissions
- Decreased fleet NOx emissions
- Increased fleet fuel consumption
- Caused spark plug failure, "check engine" light illumination on two vehicles and exhaust valve leakage on one vehicle
- Caused two vehicles to fail the 50K and 100K HC standards

A follow-on study of LEV (Low Emission Vehicles) for 100,000 miles concluded that MMT significantly:

- Increases HC emissions and causes LEVs to exceed the HC standard
- Increases CO and NOx emissions
- Impairs catalyst and emission control system performance
- Increases fuel consumption [26]

The study concluded that if MMT is used in gasoline in the U.S., the full air quality benefits of the US Tier 2 emission standards, which will be phased in beginning in 2004, will not be achieved and vehicles will fail to meet the emission standards in-use. The report also cited that problems with customer dissatisfaction will occur because of spark plug failure and maintenance, I/M failures, and fuel economy loss.

MMT is used in Canada and more recently in South Africa and China. Referring to the above study, The Canadian Vehicle Manufacturers' Association (CVMA) announced – "This study confirms that MMT is detrimental to the effective operation of vehicle emission controls systems and is ultimately harmful to the environment. Action must be taken quickly to remove this additive from gasoline in Canada" [28]. Similarly, the National Association of Automobile Manufacturers of South Africa have called upon the government "to act against the proliferation of MMT use as a lead substitute in petrol marketed in South Africa by prohibiting its addition to unleaded petrol immediately and from any Lead Replacement Petrol (LRP) by January 2006" [29].

5.0 Costs of Producing and Using Unleaded Gasoline

Making the transition to unleaded gasoline requires some investments in infrastructure changes. The most significant cost of eliminating leaded gasoline is the replacement of the high-octane values and the associated production and distribution costs. The modifications to refinery procedures that are necessary to efficiently use alternative octane enhancers are discussed below. Distribution costs attributed to the excess storage and transportation of both unleaded and leaded gasoline are also an issue, but may be significantly reduced with careful planning or avoided by using the **immediate, 100 percent switch** approach.

5.1 Experience with Refiner Costs

A variety of technical options are available to both modern and older hydroskimming refineries to increase the octane rating of gasoline. The costs of switching from lead additives to one of the alternative methods (outlined in Table 5) are dependent upon the following: (1) the extent to which refineries are utilized and alternative octane enhancements are initiated; (2) the octane requirements of the vehicle fleet; and (3) the price of additives used for octane enhancement [5].

One study of costs to switch to unleaded gasoline estimated it to be between US $0.01-0.02 per liter, which includes the costs of refinery investment, unleaded fuel production, and octane additives. Because of productivity improvement and refinery efficiency, investments in alternative refining techniques typically pay for themselves in the long run [5]. As a result, only investment costs attributed to expediting investments in refinery conversion and alterations in refinery infrastructure to produce unleaded fuel should be considered as a cost of conversion. For example, a 1996 study conducted by Abt Associates asserted that converting from leaded to unleaded gasoline at a hydroskimming refinery in Russia would cost between US $0.005 and $0.02 per liter of gasoline under the current production procedure. However, when changes in the refinery's procedure, which are expected to result in greater production, were considered, this estimate was cut in half [5]. Although this example is country-specific, refinery upgrading helps to minimize the costs of switching to unleaded gasoline in any country.

6.0 World Experience with Regulating Lead

TEL in gasoline was introduced in the 1920s and was used in many world markets by the 1930s. Because of increasing health concerns about the dangers of airborne lead due to a growing body of related health studies [5], and the need to control automobile exhaust emissions by protecting catalytic converters, leaded gasoline use began to diminish after peaking in the 1970s. Unleaded fuel use then became more prevalent because of its benefits to health and vehicle maintenance.

6.1 Leaded Gasoline Use

As previously stated, many countries eliminated leaded gasoline or significantly restricted its use in favor of unleaded fuel because of health and vehicle emission control concerns. In 1969 the United States was the pioneer in the switch to unleaded gasoline. At a time when health concerns of lead were peaking, the auto industry and government agreed to make significant reductions in vehicle emissions by 1975. They decided that this could be accomplished if clean unleaded gasoline was available. As a result, all U.S. engines were designed for unleaded gasoline starting in the fall of 1970, and unleaded gasoline was gradually introduced throughout the country so that it was available for new 1975 model vehicles. Since then, Japan, Canada, Mexico, Central and South America, all of Western Europe, Korea, Australia, China, Taiwan, and other Asian countries have introduced unleaded fuel. Soon after the introduction of unleaded gasoline, most of these countries also set vehicle exhaust emission standards to clean up the pollution caused by automobiles and trucks.

The United States, as well as other pioneers in switching to unleaded fuel, opted for the **phase-in, phase-out** approach. Completely eliminating leaded gasoline took about 20 years, which is much too long compared to the other alternatives. Japan followed suit and succeeded in eliminating leaded gasoline in 10 years [11]. Western European countries introduced unleaded fuel in the late 1980s, and a number of countries now only market unleaded gasoline, including Austria, Belgium, Bulgaria, Denmark, Finland, France, Germany, Great Britain, Ireland, Italy, Netherlands, Norway, Poland, Portugal, Spain, Sweden and Switzerland.

All of the Central America countries, as well as Colombia and China, have recently chosen to use the **immediate, 100 percent conversion** approach when switching to unleaded gasoline. The most recent switches occurred in India, Vietnam and the Philippines. Thailand and Taiwan have used the **rapid phase-out** approach for eliminating leaded gasoline. Many other countries have reduced the amount of lead allowed in their leaded gasoline from 0.8 g/liter to 0.4 or 0.15 g/liter. But by doing so, these countries have not yet realized the enormous benefits of converting their fuel supply entirely to unleaded gasoline.

Even some countries with strong economies have not yet introduced unleaded gasoline. Interestingly, many of these countries export petroleum and have the refining capabilities and expertise to convert to unleaded gasoline rapidly but lack the political will to take on the battle with the entrenched TEL industry. High octane unleaded gasoline is often exported, but leaded gasoline still remains in the domestic market in the absence of a government regulation.

Some African countries, Caribbean island countries and Middle East countries have not even begun to reduce lead concentrations in leaded gasoline. In fact, several countries during the course of the 1970s and 1980s nearly doubled the amount of lead used in gasoline.

With all the existing knowledge and understanding of lead health effects, especially its effect on children, it is a serious matter of concern that lower-income countries tend to have much higher lead concentrations in their gasoline than do other countries. For instance, many countries in Africa historically allowed 0.84 g/liter lead in gasoline whereas Asian countries, which still allow the sale of some leaded gasoline, have limited the maximum lead concentration to 0.15 g/liter. The potential for adverse physical and mental health effects is higher with high lead gasoline than with the lower value. Higher lead concentrations increases the risk of more severe health risks, as well as diminished improvement in octane value. Most of the octane increase is obtained with 0.15 g/liter lead concentration [15]. With future projections of economic growth that will foster greater urbanization and motorization in these countries, high lead concentrations represent an increasingly major future health hazard. Reducing gasoline lead concentrations from 0.84 g/liter to 0.15 g/liter clearly is good policy. However, complete elimination of leaded gasoline has additional and substantial benefits as not noted in Sections 2.2, 2.3 and 2.4.

Another cost factor to be considered by the above countries is the added cost to remove emission controls from cars and trucks imported into their countries. If the vehicles are fueled with leaded gasoline, removal of these controls is necessary because the catalytic converter on those vehicles will accumulate lead ash and increase backpressure, which adversely affects vehicle performance. Most new vehicles are manufactured for markets with emission controls and unleaded gasoline. Of the 10 percent of new vehicles destined for countries with leaded gasoline, many have to be revamped by removal of the emission control systems - an added complexity and manufacturing cost that may be added to the sales price of the vehicle. This same complexity exists with the pre-owned vehicles equipped with catalyst that are imported into the country that has not yet phased out lead.

6.2 International Efforts to Ban Leaded Gasoline

In 2001, seventeen Sub-Saharan African countries signed a resolution known as the 'Dakar Accord' agreeing to the cessation of leaded gasoline in their respective countries by 2005.

At the World Summit for Sustainable Development held in South Africa, during August-September 2002, a Clean Fuels and Vehicles Partnership was formed. One goal of the partnership is to end leaded gasoline in the world by 2005. Signatories to the global partnership include the United Nations Environment Program (UNEP), the UN Department of Social and Economic Affairs, Canada, Chile, the Central American Commission on Environment and Development (Costa Rica, Panama, Nicaragua, El Salvador, Honduras, Guatemala, and Belize), Italy, Mexico, Netherlands, South Africa, the United States and China. About 15 industry and non-governmental organizations have also joined the partnership.

The 3rd edition of World-Wide Fuel Charter (WWFC), December 2002, included a key change for all gasoline fuel specification categories, calling for the elimination lead in fuel worldwide. The WWFC states that "Leaded gasoline poses a serious direct threat to public health and is a barrier to the introduction of automotive emission control systems that can reduce exhaust emissions by 90% or more over uncontrolled levels. It also impedes harmonization of vehicle technology. Automotive and engine manufacturers around the world support efforts to end the use of lead in gasoline." [25]

Appendix I provides a country-by-country list of the progress in getting lead out of gasoline.

6.3 Case Studies of Lead Phase-out

Evidence from specific case studies where lead has been or is being removed from gasoline is useful when considering the costs and benefits of eliminating lead from fuel. Nations vary by government policy and political will in their efforts to address environmental problems. The countries selected below represent well-documented cases in which the elimination of lead from gasoline was achieved successfully, despite unique sets of circumstances.

Vietnam

Vietnam decided to comply with the ASEAN trade agreement resolution to ban lead in gasoline in the region. To understand all factors, the Ministry of Transport engaged international assistance and conducted a series of workshops that finally resulted in a plan to switch to unleaded gasoline starting July 1, 2001. The first Ministry of Transport workshop in December 1999, identified the following key factors were needed to implement the program:

- Economic measures
- Technical knowledge
- Government coordination
- International support

A key element of the implementation of Vietnam's lead ban was the attendance of a high ranking Vietnamese official at a trade event in the US where he was exposed to all the international experience and progress with leaded gasoline ban programs and found "the switch can be done quicker – not 5-6 years as they thought – but in 1 year". International meetings started in August 2000 and the first workshop resulted in formation of an international partnership that included the US EPA, the US Asia Environmental Partnership (US AEP), an U.S. auto manufacturer, an U.S. public relations firm and an international oil company. The Russian auto industry joined the partnership after the February 2001 workshop.

Two additional workshops occurred in 2001. It was found that unleaded gasoline was no more expensive than leaded gasoline. The workshops developed strong confidence on all related technical, health and practical issues. Of great importance were the positive inputs from the

Russian auto industry regarding the large existing Russian vehicle fleet in Vietnam. The Vietnam government supported a subsidy to the domestic refinery. On April 27, 2001, a directive issued by the Government of Vietnam officially announced the switch to unleaded gasoline on July 1, 2001.

A strong reason for consumer acceptance was the support of an U.S. public relations company that designed posters for public education that were distributed to gasoline and inspection stations throughout the country.

The cessation of leaded gasoline and switch to unleaded gasoline has had no negative impacts. Airborne lead has been immediately and dramatically reduced.

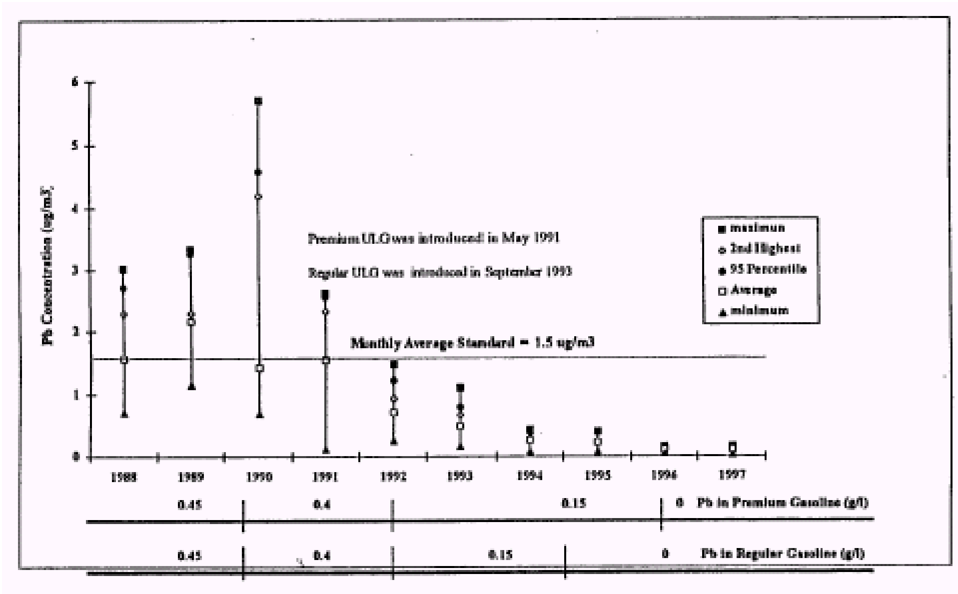
The Vietnam experience is an example for small countries now considering plans to switch to unleaded gasoline.

<u>Thailand</u>

In response to the growing concern for airborne lead health hazards resulting from a rapidly growing vehicle population and severe traffic congestion in the Bangkok metropolitan area, the Thai Government implemented the rapid phase-out approach to switch from leaded to unleaded gasoline. In 1990, the maximum lead content of gasoline was reduced to 0.4 grams per liter and then to 0.15 grams per liter in 1994. Premium unleaded gasoline was introduced in May 1991, followed by regular unleaded in 1993. A complete switch to unleaded gasoline began in January 1996 when leaded gasoline was banned altogether [18b, 21]. The record since has been without negative consequences. All vehicles use unleaded gasoline. Airborne lead has been reduced dramatically. (See previous 4.1.2.1 and 4.1.2.2 sections for actual Thailand experience).

Quantities of aromatics in gasoline were controlled in the comprehensive environment program. To achieve the necessary changes to the country's three refineries and make other modifications, the Thai government received financial assistance from the World Bank, which resulted in increased production efficiency. The fuel reformulation in conjunction with the banning of leaded gasoline has resulted in the complete elimination of vehicular lead emissions in Thailand [11]. The record of ambient roadside lead concentrations in Thailand is shown in Figure 3.

Figure 3
Trend of Monthly Average Lead Concentrations in Roadside Ambient Air in Bangkok*



**Values in 1997 are from January to July*

Sweden

In Sweden in the late 1980s, lead emissions from vehicular traffic accounted for nearly 80 percent of total atmospheric airborne lead. The government of Sweden reacted to this fact by deciding to accelerate the phase-out of leaded gasoline. The first reduction of lead in gasoline occurred in the 1970s, from 1.2 g/l to 0.8 g/l; this reduction was followed quickly by decreases to 0.4 g/l and 0.15 g/l. In addition, tax incentives designed to promote the production of unleaded gasoline were introduced by imposing a tax differentiation on leaded and unleaded fuels (unleaded had a lower pump price) [11].

A switch to unleaded gasoline occurred in 1992 as a result of extensive market research, which indicated that lubricity additives could be effectively used in older cars with non-hardened valve seats. For these cars, an unleaded gasoline containing a sodium additive to prevent valve seat recession was introduced. During this period, the government promoted the purchase of unleaded fuel by ensuring the price for leaded gasoline always exceeded that of unleaded gasoline, with the differential reaching 16% in 1993. Since 1994 all gasoline sold in Sweden has been unleaded.

Slovak Republic

In 1992, vehicular traffic represented the second largest source of lead emissions in the Slovak Republic, accounting for roughly 29 percent of airborne lead levels. In comparison to other European countries, the majority of industrial cities in the Slovak Republic did not have excessive ambient lead levels, being typically below 0.3 μg/m^3 as opposed to a range of 0.5 - 3.0 μg/m^3 for most European cities. Nonetheless, a project was conducted in the Republic between 1986 and 1991, which revealed that children's neurological development was influenced by blood lead levels lower than 10 μg/dL. As a result, Slovak policy makers immediately addressed the problem, noting positive experiences of other countries when eliminating lead from gasoline.

The Slovak Republic encountered some unique obstacles en route to banning lead from gasoline. The three major obstacles were: (1) composition of the vehicle fleet to be addressed, (2) lack of accessibility to unleaded gasoline, both in production and purchase, and (3) limited knowledge of the general population in using unleaded gasoline [11].

In 1993, only 0.4 percent of all vehicles in the Slovak Republic were equipped with catalytic converters. Legislation implemented during that year required that only cars with three-way catalytic converters be imported or manufactured, but the turnover of the vehicle fleet was expected to take a long time. Vehicles are operated longer, and due to the high price of vehicles and the low relative income level of the population, the age of the vehicle fleet in the country is much older than that of most Western countries. Since only a small fraction of the vehicles were equipped with catalytic converters, the overriding motivation for the complete conversion to unleaded gasoline was not protection of the emission control devices but the elimination of the adverse health effects from exposure to lead emissions. Only one producer of gasoline exists in the Slovak Republic and that producer did not possess the technical capability to switch completely to unleaded gasoline. Additionally, it was discovered that motorists knew very little about the use of and differences between leaded and unleaded gasoline. For example, 90% of the respondents to a particular survey believed incorrectly that unleaded gasoline could only be used in cars equipped with catalytic converters [11].

The first step in remedying the situation in the Slovak Republic was public education. This was accomplished through the dissemination of information regarding the adverse health effects of lead (especially to children) and the environmental quality status of the country. The Ministry of Environment, established as the country's sole Environmental Agency since the breakup of the former Czechoslovakia, distributed brochures on the negative effects of heavy metals and high lead levels in children. This forced an adjustment by the Slovnaft refinery (the only refinery in the Slovak Republic) through three distinct steps to a complete transition to unleaded gasoline production in 1995 [19].

7.0 CONCLUSIONS

Worldwide ban of leaded gasoline would provide significant health and economic benefits. The primary benefit of unleaded gasoline is the elimination of the lead health hazards, one of which is the impairment of children's mental development. All pro-lead arguments pale in comparison to the need to protect children's mental development, making this a powerful reason to eradicate lead from gasoline. The general population also suffers from the effects of lead, in terms of high blood pressure and related cardiovascular conditions. Health studies show the correlation between a decrease in lead content of gasoline and a corresponding decrease in blood lead levels. These studies conclude that the major human lead burden source is via exhaust emissions from vehicles using leaded gasoline.

The introduction of unleaded gasoline also provides substantial emissions benefits to vehicle operation by permitting the use of catalytic converters, which can reduce up to 90 percent of harmful air pollutants – hydrocarbon, carbon monoxide, and nitrogen oxide emissions.

Other economic benefits of unleaded gasoline include significant reductions in vehicle maintenance costs and averted earning losses by the prevention of health ailments. These cost benefits easily outweigh the costs of refinery upgrading and alternative octane additives. Arguments to sustain leaded gasoline use to protect the valve seats of older engines are overstated – even older engines benefit from a switch to unleaded gasoline. The few older engines that can be viewed as somewhat susceptible to valve wear have decreased dramatically in number, and their valve seats can, in any event, be protected with modified operation to avoid very high vehicle speeds. Alternately, non-lead additives exist that can be employed, which are proven to protect old valve seats even though such action may not be necessary. Many countries routinely rebuild old engines and, during the rebuild process, Stellite valve seats can be shrunk-fit into the engine head. The Stellite seat combined with unleaded gasoline will be very durable and the entire engine system will avoid life shortening corrosion and wear.

The most effective policy approach for introducing unleaded gasoline and eliminating leaded gasoline is either an **immediate, 100 percent conversion** approach or a **rapid phase-out** approach. These approaches require refinery capability to replace TEL with alternative equal grade gasoline or temporary reliance on outside sources. Related refinery upgrading costs are recovered over the life of the investment.

The **immediate, 100 percent conversion** approach achieves reduced lead exposure levels in the shortest amount of time and avoids the capital cost burden of a second fuel distribution system. It also avoids contamination of the fuel and reduces the complexity of the fuel tax structure. The immediate, 100 percent conversion approach is a simple and the most effective strategy for eliminating the use of lead in gasoline. This approach has recently proven successful in Central American countries, China, India, Vietnam and the Philippines. Their experience in organizing cessation of leaded gasoline could serve as an example for countries now considering such a program.

The **rapid phase-out** approach achieves a rapid decline in lead content of leaded gasoline, and provides time for refineries to phase-in modifications necessary for the total "unleaded" system. The goal of lead elimination is usually reached within 4 to 6 years under this approach. However, it is more expensive and prolongs unnecessarily the adverse health effects to the populations exposed to lead emissions and has adverse economic impacts in terms of health care costs and reduced earning capacity.

The conclusions are clear. Protection of children's mental development is paramount and makes removing lead from gasoline a national and international priority. Leaded gasoline must be eliminated with all possible speed. The **immediate, 100 percent conversion** approach achieves this objective, and is therefore the one MECA highly recommends. The immediate, significant health benefits to a total ban of lead in gasoline makes the **rapid phase-out** approach a clearly distant second choice. With either an immediate or rapid conversion, the problem of valve wear on certain older engines when operated on unleaded gasoline, if any exists, is becoming increasingly remote. To the extent it is an issue, it can be dealt with through a public education program. Indeed, several countries recently switched immediately to unleaded gasoline, and none report any issues with valve wear. The claims regarding benzene emissions can be avoided by adhering to the World-Wide Fuels Charter benzene specification limits and through the selection of various low benzene refinery processes or non-lead, non-metallic, additives (the MMT additive is to be avoided). Neither of these arguments (valve wear or benzene emissions) should enter into the discussion as reasonable arguments against the ban of leaded gasoline. The **phase-in/phase-out** approach is too lengthy a process and should not be considered. All countries that now have high leaded gas concentrations beyond 0.12 g/l should immediately take steps to reduce to this level for the protection of their citizens – especially their children.

Government officials inherited this leaded gasoline problem – action now to ban leaded gasoline will be forever to their credit. The adverse health and economic impacts of using lead in gasoline are now well established. A rapidly growing number of countries have made, or are making, the conversion to 100 percent unleaded gasoline. Unfortunately, in a number of countries, leaded gasoline is still widely used. A growing coalition of government officials, auto and engine manufacturers, environmental and health organizations, oil companies and others are calling for an end to the use of lead in gasoline, and an increasing number of world leaders are calling upon the TEL industry to put the health of the World's children ahead of corporate profits.

The Dakar Accord signed in 2001 by 17 Sub-Saharan African nations to eliminate leaded gasoline and the international assistance being provided through the Clean Fuels and Vehicles Partnership, established in September 2002, will hopefully provide the impetus to end the use of lead in gasoline worldwide by 2005. To achieve this goal, government, industry and NGOs must work together. MECA pledges its support and assistance to any government around the World working to remove lead from gasoline.

The Case for Banning Lead in Gasoline

The 3rd edition of World-Wide Fuel Charter (WWFC), December 2002, included a key change for all gasoline fuel specification categories, calling for the elimination lead in fuel worldwide to avoid potential health risks and damage to catalysts. Automakers and engine manufacturers around the world support efforts to end the use of lead in gasoline [25].

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Appendix I
Status of Lead Removal from Gasoline

Country	Mainly Leaded Gasoline	Leaded Gasoline Being Replaced By Unleaded Gasoline	Unleaded Gasoline Sales Only
North America			
Bermuda			
Canada			
Mexico			
United States			
Caribbean Sea			
Antigua			
Barbuda			
Bahamas			
Cuba			
Dominican Republic			
Haiti			
Jamaica			
Puerto Rico			
Saba			
St. Eustasius			
Trinidad & Tobago			
U.S. Virgin Islands			
Central America			
Belize			
Costa Rica			
El Salvador			
Guatemala			
Honduras			
Nicaragua			
Panama			

Country	Mainly Leaded Gasoline	Leaded Gasoline Being Replaced By Unleaded Gasoline	Unleaded Gasoline Sales Only
South America			
Argentina			
Bolivia			
Brazil			
Chile			
Colombia			
Ecuador			
French Guiana			
Guyana			
Paraguay			
Peru			
Suriname			
Uruguay			
Venezuela			
Europe			
Albania			
Andorra			
Austria			
Belarus			
Belgium			
Bosnia & Herzegovina			
Bulgaria			
Croatia			
Czech Republic			
Denmark			
Estonia			
Finland			
France			
Germany			
Great Britain			
Greece			
Hungary			

Country	Mainly Leaded Gasoline	Leaded Gasoline Being Replaced By Unleaded Gasoline	Unleaded Gasoline Sales Only
Europe Cont'd			
Iceland			■
Ireland			■
Italy		■	
Latvia		■	
Liechtenstein			■
Lithuania		■	
Luxemburg			■
Macedonia		■	
Malta		■	
Moldova		■	
Monaco			■
Netherlands			■
Norway			■
Poland			■
Portugal			■
Romania		■	
Russia		■	
San Marino		■	
Spain		■	
Slovakia			■
Slovenia		■	
Sweden			■
Switzerland			■
Ukraine		■	
Vatican		■	
Yugoslavia		■	
Africa			
Algeria	■		
Angola	■		
Benin	■		
Botswana	■		

Country	Mainly Leaded Gasoline	Leaded Gasoline Being Replaced By Unleaded Gasoline	Unleaded Gasoline Sales Only
Africa Cont'd			
Burkina Faso			
Burundi			
Cameroon			
Cape Verde			
Central African Republic			
Chad			
Comoros			
Congo			
Cote d'Ivoire			
Democratic Rep. of the Congo			
Djibouti			
Egypt			
Equatorial Guinea			
Eritrea			
Ethiopia			
Gabon			
Gambia			
Ghana			
Guinea			
Guinea-Bissau			
Kenya			
Lesotho			
Liberia			
Libya			
Madagascar			
Malawi			
Mali			
Mauritania			
Mauritius			
Mayotte (Fr.)			
Morocco			
Mozambique			
Namibia			
Niger			

Country	Mainly Leaded Gasoline	Leaded Gasoline Being Replaced By Unleaded Gasoline	Unleaded Gasoline Sales Only
Africa Cont'd			
Nigeria	■		
Reunion (Fr.)	■		
Rwanda	■		
Sao Tome and Principe	■		
Senegal	■		
Seychelles	■		
Sierra Leone	■		
Somalia	■		
South Africa		■	
Sudan	■		
Swaziland	■		
Tanzania	■		
Togo	■		
Tunisia	■		
Uganda	■		
Western Sahara			■
Zambia	■		
Asia			
Afghanistan (Islamic State of)	■		
Bangladesh			■
Bhutan			■
Brunei			■
China (People's Republic of)			■
Hong Kong			■
India			■
Indonesia (Republic of)	■		
Japan			■
Kampuchea (Cambodia)	■		
Kazakhstan (Republic of)			■
Kyrgyzstan (Republic of)		■	
Laos	■		
Macau			■
Country	**Mainly Leaded Gasoline**	**Leaded Gasoline Being Replaced**	**Unleaded Gasoline Sales**

Country	Mainly Leaded Gasoline	Leaded Gasoline Being Replaced By Unleaded Gasoline	Unleaded Gasoline Sales Only
Asia Cont'd			
Malaysia			
Mongolia			
Nepal			
Pakistan (Islamic Republic of)			
Philippines			
Singapore			
South Korea			
Sri Lanka			
Taiwan			
Tajikistan			
Thailand			
Turkmenistan			
Uzbekistan (Republic of)			
Vietnam (Socialist Republic of)			
Middle East			
Armenia			
Azerbaijan (Republic of)			
Bahrain			
Cyprus			
Gaza Strip			
Georgia			
Iran			
Iraq			
Israel			
Jordan			
Kuwait			
Lebanon			
Oman			
Qatar			
Saudi Arabia			
Syria			
Turkey			
United Arab Emirates			

		By Unleaded Gasoline	Only
Middle East Cont'd			
West Bank			
Yemen			
Indian Ocean			
Madagascar			
Pacific Ocean			
Australia			
Guam			
New Zealand			
Tasmania			

NOTE: INFORMATION UNAVAILABLE FOR COUNTRIES NOT LISTED