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Joint United Nations Development Programme / World Bank

ESMAP

Energy Sector Management Assistance Programme

Elimination of Lead in Gasoline in Latin America and the Caribbean

Status Report, December 1997

Report No. 200/97EN

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JOINT UNDP / WORLD BANK
ENERGY SECTOR MANAGEMENT ASSISTANCE PROGRAMME (ESMAP)

PURPOSE

The Joint UNDP/World Bank Energy Sector Management Assistance Programme (ESMAP) is a special global technical assistance program run as part of the World Bank's Energy, Mining and Telecommunications Department. ESMAP provides advice to governments on sustainable energy development. Established with the support of UNDP and bilateral official donors in 1983, it focuses on the role of energy in the development process with the objective of contributing to poverty alleviation, improving living conditions and preserving the environment in developing countries and transition economies. ESMAP centers its interventions on three priority areas: sector reform and restructuring; access to modern energy for the poorest; and promotion of sustainable energy practices.

GOVERNANCE AND OPERATIONS

ESMAP is governed by a Consultative Group (ESMAP CG) composed of representatives of the UNDP and World Bank, other donors, and development experts from regions benefiting from ESMAP's assistance. The ESMAP CG is chaired by a World Bank Vice President, and advised by a Technical Advisory Group (TAG) of four independent energy experts that reviews the Programme's strategic agenda, its work plan, and its achievements. ESMAP relies on a cadre of engineers, energy planners, and economists from the World Bank to conduct its activities under the guidance of the Manager of ESMAP, responsible for administering the Programme.

FUNDING

ESMAP is a cooperative effort supported over the years by the World Bank, the UNDP and other United Nations agencies, the European Union, the Organization of American States (OAS), the Latin American Energy Organization (OLADE), and public and private donors from countries including Australia, Belgium, Canada, Denmark, Germany, Finland, France, Iceland, Ireland, Italy, Japan, the Netherlands, New Zealand, Norway, Portugal, Sweden, Switzerland, the United Kingdom, and the United States of America.

FURTHER INFORMATION

An up-to-date listing of completed ESMAP projects is appended to this report. For further information, a copy of the ESMAP Annual Report, or copies of project reports, contact:

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Preface

During the Summit of the Americas held in December 1994, 34 heads of state and government of the Americas agreed to develop and implement national action plans to phase out lead additives in gasoline under the Partnership for Pollution Prevention. This initiative led to a joint effort by national, regional, and international bodies to effect the transition to unleaded gasoline. A description of the initial phase of the project, including the results of a comprehensive regional survey, can be found in a prior ESMAP publication, *Elimination of Lead in Gasoline in Latin America and the Caribbean, Status Report, December 1996* (World Bank 1997).

This second report presents technical issues related to the elimination of lead in gasoline, as well as country-specific case studies that illustrate how different aspects of gasoline lead phase-out have been examined and implemented. The technical issues covered are the health impact of lead elimination, biological monitoring of lead, the effects of lead in gasoline and of its elimination on vehicles, and motor fuel reformulation. The country case studies discussed here concern Chile, El Salvador, Jamaica, and Peru.

The report also provides an overview of the progress achieved in Latin America and the Caribbean in the implementation of the lead phase-out national action plans as of December 1997. Most countries in the region have made significant progress toward complete lead phase-out. Some countries, such as the Dominican Republic, Haiti, Peru, and Trinidad and Tobago, are now considering an earlier date for lead elimination than originally planned. Exchanging information with countries that have already phased-out lead or that are undergoing lead phase-down, and receiving technical input from international experts, has helped accelerate lead elimination. The need to build a consensus among stakeholders affected by lead removal has been widely recognized and acted upon, along with the necessity of conducting public education campaigns.

The ongoing efforts under the auspices of this project, *Elimination of Lead in Gasoline in Latin America and the Caribbean*, has led not only to rapid implementation of gasoline-lead phase-out, but also to further efforts to improve urban air quality and to foster regional economic integration, such as an initiative to explore the regional harmonization of fuel specifications.

The question of how best to reformulate gasoline after lead removal inevitably raises the issue of the effect of fuel composition on vehicular emissions in general, which in turn have an impact on air quality. Assessing parameters that affect air quality leads to examination of fuel specifications other than those for gasoline, and to the search for least-cost solutions to pollution abatement, which include an in-depth analysis of the configuration and economics of refineries. The report explores the issues arising from gasoline-lead phase-out plans that are under consideration in Latin America and the Caribbean.

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The following individuals have made significant technical contributions to this report: Luiz Augusto Cassanha Galvão of PAHO/WHO (Chapters 2 and 3); Janie Gittleman of Allegheny University (Chapter 3); Christopher Weaver of Engine, Fuel, and Emissions Engineering (Chapter 4); William Cummings of Texaco and William Keesom of UOP (Chapters 5 and 6); Claude Davis of Bovar Environmental (now of Claud Davis & Associates) (Chapter 8); and Gregorio Neglia Ortiz of Inspectra (Chapter 9).

The following government representatives were instrumental in carrying forward the country case studies discussed in this report: José Antonio Ruiz, Chief of Hydrocarbons, National Commission for Energy in Chile; Gina Navas de Hernandez, Director of Hydrocarbons and Mines, Ministry of Economy in El Salvador; Ianthe Smith, Senior Director, Pollution Control and Waste Management Division, Natural Resources Conservation Authority, Jamaica; and Eduardo Chullen Dejo, Vice-Minister of Housing and Construction, Peru.

This report was prepared by Masami Kojima. The ESMAP team that continues to work on the project includes Eleodoro Mayorga-Alba, task manager; Cor van der Sterren; and Masami Kojima, all of the Oil and Gas Unit of the World Bank. Magda Lovei of the Environment Department of the World Bank and Thuvara S. Nayar of the Oil and Gas Unit provided valuable comments on the report. The assistance of Caroline McEuen in editing the English version, and Inspectra S.A. in translating the report into Spanish is gratefully acknowledged.

Abbreviations and Acronyms

AKI	anti-knock index
ARAPER	Asociación de Representantes Automotrices del Perú
ARPEL	Asistencia Recíproca Petrolera Empresarial Latinoamericana
ASTM	American Society for Testing and Materials
bbl	barrels
b/cd	barrels per calendar day
b/d	barrels per day
BTX	benzene/toluene/xylenes
CARB	California Air Resources Board
CCR	continuous catalyst regeneration
CDC	Centers for Disease Control and Prevention
CNG	compressed natural gas
CO	carbon monoxide
CONACO	Concejo Nacional de la Construcción
CONAM	Comisión Nacional del Medio Ambiente
CONAMA-RM	Comisón Nacional del Medio Ambiente de la Región Metropolina
DIGESA	Dirección General de Salud Ambiental
DIPE	di-isopropyl ether
dl	deciliter (0.1 liter)
E100(°F)	volume percent of fuel that evaporates at 100°F
ENAP	Empresa Nacional del Petróleo
EPEFE	European Programme on Emissions, Fuels and Engine Technologies
ESMAP	Energy Sector Management Assistance Programme
ETBE	ethyl tertiary butyl ether
EU	European Union
FCC	fluidized catalytic cracking
FUSADES	Fundación Salvadoreña para el Desarrolo Económica y Social
g	gram
GDP	gross domestic product
g/l	gram per liter
h	hour
HC	hydrocarbons

HF	hydrofluoric acid
IDB	Inter-American Development Bank
I/M	inspection and maintenance
INAIT-MTC	Instituto Nacional de Investigación del Transporte del Ministerio de Transporte y Construcción
INDECOPI	Instituto Nacional de Defensa del Consumidor y de la Concurrencia
IQ	intelligence quotient
IPIECA	International Petroleum Industry Environmental Conservation Association
JBS	Jamaica Bureau of Standards
JGRA	Jamaica Gasoline Retailers' Association
km	kilometer
l	liter
LPG	liquefied petroleum gas
MACAM	Monitoreo Contaminantes Atmosféricos
Mercosur	Mercado Común de Sud América
mg	milligram, 10^{-3} g
mg/l	milligram per liter
MMT	methylcyclopentadienyl manganese tricarbonyl
Mn	manganese
MON	motor octane number
MPUT	Ministry of Public Utilities, Transport and Energy
MTBE	methyl tertiary butyl ether
NAAQS	National Ambient Air Quality Standards (U.S.)
NGO	nongovernmental organization
NHANES	National Health and Nutritional Examination Survey
NO	nitrogen monoxide or nitric oxide
NO_2	nitrogen dioxide
NO_x	oxides of nitrogen
NRCA	Natural Resources Conservation Authority
O_3	ozone
OAS	Organization of American States
OLADE	Organización Latinoamericana de Energía
OTAG	Ozone Transport Assessment Group
PAHO	Pan American Health Organization
Pb	lead
PCJ	Petroleum Corporation of Jamaica
PDVSA	Petróleos de Venezuela
PM_{10}	particulate matter with an aerodynamic diameter smaller than 10 µm

$PM_{2.5}$	particulate matter with an aerodynamic diameter smaller than 2.5 μm
ppm	parts per million
psi	pounds per square inch
(R+M)/2	average of research and motor octane numbers
RON	research octane number
RVP	Reid vapor pressure
SO_2	sulfur dioxide
SO_x	oxides of sulfur
Swisscontact	Swiss Foundation for Technical Cooperation
t	(metric) tons
T10	temperature at which 10 volume percent of fuel evaporates
TAME	tertiary amyl methyl ether
TEL	tetraethyl lead
TSP	total suspended particulates
t/y	(metric) tons per year
UNDP	United Nations Development Programme
USAID	United States Agency for International Development
U.S. DOE	United States Department of Energy
U.S. EPA	United States Environmental Protection Agency
VOC	volatile organic compounds
vol	volume
vol%	volume percent
WHO	World Health Organization
wt	weight
wt%	weight percent
wt ppm	parts per million by weight
μg	microgram, 10^{-6} g
μg/dl	micrograms per deciliter
$\mu g/m^3$	micrograms per cubic meter
μm	micron, 10^{-6} m

Executive Summary

Overview

1 There has been a concerted effort in Latin America and the Caribbean to phase lead out of gasoline. The consumption of lead decreased from 27,400 metric tons in 1990 to 8,200 metric tons in 1996, and is expected to decrease further, to 4,300 tons, by the year 2000. This significant reduction in the use of lead in gasoline is driven by concern for the adverse impact of lead on public health, particularly on the intellectual development of children.

2 A project under the sponsorship of the UNDP/World Bank Energy Sector Management Assistance Programme (ESMAP), *Elimination of Lead in Gasoline in Latin America and the Caribbean*, has acted as a catalyst in initiating (in countries where lead phase-out had not yet begun) and accelerating the formulation and implementation of national lead phase-out action plans. The project has provided a forum for collecting up-to-date information, conducting dialogue among all the stakeholders and building a consensus in individual countries, and fostering intercountry communication and cooperation. As a result, national lead phase-out action plans have been formulated by those who are ultimately responsible for formulating and implementing the new regulations.

3 There is also a growing consensus in the region that elimination of lead from gasoline cannot be tackled in isolation, but needs to be viewed as one of the first steps in a broader, integrated air pollution management program. As lead is eliminated from gasoline, the question of how to make up for the octane shortfall arises. For countries with refineries, upgrading refineries for lead elimination raises the question of how best to optimize refinery reconfiguration in order to meet overall future product demand, both in quantity and quality. Environmental ministries may be concerned about how to ensure that unleaded gasoline does not result in higher emission levels of pollutants other than lead. This concern, together with the desire to improve air quality in general, often leads to the tightening of fuel specifications, establishing air quality and vehicle emissions standards, monitoring air quality, and introducing a vehicle inspection and maintenance program. This project addresses some of the foregoing issues.

Technical Issues

4 The most frequently cited concern about removal of lead from gasoline is its impact on engine-exhaust valve-seats. Lead acts as a lubricant, and the removal of lead can result in an engine failure known as "valve-seat recession" in old cars with soft valve seats. In

practice, valve seat recession has rarely been found to be a problem, and no country in Latin America and the Caribbean has reported major consumer complaints to date.

5 Another concern that is voiced is the increased use of aromatics, including benzene, in unleaded gasoline. The amount of benzene can be controlled by proper refinery configuration and by placing a limit on benzene in gasoline standards. The addition of ethers not only increases gasoline octane but also has a dilution effect, lowering the level of total aromatics.

6 Aside from benzene, there are other parameters that may need to be controlled to ensure acceptable air quality. In terms of cost-effectiveness, sulfur and volatility in gasoline, and sulfur and distillation control in diesel, should receive high priority. In Chile, an international roundtable with industry and environmental ministry representatives was held to discuss how best to reformulate gasoline and diesel.

7 Eliminating lead from gasoline and introducing more stringent fuel specifications make it difficult for small hydroskimming refineries to operate economically. Further, international refined petroleum product prices are not necessarily directly linked to the cost of production; product prices may remain relatively low, even when the production cost has gone up because more stringent fuel specifications must be met. It is important for refineries to ensure that investments made to comply with new fuel standards also increase the efficiency of their operations so that they remain competitive.

8 The level of lead in blood has been shown to be correlated with the intelligence quotient in a number of studies. During and after the phase-out of lead in gasoline, it may be informative to monitor lead in blood to assess the impact of lead elimination. Two target populations recommended for study are children and occupationally exposed workers.

Gasoline Lead Elimination Strategies

9 In El Salvador, gasoline lead was eliminated in less than a year. This rapid phase-out had the advantage of not requiring the substantial investment needed to set up a dual gasoline distribution system and minimizing the period of possible cross-contamination and misfueling. Such a rapid transition to unleaded gasoline was possible, in part because the entire petroleum downstream sector was in private hands, prices were completely deregulated, and there were product imports. For air quality management, the government is currently involved in the regional harmonization of fuel specifications and vehicle emissions standards for Central America and is setting up a vehicle inspection and maintenance (I/M) program.

10 In Jamaica, the lead elimination strategy involves, *inter alia*, moving from a gasoline market with only one octane grade to a regime that includes two or more grades. The current gasoline research octane number (RON) is 95, which is unnecessarily high for the needs of most vehicles in the country. By introducing a lower octane grade, which is expected to capture the majority of the market, the impact of the octane shortfall created by

lead removal on the domestic refinery is reduced. During the transition period, when both leaded and unleaded gasoline is available, taxes on gasoline can be adjusted in such a way that the total fiscal intake is the same or greater for the government, while the pump price of regular unleaded gasoline is set lower than that of regular leaded as an incentive for consumers to switch to unleaded gasoline and to minimize chances of misfueling.

11 In Peru, the government has a comprehensive plan to tackle urban air pollution, and launched the *Program for the Improvement of Air Quality and the Elimination of Lead from Gasoline*. Under this program, technical committees were set up to address fuel specifications and lead removal; air quality, environmental and biological monitoring; development of air quality, fuels, and vehicle emissions standards; and public education, particularly with respect to the benefits of using unleaded gasoline.

12 The number of countries in Latin America and the Caribbean that have eliminated, or have firm plans to eliminate, gasoline lead is significant and growing. This publication presents the situation up to December 1997 and distills some of the lessons learned in the region.

1

Project Description, Key Issues, and Progress to Date

Project Description

1.1 At the Summit of the Americas held in Miami, Florida, in December 1994, the heads of state of 34 countries in the Western Hemisphere signed onto the Summit Action Plan, which included an environmental initiative, the "Partnership for Pollution Prevention." Under this initiative, the respective governments committed themselves to developing and implementing national action plans to phase out lead additives in gasoline. Lead has long been added to gasoline as an octane enhancer. It is the cheapest source of octane, but it is also extremely damaging to human health. In the last two decades, there has been mounting evidence of adverse health effects of lead, even at levels previously considered safe. Leaded gasoline is now banned in a number of countries around the world (with varying levels of per capita gross domestic product, GDP), including Austria, Bolivia, Canada, El Salvador, Japan, the Slovak Republic, Thailand, and the United States.[1]

1.2 As a follow-up to the 1994 Summit of the Americas, a meeting of technical experts was convened in Puerto Rico in November 1995. At that meeting, two lead-risk-reduction projects were designed. The first project was planned to facilitate the development of national action plans to eliminate lead from gasoline in the Americas by the year 2001. The second was to generate an inventory of the health and environmental risks from differing sources of lead exposure to support national plans to reduce concentrations of lead in blood to levels consistent with the recommendations made by the World Health Organization (WHO).

[1] An overview of the worldwide experience in eliminating lead from gasoline and issues associated with it can be found in Lovei (1996).

1.3 To ease the transition to unleaded gasoline, a group of international, regional, and national organizations has come together and initiated a joint project to accomplish the following:

- Assist governments in the Americas in formulating and implementing national plans to phase out the use of leaded gasoline
- Exchange information and experience
- Provide technical assistance
- Promote regional cooperation.

Under the leadership of the World Bank's ESMAP team, the organizations involved in the project include the Organization of American States (OAS), Asistencia Recíproca Petrolera Empresarial Latinoamericana (ARPEL), Organización Latinoamericana de Energía (OLADE), Pan American Health Organization (PAHO), Inter-American Development Bank (IDB), U.S. Agency for International Development (USAID), U.S. Department of Energy (U.S. DOE), and U.S. Environmental Protection Agency (U.S. EPA).

1.4 National lead focal points were appointed in individual countries to act as liaisons between the aforementioned organizations and those responsible within their own countries for formulating and executing the national lead phase-out plans. A detailed description of the organization of the project can be found in a prior publication, *Elimination of Lead in Gasoline in Latin America and the Caribbean, Status Report, December 1996*, ESMAP Report No. 194/97EN (World Bank 1997).

Project History

1.5 The first activity of the project was to conduct a comprehensive regional diagnostic survey. A questionnaire was distributed to countries in Central America, South America, Mexico, and the Caribbean. It was designed to provide an initial database and covered a wide range of subjects related to motor fuel production, consumption, and product specifications; vehicle fleets, regulations, and environmental and health issues; and possible opportunities for regional cooperation and technical assistance. The survey found that gasoline lead elimination was proceeding at a rapid pace in the region. More specifically, 10 countries had eliminated the sale of leaded gasoline by the end of 1996, and at the time of the survey, this number was expected to increase to 14 by the end of 2000. The consumption of lead decreased from 27,400 metric tons in 1990 to 10,300 metric tons in 1996 (subsequently corrected to 8,200 tons), and it was expected to decrease further to 6,400 tons by the year 2000. (The full results of the survey, as well as the description of the National Officials' Seminar—see below—are documented in the publication ESMAP Report No. 194/97EN.)

1.6 In parallel with the survey, a number of studies were undertaken. They concerned:

- Health and environmental impacts of using leaded and unleaded gasoline
- Technical and economic issues related to the effects of eliminating leaded gasoline on vehicles
- Biological and environmental monitoring of lead.

The results of the survey and the studies were presented at a National Officials' Seminar held in Santiago de Chile in September 1996. The seminar drew together the national focal points and representatives from international, regional, and national organizations, as well as nongovernmental organizations (NGOs). The seminar gave participants an opportunity to discuss regional trends and status, exchange information, and identify specific needs for assistance. The participants also prepared a resolution for submission to the region's political authorities.

1.7 Following the seminar, a number of countries approached the World Bank for assistance. Country case studies were launched on the basis of these requests. The countries that requested technical assistance are the following:

- Chile, to organize a roundtable discussion on fuel reformulation
- The Dominican Republic, to prepare a lead phase-out plan, including new product specifications and a public information campaign
- Ecuador, to evaluate the technical and financial feasibility of required refinery upgrade schemes
- El Salvador, to assess lead elimination and urban air-quality management
- Jamaica, to prepare a comprehensive lead phase-out plan: setting a time table for lead elimination, establishing new gasoline specifications, examining the octane requirements of the current and future vehicle fleet and assessing the likelihood of the occurrence of valve-seat recession; establishing a new gasoline tax structure; and conducting a public information campaign
- Peru, to coordinate their overall air pollution abatement strategy, with lead phase-out as a key component
- Trinidad & Tobago, to prepare a comprehensive lead phase-out plan, as in the case of Jamaica.

1.8 Using funds provided by the European Union (EU), OLADE has launched country case studies on lead phase-out in Ecuador, Panama, and Paraguay. The World Bank has worked closely with OLADE, and jointly sponsored a regional workshop in Quito, Ecuador, in October 1997 to review the results of the OLADE studies and progress made elsewhere.

1.9 In addition, the World Bank team, together with PAHO, held a series of discussions with the authorities in Venezuela to discuss the impact of gasoline lead on environmental degradation. The state oil company, Petróleos de Venezuela (PDVSA), plans to start selling unleaded gasoline at 150 retail outlets beginning in 1999. In Haiti, the World Bank has held discussions with major stakeholders in petroleum-product trade to accelerate the phase-out of lead from gasoline. After consultation with the stakeholders in the industry, a decision was made to move from a gasoline market with only one octane grade available, at 95 research octane, to a market with two grades, the lower corresponding to an octane index (average of research and motor octane numbers) of 87, to ease the transition to unleaded gasoline. A decree is currently being prepared to complete the elimination of lead from gasoline in 1998. This plan is very similar to that adopted in Jamaica (which is covered in Chapter 8).

1.10 Future programs include holding a workshop for small Caribbean countries to discuss plans for lead phase-out that are similar to the process adopted in Jamaica and Haiti, and assisting Paraguay with a very small refinery to adopt a lead-free gasoline market. The latter may entail the closure of the refinery.

1.11 Aside from country-specific case studies, there is another regional effort under the umbrella of this project—the regional harmonization of the technical specifications for LPG, gasoline, diesel, and distillate heating oil (the proposed specifications are discussed in Chapter 5). Further, there is a proposal for a related study, which is being pursued, to examine the impact of demand growth, as well as future environmental and fuel regulations, on the level of investment needed by the refining industry in the region and financing options for that investment.

Key Issues

1.12 There are a number of issues that arise from the phase-out of lead in gasoline. It is important to consider and address carefully each of these issues in the process of gasoline-lead elimination.

Monitoring the Impacts of the Lead Phase-out

1.13 One of the principal objectives of the lead phase-out is to reduce the amount of airborne lead and lead deposited in soil, water, and vegetation, and to lower overall lead intake, as indicated, for example, by the level of lead in blood. If there are other significant sources of lead, such as lead in drinking water or lead-based paint, elimination of lead from gasoline may have a limited impact on the level of lead in the human body. It would therefore be useful to monitor the level of airborne lead, as well as lead in blood, which is generally accepted as a good biological marker for lead. It is also important to identify all sources of lead and to estimate the contribution of each individual source. (A proposal for biological monitoring of lead is presented in Chapter 3.)

Effects of Lead Elimination on Vehicles

1.14 In order to prevent the buildup of lead deposits in the combustion chamber, lead is added to gasoline with ethylene dichloride and ethylene dibromide, which upon decomposition form hydrochloric and hydrobromic acids, respectively. Lead in gasoline also acts as a lubricant. These elements affect the performance, durability, and maintenance of vehicles and vehicle parts. In the past, the lubricating properties of lead enabled car manufacturers to use soft metals for engine exhaust valve seats. In extreme cases, the elimination of lead has resulted in the failure of these older engines through what is known as "valve-seat recession." The percentage of cars likely to be affected by valve-seat recession depends on the driving mode, as well as the age of the vehicles. While this issue should be examined and addressed in the process of lead elimination, valve-seat recession has rarely been found to be a problem in practice. In Latin America and the Caribbean, the vehicle fleet is often dominated by Japanese cars, and although anti-valve-seat recession additives have not been used following lead removal, there have been no serious claims of valve-seat damage from automobile owners.

1.15 Lead elimination decreases the overall maintenance costs of cars because lead, with its chlorine- and bromine-containing additives, builds up deposits, corrodes engine exhaust valves and vehicle exhaust systems, fouls spark plugs, and contaminates engine oil. The savings in vehicle maintenance offset the higher cost of producing unleaded gasoline (These issues are covered in Chapter 4).

Gasoline Composition after Lead Removal

1.16 Because lead is an octane booster, lead removal lowers the octane of the unleaded gasoline. The octane shortfall must be compensated by other components. There are refinery streams that are high in octane: light hydrocarbons, such as butanes; reformate; alkylate; isomerate; fluidized catalytic cracker (FCC) naphtha; and light olefin oligomers. Ethers and alcohols are also high in octane, and may be added to gasoline.

1.17 There are, however, environmental consequences for any changes made in gasoline composition. Reformate has a high content of aromatics, including benzene, a known carcinogen. Aromatics with two or more alkyl branches are known to be photochemically reactive and participate in ground-level ozone formation. FCC naphtha contains a fair amount of light olefins, which are also photochemically reactive. Butanes have high volatility, so that if the Reid vapor pressure (RVP) of gasoline is raised through butane addition, gasoline volatility increases, resulting in higher hydrocarbon emissions. Ethers such as methyl tertiary butyl ether (MTBE) are more soluble in water than hydrocarbons and are also more readily detected because of their smell. There have been a few isolated cases in California of gasoline containing MTBE leaking from underground storage tanks, which led to MTBE contamination of groundwater that required cleanup. These incidents have been rare, however, and do not necessarily suggest that the addition of MTBE in itself is undesirable, but rather highlight the importance of ensuring that fuel-storage tanks are leak-free.

1.18 In the case of catalyst-equipped cars, the total amount of aromatics in gasoline has been shown to have essentially no effect on ozone formation. For cars not equipped with catalytic converters, however, an increase in aromatics raises the emissions of oxides of nitrogen (NO_x), and old data indicate that increasing aromatics could also increase hydrocarbon emissions.

1.19 There are steps one can take to minimize the potentially adverse consequences of eliminating lead from gasoline. These measures are discussed in Chapter 5. It is clear that the selection of gasoline components for octane-loss compensation after lead elimination should take into consideration overall air quality, as well as vehicle fleet characteristics in a given city. The Chilean country case study focused on this issue (presented in Chapter 6). It should be borne in mind, however, that the toxicity of lead is much greater than the adverse health effects of other vehicle emissions.

Refinery Modifications

1.20 Alkylation, high-severity reforming, catalytic cracking, skeletal isomerization, and etherification are refinery processes that may need to be added or expanded as a result of lead removal. These refinery modifications require a capital outlay, and sources of funding must be found. In Latin America and the Caribbean, these investments must sometimes take place in the context of increasing market deregulation and, in some instances, privatization. The pace of gasoline-lead phase-out, the new gasoline composition selected, and the total cost of eliminating lead from gasoline are all affected by the state of the refineries in the country in question and relative costs of domestic refining compared with those of importing unleaded gasoline or high-octane gasoline-blending components, including oxygenates.

1.21 Further, refinery modifications for lead elimination nearly always affect the production of other fuels. Therefore, changes in gasoline specifications may affect the production or yield of diesel and fuel oil, and changes in the specifications of the latter may affect gasoline production. For example, reduction of sulfur in diesel will require more hydrogen, so that the expansion of a reforming unit may benefit both gasoline octane and reduction of diesel sulfur. Concerns over aromatics and decreasing the severity of the reformer will decrease hydrogen production, which will affect the availability of hydrogen to reduce sulfur in other refinery streams.

Pricing

1.22 Because lead is the cheapest octane booster, the cost of producing unleaded gasoline has historically been higher than that of producing leaded gasoline. Prices, in contrast, are determined by many competing factors, and they do not necessarily reflect the cost of production. Along the U.S. Gulf Coast, the implementation of the 1990 Amendments to the Clean Air Act did not result in a dramatic increase in the price of reformulated gasoline relative to conventional gasoline. Refiners typically do not fully recover the cost of investments made to meet more restrictive fuel specifications, such as the removal of lead. Countries that import gasoline benefit directly from the differential between cost and price increases, because they may not have to pay much more for the new fuel. In contrast, small hydroskimming refineries become decreasingly competitive as fuel specifications become increasingly stringent.

1.23 Nearly all countries choose to have a transition period, during which both leaded and unleaded gasolines are available on the market. If the pump price of unleaded gasoline simply reflects the cost of production and is higher than that of leaded gasoline, "misfueling" becomes a serious problem: car owners who have catalyst-equipped vehicles purchase leaded rather than unleaded gasoline. Lead in gasoline poisons the noble metals in catalytic converters, permanently deactivating them. Leaded gasoline should thus never be used in cars equipped with catalytic converters.

1.24 In order to minimize the chances of misfueling, many governments have elected to lower the tax on unleaded gasoline so that the pump price of unleaded gasoline is actually lower than that of leaded gasoline. This, in turn, has ramifications for the overall fiscal receipts unless the tax on leaded gasoline is increased or there is a rapid increase in gasoline consumption. The study on Jamaica detailed in Chapter 8 shows how the government might be able to increase tax revenues while eliminating lead in gasoline, taking advantage of the unnecessarily high octane currently in use in Jamaican gasoline.

Integrated Air Pollution Abatement Strategy

1.25 Because the elimination of lead in gasoline has ramifications far beyond simply removing lead from the fuel, an integrated strategy for air pollution abatement should ideally be pursued in developing a plan for lead elimination. High levels of airborne lead from gasoline-fueled vehicles typically go hand in hand with serious air pollution from mobile sources in general. The availability of accurate data on air quality and an emissions inventory would help enormously in formulating a sound strategy. Both mobile and stationary sources of emissions should be examined to identify the least-cost solution. Air quality standards, vehicle emissions standards, and fuel specifications should be established in the context of prevailing local conditions.

1.26 In many developing countries, however, the necessary data are not available. While it would be very important to start obtaining reliable air quality data and setting up an emissions inventory, one can also draw lessons from experience elsewhere and start implementing certain steps in advance of gathering local data. Some pollution control measures fall in the category of "no regrets" policy, and lead removal is one of them. It would not make much sense to delay lead phase-out by a number of years in order to launch and complete a comprehensive study of air quality and fuel reformulation. The collective experiences of other countries are available to countries now attempting to devise cost-effective and environmentally beneficial solutions to their urban air quality concerns.

1.27 The most effective measure for combating air pollution from gasoline-fueled vehicles is the use of catalytic converters. This technology, in turn, requires lead elimination. Further, the level of sulfur in the fuel should be minimized for catalytic converters to be effective. Poorly maintained old engines are the most serious source of pollutant emissions. Maintaining and improving overall vehicle technology in general has an even greater impact on improving air quality than does fuel reformulation.

1.28 A significant level of investment might be needed in refining as well as in the provision of appropriate vehicle technology to regulate emissions. The benefit to society of the investments would be substantially lower, however, if compliance is not monitored through an effectively enforced inspection and maintenance (I/M) program. Carrying out such a comprehensive air pollution abatement strategy would require the cooperation of not only the refining and automobile industries, but also of scientists, state regulators, and those responsible for stationary sources of emissions.

Regional Progress in Lead Phase-Out

1.29 In 1990, a total of 27,400 metric tons of lead was added to gasoline in Latin America and the Caribbean. This amount has since been reduced substantially. By the end of 1997, 14 countries in the region had eliminated lead in gasoline: Antigua & Barbuda, Argentina, Bahamas, Bermuda, Bolivia, Brazil, Columbia, Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua, Saba, and St. Eustasius. A survey conducted by Alconsult at the beginning of 1996 projected the amount of lead that would be added to gasoline in 1996 and 2000. The results are summarized in Table 3.8 in the publication *Elimination of Lead in Gasoline in Latin America and the Caribbean, Status Report, December 1996*. Since the survey, much progress has been made, and revised estimates are given in Table 1.1. The table shows the total amount of lead added to gasoline in 1996; the estimated amounts in the year 2000 according to the original survey and the new estimates based on more accelerated lead phase-out plans; and a forecast for the year 2005. There are several figures for 1996 that differ from the original survey results; the new figures reflect the actual amounts added in 1996.

1.30 Notably, the Dominican Republic and Haiti, which at the time of the survey did not have a plan to eliminate gasoline lead, have since decided to eliminate lead by the end of 1998. Paraguay, which also had no plan to eliminate lead, is now considering total elimination of lead by the beginning of the year 2000. Consultations among the major stakeholders in Trinidad & Tobago have led to a consensus to advance the date for elimination of lead from gasoline from the year 2005 to 2000. Peru is working toward advancing the date for lead removal from the year 2009 to 2005. The revised estimates include an overall reduction of approximately 1,200 tons of lead in the year 2000 relative to the original forecast.

1.31 Although Chile has not officially set a date for removal of lead from gasoline, the consumption of lead has been declining rapidly. The addition of lead to gasoline in the Netherlands Antilles will be determined primarily by regional trends in lead elimination because of its significant gasoline export trade. As the demand for leaded gasoline declines, and eventually disappears, the amount of lead added to gasoline in the Netherlands Antilles will decrease correspondingly. Uruguay is another country that has not set a date for lead elimination. Its only refinery is currently not competitive in the Mercosur market and is seeking a strategic partner to invest in refinery expansion and modernization. Whatever the decision that will be made concerning the refinery in the next few years, Uruguay is almost certain to eliminate lead from gasoline during the period 2000–2005. This leaves Venezuela as the most significant consumer of gasoline lead in the region. It is currently one of few countries where unleaded gasoline is not available on the market, which excludes the possible use of catalytic converters to combat air pollution from transport. As mentioned earlier, Venezuela does intend to start selling unleaded gasoline in 1999.

1.32 There are several countries in the Caribbean that currently sell only 95 research octane number (RON) gasoline. For most cars, such a high RON is unnecessary, and it would make more sense to introduce regular gasoline with a lower octane number. This would ease the transition to unleaded gasoline, because the cost of phasing-out lead would not be as high as if the same high octane were to be maintained. Indeed, in countries such as Haiti, Jamaica, and Trinidad & Tobago, the plan for lead removal includes the introduction of 87 octane index gasoline to the market in addition to 95 RON.

Conclusions and Recommendations

1.33 For a smooth transition to unleaded gasoline, it is crucial to build a broad consensus among all the key stakeholders. The national lead phase-out action plans should be formulated by those in the individual countries who are ultimately responsible for formulating and implementing the new regulations, thereby instilling a strong sense of ownership. A consensus is more easily reached if the stakeholders become convinced that the proposed plan for lead removal is based on sound science, a reasonable time table, and least-cost solutions. In timing the change, countries that rely on gasoline imports are likely to find it easier to eliminate lead more rapidly than those that are self-sufficient in gasoline supply.

1.34 As will be shown in Chapter 7, El Salvador effectively eliminated gasoline lead in less than a year. There are significant advantages in effecting a rapid transition to unleaded gasoline. A short transition period allows one to avoid the heavy investment of setting up a dual gasoline distribution system, one for leaded and the other for unleaded gasoline, and minimizes the chances of cross-contamination of unleaded gasoline with lead or of misfueling cars equipped with catalytic converters.

Table 1.1 Lead Addition to Gasoline, 1996 to 2005
(in tons per year)

Country	*1996*	*2000 (survey)*	*2000 (revised)*	*2005 (forecast)*	*Comments*
Argentina	0	0	0	0	
Barbados	127	25	25	0	lead removal in 2000
Bolivia	0	0	0	0	
Brazil	0	0	0	0	
Chile	250	200	113	50	no date set
Colombia	0	0	0	0	
Costa Rica	13	0	0	0	
Dominican Republic	180	350	0	0	lead removal by 1/1/99
Ecuador	569	0	100	0	lead removal by 1/1/2001
El Salvador	84	0	0	0	
Guatemala	0	0	0	0	
Honduras		0	0	0	
Jamaica	245	243		0	lead removal by 1/1/2001
Mexico	924	0	0	0	lead removal in 1999
Netherlands Antilles	1,400	600	400	?	no plan for lead removal
Nicaragua	90	0	0	0	
Panama	157	321	55	0	considering lead removal by 2001
Paraguay	95	80	0	0	considering lead removal by 1/1/2000
Peru	300	457[a]	337	70	
Trinidad & Tobago	160	8		0	lead removal by 6/2000
Uruguay	410	410	410	?	no date set
Venezuela	3,160	2,853	2,853	?	
Total (22 countries)	8,164	5,547	4,293		

a. The previously published figure for 2000 was incorrectly computed and has been corrected.

1.35 One consensus that has emerged in this program is that all the countries acknowledge that lead phase-out cannot be carried out isolation; in particular, it cannot be separated from the question of how to reformulate gasoline after lead removal. Further, the latter question in itself should be considered in the broader context of integrated air pollution abatement.

1.36 In addressing these broader issues, it is important to distill lessons from other countries. Experience over the past 25 years in the United States, Europe, and elsewhere has shown that fuel reformulation, and air quality management strategies in general, have a wide range of effectiveness and cost. Governments and industry learned that control measures successfully adopted in one area may not prove as successful in others—technically, financially, or politically—because of the differing circumstances in each location. Each country should develop a plan that is based on the best technical analyses available and uses cost-effectiveness as a primary criterion.

1.37 These lessons are applicable not only to Latin America and the Caribbean, but to all developing countries that are in the process of eliminating lead in gasoline and improving the quality of refined products for greater environmental benefits.

2

Health Impact of Lead Elimination

2.1 The combustion of leaded gasoline contributes to the majority of airborne lead in many cities. The toxicity of lead has been known for centuries. At levels of lead exceeding 70 micrograms (μg) per deciliter (dl) of blood for children and 100 μg/dl for adults, lead can cause paralysis, seizures, coma, and death. What has come to light only in the last two decades, however, is the adverse health effects of lead even at levels previously considered safe. As a result of new research findings, health organizations such as the U.S. Centers for Disease Control and Prevention (CDC) have steadily revised their guidelines for lead. Today, environmental intervention is recommended for blood lead levels above 10 μg/dl (WHO 1995a).

Sources of Lead

2.2 An estimate of worldwide anthropogenic emissions of lead into the atmosphere for 1983 suggests that leaded gasoline accounted for three-quarters of the total emissions (Nriagu and Pacyna 1988). In 1983, with the exception of a few countries such as the United States and Japan, most countries had barely begun to phase lead out of gasoline, so that this estimate is probably applicable to the developing countries that are still using lead in gasoline.

2.3 Anthropogenic sources of lead include not only lead in gasoline, but also lead in drinking water, because of the historical use of lead in pipes for water distribution; lead-based paint; stationary sources such as smelters and lead battery recycling/manufacturing facilities; activities such as mining; tobacco; food; lead-soldered beverage and food cans; dust and soil; traditional cosmetics and medicines; and lead-glazed ceramics. Where lead from gasoline has already been eliminated for the most part, other sources of lead dominate. For example, developing an effective, long-term lead-based paint abatement effort is now considered the most critical factor in eliminating childhood lead poisoning in the United States (CDC 1991).

2.4 It should be noted that airborne lead settles on dust, falls on vegetation, and may contaminate drinking water. Therefore, airborne lead cannot be delinked from lead found in food and water. For nonsmoking adults, major sources of lead are food, water, and airborne lead, if the level of the latter is high. For children, in addition to food, water, and air, dust and soil constitute a significant exposure pathway, as described more fully in Chapter 3. Any program to combat the adverse health effects of lead should attempt to estimate all significant sources of lead exposure so that effective steps can be taken to reduce exposure. Whatever additional sources of lead emissions may exist, eliminating lead in gasoline is important. Unlike other pollutants, such as hydrocarbons, lead does not degrade and continues to accumulate in the environment unless the continuing addition of lead, including that from gasoline, is stopped.

2.5 Further, the levels of air pollutants such as carbon monoxide (CO), NO_x, airborne toxics, and ground-level ozone exceed WHO guidelines in many major cities. Removal of lead from gasoline makes possible the installation of catalytic converters, by far the most effective means of reducing the exhaust emissions of CO, hydrocarbons (airborne toxics as well as ozone precursors) and NO_x. Reductions in these pollutants, in turn, bring significant health benefits.

Health Effects of Lead

2.6 An excellent overview of the health effects of lead can be found in a 1995 WHO publication (WHO 1995b). Unless indicated otherwise, all the information presented in this section on the health effects of lead is taken from the WHO publication. Most of the lead that is absorbed by the body is found in the bones, and some is found in blood. Bone is a major storage site of lead, and serves as an endogenous source of lead even after exposure to environmental lead has ceased. During pregnancy (Silbergeld 1991) and in old age, lead from the bones is released into the blood.

2.7 The absorption of lead from environmental sources is not a linear function of the amount of lead intake. It depends on the chemical and physical state of the lead, and factors such as the age, nutritional condition, and physiological status of the individual. For example, there is evidence that more lead is absorbed when dietary calcium intake is low or if there is iron deficiency. The amount of lead absorbed by the body increases significantly when the stomach is empty. The rate of absorption is also higher for children than for adults. That is to say, poor, malnourished children are even more susceptible to lead poisoning than others.

2.8 The largest body of observational studies on the health effects of lead concerns its impact on the intellectual development, typically measured in terms of intelligence quotient (IQ), and behavioral problems of children. There has been much public health interest in this issue because of mounting evidence that continual exposure of children to even low levels of lead could have a negative impact on their intelligence. A systematic review of 26 epidemiological studies can be found in Pocock *et al.* (1994). The published studies can be divided into two broad categories: prospective and cross-sectional. Prospective studies collect data from the same group of children over a number of years, so that it might be possible to identify whether there is a specific period in a child's intellectual development when exposure to lead is particularly damaging. Cross-sectional studies attempt to correlate the body burden of lead with children's intelligence, both measured at the same time. If environmental exposure to lead before commencement of the study contributed significantly to the child's IQ, cross-sectional studies would not be in a position to identify the causal link unless the level of environmental exposure to lead has been constant.

2.9 A large number of factors affect IQ, so that a multiple-regression analysis with a large number of independent variables, of which lead is one, needs to be conducted in order to isolate the effect of lead. As a result, the statistical significance of the results increases markedly with increasing sample size. The small sample size of any given study, coupled with the complexity of identifying all the relevant covariates (factors affecting IQ, or independent variables on the right-hand side of the equation) make it impossible to draw definitive conclusions from any single study; a synthesis of a number of studies is needed to overcome these impediments. Further, lead is an endogenous variable (that is, the level of body burden of lead depends on factors such as the family income level), so that a simultaneous-equation approach is required. All published papers, however, have used a single-equation approach, resulting in biases of unknown size.

2.10 These limitations not withstanding, the studies that have been conducted strongly support an inverse association between the body burden of lead and children's IQs. A good rule of thumb appears to be that increasing the level of blood lead from 10 μg/dl to 20 μg/dl causes an average decrement of about 1–2 IQ points.

2.11 A follow-up study by Bellinger *et al.* (1992) found that there was an age of critical exposure. IQ was strongly and statistically negatively associated with the level of lead in blood measured at two years of age. This was also supported by a study conducted in the lead-smelting community of Port Pirie in Australia (Baghurst *et al.* 1992). The evidence from other prospective studies, however, is conflicting.

2.12 One of the motivations for conducting prospective studies was to see if very early measures of body lead burden could be correlated with subsequent neuropsychological development. None of the prospective studies, however, has shown a statistically significant association between lead in the umbilical cord and IQ. Factors other than lead have been shown to compensate for high lead levels at birth.

2.13 Unless the level of blood lead is extremely high, the impact of lead on IQ for a given individual may not be noticeable. It is, however, a serious public health concern for the community as a whole, because as Figure 2.1 illustrates, exposure to lead shifts the IQ distribution curve of the entire population, reducing average intelligence. While it is difficult to estimate the economic costs of loss in IQ, losses are substantial. Costs incurred include additional remedial education, health care, and loss in productivity.

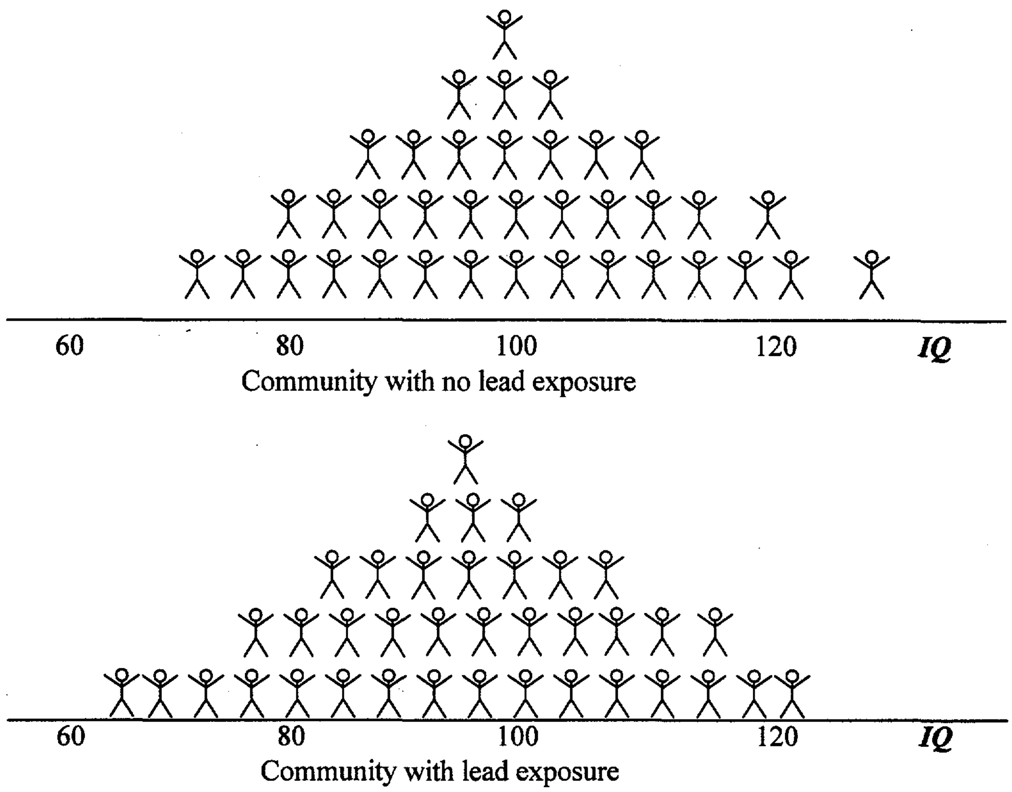


Figure 2.1 Distribution of IQ in a Non-Lead-Exposed and in a Lead-Exposed Population

2.14 While the effect of lead on children's IQ is probably the most significant impact of using leaded gasoline, there are other health effects of lead. There is qualitative evidence that lead may adversely affect the reproductive process in men and women, including increased frequency of miscarriages, although the results are conflicting below lead blood levels of 30 μg/dl. Renal function impairment has been correlated with blood lead above 35 μg/dl. In Latin America and the Caribbean, only a minority of the population is likely to have blood lead exceeding 30 μg/dl. The effect of lead on the cardiovascular system has been studied extensively. There appears to be a weak but positive association between lead in blood and blood pressure. Given the small magnitude and uncertainty involved, however, this association should be considered a public health concern only if further studies are carried out and their findings indicate that this is the case under the living conditions typical in Latin America and the Caribbean.

2.15 Finally, it should be noted that many, if not most, of the studies examining the health impact of lead have been undertaken in the United States, Australia, and Britain, where living conditions are not the same as those in some parts of developing countries. Any deleterious effects of lead exposure, even at low levels, may be exacerbated when additional factors such as malnutrition are present, or even prevalent. Studies examining and quantifying the covariate effects of lead in combination with these factors are likely to underscore the importance of lead reduction further, and would be helpful in guiding policymakers in developing countries.

Secondary Health Effects of Using Leaded Gasoline

2.16 Aside from the direct health effects of lead, lead in gasoline is also a significant contributor to PM_{10} (particulate matter with an aerodynamic diameter of 10 microns or smaller). PM_{10} arises directly from the emissions of lead particulates, and indirectly as a result of a greater share of unburned hydrocarbons in the exhaust gas because lead precludes the use of catalytic converters. In health impact, PM_{10} is much more serious than total suspended particulates (TSP), which include particulate matter of all sizes. In the United States, the federal TSP standards were superseded by PM_{10} standards in 1987, and there are now standards for $PM_{2.5}$ (particulate matter with an aerodynamic diameter of 2.5 μm or smaller) in addition to PM_{10}. Particulate matter emitted by the combustion of transportation fuels falls predominantly in the PM_{10} range. A recent estimate of the inventory of emissions in Tehran, where gasoline is generally leaded, indicated that gasoline-fueled vehicles were responsible for more than 50 percent of the total emissions of PM_{10} from transport (Sweco *et al.* 1997). This is in sharp contrast to cities where the use of unleaded gasoline combined with catalytic converters is the norm, and where diesel, not gasoline, is responsible for the majority of PM_{10} emissions. Particulate matter causes respiratory illness.

2.17 Rapid urbanization and economic expansion have created serious air pollution problems in many large cities in developing countries. Pollutants regularly exceeding WHO guidelines include CO, NO_x, and ozone (O_3). CO is a colorless, odorless gas that inhibits the capacity of blood to carry oxygen to organs and tissues. People with chronic heart disease may experience chest pains when carbon monoxide levels are high. At very high levels, carbon monoxide impairs vision, manual dexterity, and learning ability, and can cause death. Ozone is responsible for photochemical smog and has been associated with transient effects on the human respiratory system. Of the documented health effects, the most significant is decrements in the pulmonary function of individuals participating in light to heavy exercise (NRC 1991).

2.18 Gasoline-fueled cars account for the bulk of CO emissions, and a significant fraction of NO_x and volatile organic compounds (VOC) emissions. The latter two are precursors for ozone formation. The most effective measure for reducing the emissions of CO, NO_x, and VOC is the installation of catalytic converters, but lead in gasoline precludes their use, because catalytic converters are poisoned by lead, mainly by pore-mouth plugging. By continuing to include lead additives in gasoline, chances of misfueling (fueling catalyst-equipped cars with leaded gasoline) and contaminating unleaded gasoline with lead are increased, which would deactivate catalytic converters permanently. When only leaded gasoline is available, as in Venezuela, the entire vehicle fleet is excluded from catalytic converter use.

Health Risks of Unleaded Gasoline

2.19 There are several public health concerns about removing lead from gasoline. Options for compensating for the octane loss arising from lead elimination include adding butane to gasoline (potentially resulting in higher gasoline volatility), increasing the amount of reformate blended into gasoline, or increasing the severity of reformer operations; the latter two options increase the yield of aromatics, including benzene. Other solutions are adding isomerate, alkylate, light olefin oligomers, and FCC naphtha, which contains light olefins. The addition of isomerate and alkylate to increase octane has no adverse health effects. Finally, methylcyclopentadienyl manganese tricarbonyl (MMT) and oxygenates such as MTBE or ethanol may also be added to gasoline to boost octane.

2.20 Higher gasoline volatility increases the emission levels of VOC. Therefore, it is necessary to establish a maximally permissible level of volatility expressed in RVP. The limits on RVP depend on the climatic conditions of the geographic region being regulated. For example, under the simple model of the reformulated gasoline program in the United States, an RVP limit of 7.2 pounds per square inch (psi) is imposed in the southern half of the United States in summer, while the corresponding figure for the northern half is 8.1 psi. In many countries in Latin America and the Caribbean, the climate is comparable to that found in the southern part of the United States, and yet they often have RVP specifications of 10 psi or above year-round. In such situations the limits on RVP during the ozone season should be reexamined.

2.21 Higher emission levels of benzene, which is a carcinogen, have been cited as a rationale for slowing down the phase-out of lead in gasoline until the entire vehicle fleet is equipped with catalytic converters. The most significant source of benzene emissions from gasoline-fueled vehicles is benzene itself in gasoline. While other aromatics are also emitted as benzene from the exhaust pipe as a result of dealkylation during combustion, their contribution to benzene emissions is an order of magnitude smaller, so that benzene need not become a serious health concern after lead removal, as long as the amount of benzene in gasoline is not markedly increased.

2.22 Aromatics with two or more alkyl branches (starting with xylenes) and olefins are photochemically reactive. By increasing their emission levels, airborne ozone levels may increase if the ratio of airborne VOC to NO_x is relatively low. As will be shown in Chapter 5, increasing aromatics has been shown to have no effect on ozone if cars are equipped with catalytic converters, while the reduction of RVP minimizes the impact of olefins on ozone. For cars not equipped with catalytic converters, increasing aromatics has been shown to increase NO_x emissions, while the data on VOC emission levels have been contradictory. If ozone is indeed a serious problem, if the ratio of airborne VOC to NO_x is relatively low, if biogenic sources of VOC are not significant, and if a large fraction of cars are not equipped with catalytic converters, then the content of total aromatics should not be increased markedly following removal of lead from gasoline.

2.23 Although the health effects of the addition of MMT to gasoline have been debated in the United States and Canada, in the regional survey conducted under the auspices of this project, only El Salvador planned to add MMT to gasoline after lead removal. In Canada, where MMT has been used in gasoline for a number of years, its contribution to ambient exposure of the general population to manganese (Mn) is estimated to be very low because of its low concentration in gasoline (legal limit of 18 mg Mn/liter) and the low volatility of MMT.

2.24 Of the oxygenates added to gasoline, the health effects of MTBE have been the most extensively studied, with generally no harm identified. The use of MTBE in reformulated gasoline in the United States has been associated by some with increased incidence of headaches. Further, MTBE has been found in groundwater in the United States. Little definitive data are available to indicate how MTBE in drinking water affects human health. It has greater water solubility than hydrocarbons, and thus moves more readily into groundwater. In addition, MTBE has a low taste and odor threshold, which makes leakage of tanks storing MTBE-containing gasoline more likely to be detected. Studies on the health effects of MTBE and other oxygenates with a view to setting guidelines are under way in the United States and Canada. California had a bill in preparation that proposed a ban on MTBE in gasoline on health grounds, but this bill has since been modified to delete an automatic ban if a health study, to be completed by the end of 1998, finds no substantive negative effects (*Financial Times Automotive Environment Analyst*, July 1997).

2.25 The addition of oxygenates is mandated in the United States under the reformulated gasoline program in CO nonattainment areas. The presence of oxygenates in gasoline decreases CO and hydrocarbon emissions from cars with and without catalytic converters (*Oil & Gas Journal*, 19 May 1997), benefiting human health. The addition of oxygenates may increase the emission levels of aldehydes. Formaldehyde and acetaldehyde are toxic. Nevertheless, the amount of aldehydes emitted by gasoline-fueled vehicles is small and is unlikely to cause concern about health.

2.26 While no fuel is risk-free, there is a general consensus among scientists who have investigated the health effects of various fuel compositions that the overall adverse impact of lead is more serious than the risks associated with the use of unleaded gasoline, and that the removal of lead in gasoline is a positive step for the public health.

3

Biological Monitoring of Lead

3.1 This chapter, taken in part from a report prepared by Janie Gittleman (1997) for a USAID/Environmental Health Project cooperative project, describes options for monitoring blood-lead levels during a national phase-out of lead in gasoline to track changes in exposure to environmental lead. The information can then be used to aid policymakers and health professionals in evaluating the impact of the phase-out. Development of a comprehensive, continuous human surveillance system for tracking lead exposures in the population is expensive. Lack of infrastructure and competing public health priorities require the development of a relatively simple, flexible, and inexpensive approach to monitoring the phase-out of lead. An important aspect of carrying out the monitoring options is the requirement that they be implemented in the context of existing programs and with current facilities in Latin America and the Caribbean.

Rationale and Experience: Biological Monitoring of Lead

3.2 As noted in Chapter 2, there is a very strong health justification for lowering the exposure of children to lead in the environment. Monitoring changes in the body burden of lead in human populations has allowed scientists to present evidence that their health policy interventions were successful in lowering lead levels. While there are several biomarkers of lead exposure, PAHO (1989) recommends blood lead as the most appropriate indicator for evaluation of exposure to lead in both occupational and general populations. Blood lead is a common, simple, and practical indicator, and it has been the basis for most of the studies that have established the cause-and-effect relationships between lead exposure and adverse health effects, making it the biomarker of choice. It is a measure of recent exposure to lead, because the half-life of lead in blood is approximately 28–36 days (WHO 1995b).

3.3 In the Americas, no country has a continuous, nationwide monitoring program for biological lead, but the periodic National Health and Nutritional Examination Survey (NHANES) studies in the United States helped track the changes in blood-lead levels among children and adults in the 1970s and 1980s, the period of phase-out of lead in gasoline. These studies found significant lowering of blood-lead levels among the general public. In Mexico, prior to the phase-out of lead in gasoline in Mexico City, a 1982 study reported that the median blood-lead level of a cohort of 85 adult schoolteachers was 22 µg/dl (Vahter 1982). Periodic monitoring of blood-lead levels in the metropolitan zone of Mexico City has found that blood-lead levels in the general population have decreased since 1991. Even so, approximately 30 percent of children are currently estimated to have blood-lead levels exceeding 10 µg/dl (PAHO 1996). The use of ceramics with lead-based glazes fired at low temperatures is suspected as a cause of continuing high blood-lead levels in the children of Mexico City.

3.4 The amount of lead added to gasoline in Mexico decreased from 9,000 metric tons in 1990 to 1,500 tons in 1995 (World Bank 1997). In the metropolitan area of Mexico City, sequential ambient air monitoring carried out continuously since 1988 has documented a marked decrease in lead levels in ambient air. In 1988, 1.95 $\mu g/m^3$ was measured, but by 1994 the level had fallen to 0.28 $\mu g/m^3$. Over the same period, a parallel decrease in blood-lead levels in the residential population of the area was also observed (PAHO 1996). This combination of biological (blood lead) and environmental (ambient air) monitoring data has allowed PAHO (1996) to conclude that the decrease is probably related to the reduction in the lead content of leaded gasoline and the introduction of unleaded gasoline in Mexico.

Target Populations

3.5 Monitoring is proposed for urban areas where the number of automobiles has been increasing and exposure to airborne lead from leaded gasoline is high, in contrast with rural areas, where general population exposure to leaded gasoline is usually low. Two target populations are recommended in this chapter: occupationally exposed adults and children. If resources permit, it would be desirable to target more than one population group to minimize the chances of sample bias.

Occupationally Exposed Adults

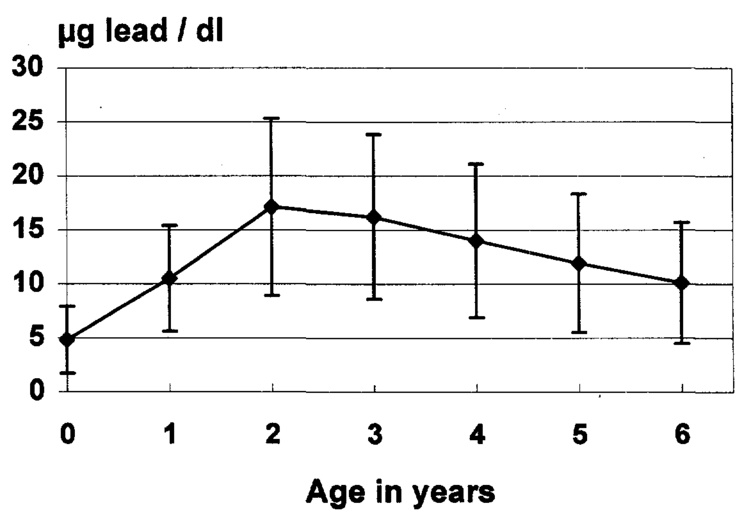
3.6 Workers occupationally exposed to airborne lead from gasoline—such as bus and taxi drivers, traffic police, street vendors, and gasoline-pump attendants—represent a population with the highest expected risk of exposure to lead from gasoline. Biological monitoring studies of traffic police, bus drivers, and auto-body-shop workers have shown higher exposures, and consequent elevated blood-lead levels, than those of non–occupationally exposed populations. For example, in a recent study conducted in India, three groups of workers—traffic police, bus drivers, and auto-body-shop workers—exposed to leaded gasoline had blood-lead levels ranging from 11 to 17 µg/dl, compared with the corresponding values for urban controls (office workers), who averaged 4.1 µg/dl (Potula and Hu 1996). Surveying adults with significant exposure to airborne lead from leaded gasoline minimizes the impact of other potential sources of lead, making it easier to evaluate the effects of the reduction of lead in gasoline. If an age- and gender-matched control group of non–occupationally exposed individuals is also monitored, as in the Indian study, the effect of high exposure to lead emissions from vehicles can be quantified.

3.7 There are factors to consider in targeting workers occupationally exposed to leaded gasoline. The effort requires gaining the cooperation of employers, as well as individuals. The possibility that workers may seek additional compensation for exposure to lead at work may deter employers from granting permission. If occupational health and safety regulations are not in place, and workers are found to have very high blood-lead levels, there may be a call for action from workers, unions, or employers. Such a consequence would benefit public health.

Children

3.8 Children are more vulnerable to the adverse health effects of lead than adults. Children's absorption rate of ingested lead has been found to be higher than that of adults (WHO 1995b). Pre-school children have a significant additional source of lead because of their mouthing activity, and they ingest lead from toys, chipped lead-based paint, dust, and soil. As a result, their body burden of lead, measured in lead in the blood, tends to be higher than that of adults. Postnatal blood-lead levels begin to rise after about six months of age, with increasing progression toward mobility (including the pre-walking stage) and hand-to-mouth behaviors. Mean blood levels obtained in a study of 245 children by Dietrich *et al.* (1993) are given in Figure 3.1 as an illustrative example.

Figure 3.1 Blood-Lead Level as a Function of Child's Age



3.9 As discussed in Chapter 2, there is a statistically significant association between children's IQs and lead in the blood. There may be a critical age of exposure, but the evidence is conflicting. If there is a critical age of exposure, it appears to be around the time the level of lead in blood reaches a maximum. No relationship between lead at birth and IQ in later years has been demonstrated.

3.10 For all these reasons, it would be desirable to monitor blood lead in preschool children. From a practical viewpoint, however, it would be easier to monitor blood lead in young school-age children (ages five and six) because they congregate at school every day. The collection of samples and risk factor data is more efficient when carried out at several selected schools within the urban environment, rather than at clinics dispersed throughout the city where children are taken sporadically for well-care visits or immunizations.

3.11 The difficulties of targeting school-age children are related to administrative and medical issues. Sampling these children requires cooperation from school systems, principals, and state authorities. Parental authorization must be obtained, and this requires careful education about the rationale for the monitoring effort. For example, meetings with parent associations may need to be held to raise consciousness about the importance of monitoring and education about the health effects of lead. It may also be difficult to obtain blood specimens from young children, although phlebotomists appropriately trained in collection of specimens from this age group can minimize the duration of discomfort.

Monitoring Procedures

3.12 At least three surveys should be conducted to assess the impact of the elimination of lead from gasoline: a baseline survey taken before lead phase-out (or at the latest, during the early stage), a second taken half-way through the phase-out, and a third survey conducted approximately a year after the completion of the program. More surveys may be carried out as resources permit.

3.13 To assess the impact of the phase-out of lead on the body burden, airborne lead and blood lead should be sampled at the same time. Monitoring stations for airborne lead should be located close to locations where the target populations spend much of their time.

3.14 The phase-out of lead in gasoline may cause the level of airborne lead to fall significantly faster than that of lead deposited in soil if the lead removal program in implemented rapidly. It would be useful to monitor the level of lead in soil and dust in areas such as the playgrounds of the schools attended by the children being monitored, because lead in soil and dust could have a marked effect on their level of blood lead. In an extreme example of this effect, a study of schoolchildren near a primary lead smelter in Belgium (Roels *et al.* 1980) found that the level of blood lead was correlated much more strongly with the level of lead on children's hands, which was probably transferred from dust and dirt, than with that of airborne lead. If lead removal occurs over a number of years, or if the level of airborne lead is not extremely high, the effect of residual lead in soil and dust is unlikely to have a significant impact.

3.15 The cost of the blood specimen collection and analysis is estimated to range between $12 and $35 for each sample. The procedures to be followed for blood specimen collection, laboratory analysis, and data analysis are described in detail in the report by Gittleman (1997).

Study Design for Survey of Occupationally Exposed Workers

3.16 Study subjects should be selected from a cohort of workers. Subjects selected for this kind of monitoring effort should be randomly chosen from the occupational group. It is preferable that all workers selected work a full eight-hour day at the exposure site. The control group should consist of age- and gender-matched workers in a non–occupationally exposed environment, such as office workers within the same occupational group selected who are not exposed to significant ambient atmospheric pollution in the course of their daily jobs. Participants should be asked to complete a risk factor questionnaire providing data on their occupation, including job category, duration of employment, and aspects of their lifestyle likely to affect the level of blood lead, such as smoking behavior, diet, and area of residence.

Study Design for Survey of School-Age Children

3.17 In order to evaluate the impact of the lead phase-out on children in the Americas, surveys of schoolchildren living in central cities during the first year of school (ages five or six) are proposed. Participants will change from survey to survey, but consistency can be maintained by selecting pupils from a representative sample of schools at a standardized time of year and including children of similar ages in the same grade. Both biological measurements of lead and minimal demographic questionnaire information should be collected to identify other potential sources of lead that may influence blood-lead levels.

3.18 In order to obtain diversity of environment, schools should be selected from commercial neighborhoods, industrial neighborhoods, neighborhoods along highways, residential neighborhoods, and center-city neighborhoods. Oversampling from portions of the city likely to show traffic effects should be utilized so that monitoring over time will demonstrate traffic-related changes in blood-lead levels. After identifying schools within each central city, a random selection of four or more schools should be made.

3.19 Based on a statistical analysis of data from NHANES in the United States, and assuming a standardization of 8 μg/dl, an annual change in blood lead of 1 μg/dl, and 5 percent significance, groups of 64 subjects would enable the detection of change with 80 percent power after four years. Based on these estimates, a minimum of 200 subjects—groups of 50 pupils from four schools—is recommended.

3.20 Examples of information relevant to the risk of lead exposure should be collected. The survey questionnaire should include age; gender; weight of the child; industrial or commercial activities located near the child's residence that release lead into the air (for example, gasoline stations, paint manufacturing industries, heavy-metal smelters, and battery manufacturers); the child's diet and nutritional status; the use of lead-glazed pottery for food storage and cooking in the home; use of lead-based paint in the house and the condition of the paint; the parents' education, occupation, and hobbies; and activities or behaviors of the child that may cause exposure to lead, such as chewing lead pencils.

3.21 A standardized questionnaire with this set of demographic, environmental, and behavioral data should be used. This information will be useful for checking the blood lead data for outliers, which may provide clues if unusually high lead concentrations are associated with risk factors such as the use of lead-glazed ceramics. These data could also be useful in multiple regression analyses of the determinants of elevated blood lead levels, especially with data pooled from a number of countries over several years. The collection and use of questionnaire data requires careful training of interviewers, validation of the questionnaire, and other efforts to assure data quality. Additions to the core set of questions can be made to adapt the survey to specific risk factors that may vary from country to country.

Laboratory Quality Control and Quality Assurance Procedures

3.22 In order to ensure the accuracy of the data collected, it is crucial to have strict quality control. Effective quality assurance/quality control for the monitoring activities includes instrument calibration and technique certification using calibration standards, checking reproducibility, assessing standard errors, and interlaboratory comparisons. PAHO is running a Pan-American network of laboratories, and their program includes several activities for quality control and quality assurance of analytical results. In addition, the U.S. CDC and the American Industrial Hygiene Association are also actively engaged in helping to run quality assurance/quality control programs in the region.

4

Effects of Lead Elimination on Vehicles

4.1 The use of lead additives to increase the octane rating of gasoline made possible the development of modern high-compression gasoline engines, but has also resulted in dangerously high levels of lead pollution in cities around the world. There remain, however, certain misconceptions and myths that have created popular concern, and these ideas are obstructing the phase-out of lead in gasoline. These misconceptions include the beliefs that older engines require leaded gasoline to prevent damage to exhaust valve seats, and that emissions of toxic hydrocarbons such as benzene increase greatly with unleaded gasoline, making it necessary to use catalytic converters if unleaded fuel is used.

4.2 This chapter, based on a report prepared by Christopher Weaver of Engine, Fuel, Emissions Engineering, Inc., reviews the role of lead additives in gasoline, and summarizes the positive and negative effects of lead additives in the engine. It is shown that the incidence of valve-seat damage caused by unleaded fuel is very small, and in Latin America and the Caribbean, there have been no serious claims of valve-seat damage following lead elimination. Overall, the use of unleaded gasoline reduces vehicle maintenance costs.

Gasoline Properties

4.3 Gasoline is a mixture of hydrocarbons produced by distillation and chemical processing of crude oil, along with chemical additives and blending agents used to improve its properties as a motor fuel. Gasoline characteristics that have an important effect on engines and emissions include its knock resistance rating or octane number, volatility characteristics, and chemical composition. The use of tetraethyl lead (TEL) as a gasoline additive is especially important because of its implications for catalytic converters, lead emissions, gasoline composition, anti-knock performance, valve wear, and engine life.

4.4 The octane number of a fuel is a measure of its resistance to autoignition or detonation ("knocking") in a spark-ignition engine. Knock occurs when the unburned gases ahead of the flame front during combustion ignite spontaneously, causing a sudden rise in cylinder pressure. Knock reduces engine power output, and severe or prolonged knock will damage the engine. The tendency to knock increases with increasing engine compression ratio. Higher-octane fuels are more resistant to knocking, and can thus be used in engines with higher compression ratios. Higher compression ratios, in turn, result in better thermodynamic efficiency, and hence greater fuel economy and power output for a given size engine. Engines designed for use with high-octane fuels can produce more power and use less fuel than engines designed for lower-octane fuels. For a given engine design, however, there is no advantage in using a higher octane fuel than the engine requires. Higher-octane "premium" gasoline, unless required to avoid knocking, is not necessarily of higher quality, and provides no benefit in most cases.

4.5 Octane number is measured by two standard tests, the research and motor octane tests. The results of these tests are expressed as either the research octane number (RON) or the motor octane number (MON) of the fuel. Both tests involve comparing the anti-knock performance of the fuel to that of a mixture of iso-octane and n-heptane, with the octane number being defined as the percentage of iso-octane in the reference octane/heptane mixture that gives the same anti-knock performance as the fuel under test. For fuels with octane numbers above 100, mixtures of iso-octane and TEL are used to extend the octane scale to 130. The research and motor tests differ in detail: the research test primarily reflects low-speed, relatively sedate driving, while the motor test reflects high-speed, demanding driving. Most fuels have a higher RON than MON. In the United States and parts of Latin America, gasoline anti-knock ratings are expressed as the average of RON and MON, denoted by (R+M)/2 and referred to as an anti-knock index (AKI). Elsewhere, RON is typically used.[2]

4.6 The octane rating of a given gasoline blend is determined by the hydrocarbon composition of the fuel, the content of high-octane, nonhydrocarbon blendstocks such as ethers and alcohols, and the amount of anti-knock additives used, if any. Straight-chain paraffins have low octane values, while branched-chain paraffins, olefins, cycloparaffins, and aromatic hydrocarbons have higher octane values.

4.7 TEL has been used to reduce the knocking tendencies of gasoline since 1922. In the days before advanced refining technology, the anti-knock properties imparted to gasoline by TEL made possible the development of efficient, high-compression gasoline engines. Typical straight-run gasoline produced by distillation of crude oil comprises mostly straight-chain hydrocarbons, and typically has a RON in the

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[2] A gasoline may have a RON of 94 and a MON of 88; in the United States and parts of Latin America, the two numbers are averaged and expressed as (R+M)/2, or AKI of 91. This is comparable to a European rating (usually RON) of 94.

vicinity of 70. By adding approximately 0.8–1.0 gram of lead per liter of fuel, the octane rating of straight-run gasoline can be raised to the values of 85 to 93 RON commonly specified for regular motor fuel. This is the way in which the first high-octane gasolines were produced, and many of the smaller and older refineries in developing countries are still configured in this manner.

4.8 The octane boost provided by lead does not increase linearly with lead concentration. The first 0.1 gram per liter (g/l) of lead additive provides the greatest octane boost; subsequent increases in lead concentration yield progressively smaller returns. This means that less lead is required to supply two units of low-lead gasoline than to supply one unit of high-lead and one unit of unleaded gasoline with the same octane value. If the octane capacity of the refinery is limited, therefore, the quickest and most economical way to reduce lead emissions will generally be to reduce the lead content of existing leaded gasoline grades as much as possible.

Effects of Lead Anti-knocks on Engines

4.9 In addition to its effects on the fuel octane level, the use of lead additives in gasoline has many other effects in the engine, most of them undesirable. These include corroding exhaust-valve materials, fouling spark plugs, contaminating engine oil with corrosive acids, and corroding exhaust systems. The one desirable effect of gasoline lead in the engine is that it serves as a lubricant between exhaust valves and their seats, helping to prevent excessive wear. In the absence of lead, older-technology engines can suffer from rapid wear of the exhaust valve seats when operated at high speeds for long periods of time. This phenomenon, known as *valve-seat recession*, has been the subject of considerable misinformation, confusion, and public concern, and this concern is one of the main obstacles to eliminating leaded gasoline in many countries. Nevertheless, detailed studies and extensive practical experience in a number of countries have shown that the potential problems of valve-seat recession have been grossly exaggerated (in some cases, deliberately), and that the use of low-lead or unleaded gasoline will result in longer engine life and lower maintenance costs overall.

4.10 The positive and negative effects of lead additives in the engine were examined in detail for the U.S. EPA (Weaver 1986). The following sections summarize the results of the study.

Valve-Seat Recession

4.11 In modern gasoline engines, the exhaust valves and the valve seats operate at high temperatures and under great mechanical stresses. In closing, the valve strikes the seat with great force thousands of times each minute. Under conditions of high speed and high power output, small "warts" of iron oxide may form on the valve, as a result of segments of the valve seat welding to the valve upon impact, and then being torn loose when the valve opens. Repeated impact of these "warts" against the valve seat leads to deformation, cracking, and flaking of the seat, while the scrubbing of hard-iron oxide particles across the valve face causes abrasive wear. The resulting rapid wear of the valve seat can lead to loss of compression and require major repairs to the engine in less than 10,000 kilometers.

4.12 The presence of lead deposits on the valve seat appears to prevent the initial adhesion and welding that leads to valve-seat recession. Only a small amount of lead is required to provide this protection: 0.02 g/l has been found to be effective in laboratory tests. A similar protective effect is obtained from deposits of other elements such as manganese (from MMT), phosphorus, zinc, and calcium (from engine oil). Valve seat recession can also be prevented by heat-treating the valve seat area to harden it, or by the use of valve seat inserts made of hard material. A hardness of approximately 30 on the Rockwell C scale is adequate to prevent valve-seat recession. Nearly all gasoline engines and replacement cylinder heads now produced have hardened valve seats, and thus are not subject to valve-seat recession. This applies generally to vehicles made in the United States after 1970, and European vehicles made in the early 1980s and thereafter. Some older engines still in service may have soft valve seats, however, and could potentially experience valve-seat recession.

4.13 Although valve-seat recession can be produced readily in the engine laboratory, practical experience and a number of studies have shown that it is very uncommon in actual use. This is apparently because few gasoline vehicles (especially old ones) experience long periods of uninterrupted operation at high speeds and loads. Much of the research examining the effect of varying engine operating conditions on valve-seat recession has been conducted by running the engines continuously for tens or hundreds of hours under very severe operating conditions—for example, at 110 kilometers an hour. There appears to be a threshold effect; a certain period of high-speed operation is required to wear through the deposit layer on the valve seat before recession can begin. Interrupting this period of high-speed operation with periods of less-demanding use may allow the deposit layer to re-form, prolonging engine life. In the minority of vehicles that do experience valve-seat recession, the problem can be corrected and kept from recurring by either replacing the cylinder head with a new one with hardened valve seats, or by machining-out the valve seats in the old cylinder head and replacing them with hardened inserts. The cost of this operation is about US$500 in the United States, and is expected to be considerably less in most developing countries because of the lower cost of labor.

Valve Corrosion and Guttering

4.14 Although lead deposits protect valve seats from accelerated wear, they can reduce the life of exhaust valves. At high temperatures, the lead oxide layer on the seat can attack the protective oxide layer on the valve, causing corrosion. This weakens the metal and can eventually cause *guttering*, which is the formation of a channel on the valve surface. Hot combustion gases escaping through this channel rapidly enlarge it, causing the valve to fail. A similar effect can occur when lead deposits build up too thickly on the valve seat. Flaking of these deposits can create a path for hot gases to move past the valve face.

Oil Changes and Engine Life

4.15 Before the advent of unleaded gasoline, engine rusting was one of the most significant and widely studied problems in lubricant development. To prevent excess buildup of lead deposits, leaded gasoline includes ethylene dichloride and ethylene dibromide to serve as scavengers. The bromine and chlorine atoms thus introduced to the combustion chamber combine with the lead, forming compounds that are more easily removed. Unfortunately, chlorine and bromine also form corrosive hydrochloric and hydrobromic acids, respectively. Some of these acids get into the engine oil, where they will readily combine with any water that may be present to cause internal corrosion and rust. To delay this phenomenon, engine oils contain special basic additives that react with the acids to neutralize them. Since the reaction consumes the additives, the oil must be changed at intervals to supply fresh additive. Reducing the lead content of the fuel reduces the corrosive burden on the lubricating oil, and allows oil-change intervals to be extended.

4.16 The lead scavengers used with leaded gasoline also contribute to corrosive wear inside the cylinder, especially wear of the piston rings. For example, taxi studies in the 1970s showed that corrosive wear of the piston rings and cylinder walls were 70 to 150 percent greater with leaded gasoline than with unleaded fuel (Carey *et al.* 1978; Gergel and Sheahan 1976). Switching to unleaded gasoline can be expected to result in significantly extended engine life.

Spark-Plug Fouling and Replacement Frequency

4.17 Lead deposits can physically foul spark plugs, and also contribute to chemical corrosion. Spark plugs used with leaded gasoline can suffer serious corrosion and require replacement within 10,000 kilometers, while those used with unleaded fuel can go 40,000 kilometers or more without replacement. As a result, spark plug changes are a significant maintenance cost for vehicles using leaded gasoline, and a minor one for those using unleaded fuel.

Exhaust-System Corrosion

4.18 Vehicle exhaust systems are subject to corrosion from both the inside and the outside. From the inside, the primary corrosion process is cold corrosion, which occurs when water condenses inside the exhaust system. Where leaded gasoline is used, this water is contaminated with hydrochloric and hydrobromic acids. Exhaust gas condensates in engines burning leaded gasoline typically have pH values in the range of 2.2 to 2.6, which is highly corrosive. The pH values of unleaded gasoline condensates are about 3.5 to 4.2. Fleet tests comparing leaded and unleaded fuel show that vehicles using leaded gasoline require four to ten times as many replacements of exhaust system components. In warm climates, where road salt is not used, exhaust systems used with unleaded gasoline can be expected to last for the life of the vehicle, while those used with leaded fuel require replacement about every 50,000 kilometers.

Experience with Unleaded Gasoline in Older Engines

4.19 As the preceding review has shown, the use of unleaded gasoline offers many advantages in the areas of vehicle life and maintenance costs. Proposals to eliminate leaded gasoline have caused public concern because of the prospect of valve-seat recession. The likelihood of occurrence and the consequences of valve-seat recession have sometimes been exaggerated in discussions of this issue. The great body of in-use experience with unleaded gasoline, including widespread use of unleaded fuel in vehicles without hardened valve seats, shows that the likelihood of engine damage is very small, while the overall savings in maintenance costs can be substantial. This experience was also reviewed for the U.S. EPA (Weaver 1986).

Fleet Studies

4.20 A number of controlled fleet studies were carried out in the 1960s to compare maintenance costs associated with the use of leaded and unleaded gasoline. A five-year study financed by Ethyl Corporation, a major lead-additive supplier, showed that 4 of 64 vehicles using unleaded gasoline required cylinder-head replacement during that time (one vehicle required two replacements), compared with 1 of 64 vehicles using leaded gasoline (Wintringham *et al.* 1972). The unleaded gasoline group required only 6 valve repairs, compared with 16 of the vehicles using leaded gasoline. Other studies conducted in the same time period showed that overall maintenance costs were lower with unleaded than with leaded gasoline.

4.21 Engines in heavy-duty gasoline vehicles are more likely to undergo severe service than those in passenger cars, and thus might be expected to show an increased incidence of valve-seat recession. Such is not the case, however. A major fleet test conducted by the U.S. Army involved switching the vehicle fleets of three army posts to unleaded gasoline. This included some 7,600 vehicles (some dating from the 1940s), as well as many items of power equipment. The results of this test were definitive—no untoward maintenance problems were experienced that could be attributed to the use of unleaded gasoline. The U.S. Army subsequently converted its entire establishment to unleaded gasoline without ill effects. Analyses of maintenance data for the U.S. Postal Service and a number of public utility fleets also showed no increase in valve- or valve-seat-related problems with the use of unleaded fuel.

International Experience

4.22 In recent years, leaded gasoline has been eliminated in a number of countries in Latin America and the Caribbean, including Argentina, Brazil, Colombia, and all of Central America except Panama. In none of these countries has any marked increase in valve-seat problems been observed. The case of Brazil is especially significant, given the size of the Brazilian vehicle fleet. With the inclusion of 22 percent ethanol by volume in gasoline as part of the Pro-alcohol program, lead additives were no longer needed, and Brazil began eliminating gasoline lead in 1979, with lead phase-out completed in 1991 (World Bank 1997). Despite the presence of large numbers of vehicles with soft valve seats, no significant or widespread problems were experienced with valve-seat recession.

Effect of Lead Elimination on Exhaust Emissions

4.23 One argument that has been advanced against eliminating lead from gasoline is that this will require an increase in the percentage of aromatic hydrocarbons in the fuel to maintain octane quality, and therefore an increase in benzene emissions if a large fraction of cars in the country are not equipped with catalytic converters. It is argued that the adverse health impact of increased emissions of benzene, and of photochemically reactive olefins and aromatics that might give rise to greater ozone formation, would offset the health benefits of reducing lead. This argument does not apply if there is a rapid transition toward cars with catalytic converters, because the use of converters is by far the most effective means for controlling CO, hydrocarbon, and NO_x emissions. A dual distribution system for leaded and unleaded gasoline is the most serious source of lead contamination of unleaded gasoline, which deactivates catalytic converters through pore-mouth plugging.

4.24 Even in the case of cars not equipped with converters, this argument is not sustainable for two reasons. First, there is no *necessary* tradeoff between lead and benzene emissions. By appropriate choice of refining technology, it is possible to eliminate lead without increasing benzene emissions, although the costs incurred will be higher. Second, even if there were a direct tradeoff between lead and benzene or ozone, the toxic effects of benzene and ozone are much less significant, so that the change would still be beneficial to public health.

4.25 In some countries in Latin America and the Caribbean where unleaded gasoline is not widely available, catalytic converters are removed from imported cars in a practice known as the "tropicalization" of vehicles. This means that consumers pay the full price of catalytic converters without seeing any of the environmental and health benefits. There is a false economy in such a practice that would be eliminated by a rapid transition to unleaded gasoline.

4.26 As will be discussed in Chapter 5, a number of refining technologies can be used to make up the octane deficit created by eliminating lead. Where lead use is limited or prohibited for public health reasons, refiners have often chosen to compensate by increasing the severity of catalytic reforming (thereby increasing aromatic hydrocarbon yields). This is the basis for the claim that one must choose between lead and aromatics. The real choice, however, is considerably wider. In addition to increasing the percentage of aromatics in the fuel, refiners can increase octane by isomerization or alkylation. The output from a refinery alkylation unit is almost 100 percent paraffinic, and has a typical octane rating of about 95. Octane values can also be increased by blending alcohols (as in Brazil) or ethers (as in some parts of the United States and in many other countries).

4.27 A counter-example to the claimed tradeoff between lead and aromatics can be illustrated by current data from Mexico. Table 4.1 shows some key parameters and emission test results using the leaded regular gasoline blend sold in Mexico City, compared with those of two unleaded regular formulations being considered as substitutes. As the table shows, aromatic hydrocarbon levels in all three blends are similar, and benzene emissions with the unleaded blends are slightly reduced. Emissions of 1,3-butadiene (a much more potent carcinogen than benzene) are also reduced slightly using the unleaded blends.

Table 4.1 Toxic Emissions from Leaded and Unleaded Gasoline Produced by Petroleos Mexicanos

Item	*Reference*	*Reform A*	*Reform B*
RON	81.7	81	81
Aromatics, percent	17.0	19.6	18.1
Olefins, percent	10	10	8.3
Lead (g/l)	0.37	0.19	0
Benzene, mg/km	82.6	79.8	72.4
1,3-butadiene, mg/km	87.6	81.6	87.3

4.28 During the phase-out of lead anti-knocks in a given country, short-run economic factors may require some increase in the level of aromatic hydrocarbons used (or permitted) in gasoline in order to maintain octane. This need not result in an increase in benzene emissions, especially if cars using unleaded gasoline are equipped with catalytic converters. Even for cars without converters, it would be possible to maintain the overall benzene emissions at the same level by limiting benzene, rather than total aromatics, in gasoline and reducing RVP to minimize evaporative emissions of benzene further.

5

Motor Fuel Reformulation

5.1 Vehicular emissions are often significant contributors to airborne lead, PM_{10}, CO, NO_x, VOCs, and ground-level ozone in major cities. There are several options available to reduce vehicular emissions, including establishing vehicular emissions standards; effectively enforcing I/M programs; mandating catalytic converters and other emission control devices (such as canisters for evaporative control or exhaust-gas recirculation to reduce NO_x and PM_{10} emissions from diesel-fueled vehicles) in all new vehicles; traffic management; and motor fuel reformulation, *viz.*, improving the quality of transportation fuels.

5.2 Before measures are taken to tackle vehicular emissions, it is important to get an accurate inventory of emissions from all sources in a given city, as well as accurate air quality measurements. In the case of CO, vehicles almost always account for the bulk of emissions. With respect to other pollutants, each situation needs to be assessed separately. Utility boilers may be contributing significantly to NO_x emissions, or smelters to lead emissions. In order to assess the overall health impact of lead, examining sources of airborne lead alone could be insufficient, because drinking water or lead-based paint could be contributing substantially to the total lead intake. It is only after identifying all sources of pollution and enumerating possible mitigation options that cost-effective measures can be selected.

5.3 After a careful inventory assessment, mobile sources may be found to make a significant contribution to the deterioration of overall ambient air quality, particularly in urban areas. Among available technical solutions, improved vehicle technology (such as three-way catalytic converters) has a far greater impact on air quality than fuel reformulation. For example, no amount of gasoline reformulation can achieve the reduction in the emissions of CO, hydrocarbons, and NO_x that is possible with the use of catalytic converters, provided that contaminants such as lead, sulfur, and phosphorus in motor fuel have been eliminated or reduced. Catalytic converters should therefore receive high priority in mitigating transport pollution, and their installation made mandatory in new cars.

5.4 Further, old engines that have been poorly maintained are high pollutant emitters. They suffer both from not utilizing modern vehicle technology and mechanical deterioration with age, which gives rise to much higher emission levels than when these vehicles were new. A rigorous program of vehicle inspection and maintenance should be enforced to maximize the overall effectiveness of abatement measures.

5.5 This chapter assumes that motor fuel reformulation has been deemed necessary, and will illustrate that, depending upon the level, fuel reformulation can be cost-effective. It draws largely from the presentations made by William Cummings of Texaco, William Keesom of UOP, Mario Camarsa of International Petroleum Industry Environmental Conservation Association (IPIECA), and Orlando Grassetti of Ford Argentina at the roundtable discussion held in Santiago de Chile on 12 May 1997. A description of basic approaches to setting fuel specifications is followed by a review of studies and experience in North America and Europe. Lessons are distilled from the collective experience of these regions, and general recommendations are made, using cost-effectiveness as a primary criterion.

Approaches to Setting Fuel Specifications

5.6 Fuel specifications can be broadly categorized into those that are composition-based and those that are emission-based.

Composition-Based Fuel Specifications

5.7 Composition-based specifications limit the amount of some components or elements in the fuel. Examples include placing limits on the amount of lead, sulfur, oxygen (minimum and/or maximum), aromatics, olefins, and benzene used. Composition-based specifications are easier to monitor and enforce than emission-based specifications. With the exception of additives such as lead, however, they may not be as cost-effective in the long run because they offer less flexibility to refiners.

Emission-Based Fuel Specifications

5.8 Emission-based specifications rely on empirically derived models to identify a range of fuel compositions that will achieve emission targets. They require an extensive database of emission levels as a function of fuel composition and vehicle characteristics. The empirical relationships may have to be updated from time to time as the vehicle fleet characteristics evolve over time. Monitoring is more complicated, because the compositional analysis of the fuel must be checked against empirical equations. These standards are hence more expensive to implement and enforce than composition-based standards.

5.9 Once the mathematical models are set up, however, these specifications offer far greater flexibility to refiners, enabling them to select the most economic way to meet emission targets. The United States, including California, makes extensive use of emission-based specifications. This, together with regionally differentiated fuel standards, provide a significant cost-advantage to the refining sector in the United States, making it less expensive to meet clean air targets than if there had been uniform, nationwide, composition-based fuel specifications.

Proportionality

5.10 It might be expedient to impose the same percentage reduction in a given pollutant across all sectors rather than to target selected industries where additional controls would be most cost-effective. The former approach, however, referred to as proportionality, is generally not cost-effective. As an illustrative example, Table 5.1 lists the results of a NO_x-reduction study of the states east of the Mississippi River in the United States presented in 1996 by the Ozone Transport Assessment Group (OTAG) under the direction of U.S. EPA. It is immediately clear from the table that from the viewpoint of NO_x reduction, fuel reformulation is a very expensive option, and one that will have only a limited impact on the total NO_x reduction. Much more effective, from both the perspective of cost and overall reduction, would be the implementation of utility controls.

Table 5.1 Cost-Effectiveness of NO_x Reduction

Measure	*Reduction, tons/day*	*US$ per ton*
Utility controls, low-NO_x burner	1,700	300–466
Utility controls, selective catalytic reduction	9,360	907–1,090
National low-emission vehicle (I/M)	1,600	3,100–8,900
Low-sulfur gasoline, 150 wt ppm average	350	4,700–12,000
Federal reformulated gasoline, phase II	400	25,000–45,000

5.11 The following example illustrates the difference in cost-effectiveness between proportionality and least-cost solutions. Assume that an emission strategy suggests that a reduction of 50 percent of NO_x from the inventory of 13,410 tons/day is needed to achieve the air quality goal. Table 5.2 shows that the total cost incurred by requiring a 50 percent reduction from all sectors amounts to over $18 million daily, or $6.7 billion each year. In contrast, by targeting the two least-costly options, it would be possible to achieve the same level of NO_x reduction at a cost of $5.7 million a day, as shown in Table 5.3, equivalent to $2 billion each year. The latter approach results in total annual savings of $4.6 billion.

Table 5.2 Proportionality: 50 percent Reduction

Measure	*Reduction, tons/day*	*US$ per ton* [a]	*Total cost, US$/day*
Utility controls, low NO_X-burner	850	383	326,000
Utility controls, selective catalytic reduction	4,680	999	4,670,000
National low-emission vehicle (I/M)	800	6,000	4,800,000
Low-sulfur gasoline, 150 wt ppm average	175	8,350	1,460,000
Federal reformulated gasoline, phase II	200	35,000	7,000,000
Total			18,300,000

a. Mid-range.

Table 5.3 Least Cost

Measure	*Reduction, tons/day*	*US$ per ton* [a]	*Total cost, US$/day*
Utility controls, low-NO_X burner	1,700	383	651,000
Utility controls, selective catalytic reduction	5,005	999	5,000,000
National low-emission vehicle (I/M)	0	6,000	0
Low-sulfur gasoline, 150 wt ppm average	0	8,350	0
Federal reformulated gasoline, phase II	0	35,000	0
Total			5,650,000

a. Mid-range.

5.12 Similarly, it would generally not be cost-effective to impose the same percentage reduction on all pollutants from mobile sources. For example, in dealing with ozone, decreasing VOC and NO_x emissions by the same amount might not be appropriate. It is important to study the ratios of hydrocarbon to NO_x and get some idea of ozone isopleths in order to identify a suitable, cost-effective solution.

Gasoline Reformulation

Octane Source

5.13 The first step in gasoline reformulation is lead removal. Lead should be removed on health grounds, as well as because of its incompatibility with catalytic converters. The central issue in gasoline-lead phase-out is selecting alternative octane sources. Representative blending-research-octane numbers of a selection of refinery streams are listed in Table 5.4. Motor octane numbers are typically lower, in some cases by 10 or more (for example, reformate, ethers). Ranges are given, because actual numbers depend on the specific composition of the starting stream (for example, propene versus butenes versus pentenes in alkylation), reaction conditions (such as severity of reforming), process unit configuration (product recycle in isomerization, for example), and what is present in the rest of the blended gasoline.

Table 5.4 Octane Sources

Source	*RON*
Normal butane	93
Light straight run	60–73
Isomerate	82–92
FCC naphtha	90–93
Reformate	90–103
Alkylate	90–97
MTBE (ether)	118

5.14 Butane is by far the cheapest source of RON in the table, but has high volatility. Refiners typically add as much butane as possible until the maximally permissible RVP level is reached.

5.15 Oxygenates such as MTBE have extremely high blending RON and MON. In the United States, MTBE has been used in gasoline since 1979, at first largely as an octane enhancer, and later to lower CO levels. Although gasoline with oxygenates has slightly lower fuel economy, the presence of oxygen enables more complete combustion of fuel, resulting in lower CO and hydrocarbon emissions. The use of oxygenates to lower CO levels is particularly effective in older cars. Newer cars have sensors that automatically adjust the ratio of oxygen to fuel, so that they benefit less from oxygenated gasoline in their CO emissions.

5.16 In order of decreasing blending octane, oxygenates are followed by reformate and alkylate. Alkylate is particularly attractive in pollution mitigation, because it contains little olefins, no sulfur, virtually no aromatics, and burns cleanly. In addition, alkylate has comparably high values of RON and MON, and it increases the gasoline yield. Alkylation, however, is a relatively costly option and requires specific feedstocks, including olefins from FCC units. A competing use for alkylate is aviation gasoline, for which other octane streams are used sparingly, if at all.

5.17 Reformate has come under increasing scrutiny recently because of concerns over the carcinogenicity of benzene, and the photochemical reactivity of xylenes and the higher molecular weight aromatics. It will, however, continue to be a major source of octane in the foreseeable future. Reducing the amount of reformate in gasoline affects the overall profitability of the refinery. The reformer is the least expensive source of hydrogen, and the hydrogen produced is used in hydrodesulfurization for sulfur reduction. Any reduction in the feed rate to the reformer reduces hydrogen production and forces the refiner to resort to more expensive hydrogen sources. As will be seen below, adjusting other gasoline parameters is a more cost-effective way to compensate for high levels of reformate in the pool.

5.18 FCC units are able to increase the yield of gasoline, while providing octane at the same time. From an environmental viewpoint, there are two concerns. Light olefins in FCC naphtha have high blending RVP, are photochemically reactive, and contribute to the formation of 1,3-butadiene, a carcinogen with greater potency than benzene. The heavy end of FCC naphtha tends to be high in sulfur, nitrogen, and aromatics. The light olefins from FCC, however, can be used as a feedstock for alkylation or etherification (production of oxygenates). If these are not used, the amount of light olefins should be controlled, most effectively by lowering RVP. As for the heavy end of FCC, it can be hydrotreated (hydrodesulfurization of this fraction results in some octane loss with low hydrogen consumption) or fractionated out of gasoline, or hydrocracked to lower boiling fractions.

5.19 Isomerization converts straight-chain pentane and hexane, both of which are low in octane, to branched C_5 and C_6. It is an inexpensive process, and the product has nearly the same values of RON and MON. By recycling unconverted normal paraffins, RON of up to 92 can be obtained. C_5 paraffins, however, are under increasing scrutiny because of their relatively high blending RVP. Another application of isomerization is to fractionate benzene precursors out of the feedstock charged to the reformer and to divert the stream to an isomerization unit, thereby reducing benzene in gasoline.

Setting Gasoline Specifications

5.20 The parameters for discussion here are RVP; lead; oxygen; sulfur; aromatics; benzene; olefins; and, in some cases, distillation points expressed as E100 (°F) (vol% of gasoline that evaporates at 100°F), E200, T10 (temperature at which 10 vol% of gasoline evaporates), T50, and T90. For cost-effectiveness, lead removal, RVP reduction, sulfur reduction, and benzene reduction should receive priority.

5.21 **Lead.** The first step in gasoline reformulation should be to remove lead. Lead is extremely toxic, is emitted from the exhaust pipe as particulate matter, and permanently deactivates catalytic converters. While PM_{10} is normally regarded as primarily produced by diesel, light-duty gasoline vehicles and trucks can account for over 50 percent of the total PM_{10} in cities where most gasoline is leaded, as in Tehran (Sweco *et al.* 1997). High levels of PM_{10} emissions are the product of lead particulates as well as a greater amount of incompletely burned hydrocarbons in the exhaust produced in the absence of catalytic converters. The standard maximally permissible level of lead in unleaded gasoline is 13 mg lead/liter, but even 5 mg/liter (mg/l) has been demonstrated to poison catalytic converters. For this reason, Ford recommends a lead specification of 3 mg/l (Grasetti 1997), and Toyota recommends no more than 1 mg/l (Chris Pappas, Vehicle Marketing Department, Toyota Canada, personal communication 1997). Residual lead in gasoline arises mainly from lead contamination of the distribution system. Once the distribution system is free of lead, the amount of lead in gasoline falls well below 13 mg/l.

5.22 **Sulfur.** To take full advantage of catalytic converters, the amount of sulfur in gasoline should be kept as low as possible, preferably below 500 parts per million by weight (wt ppm). The sulfur specification should be seriously reexamined in Latin America and the Caribbean, where many countries still have gasoline sulfur limits in the neighborhood of 1,500 wt ppm. The U.S. Auto/Oil Air Quality Improvement Research Program found that decreasing gasoline sulfur from 450 to 50 wt ppm decreased "current" (that is, model year 1989) vehicle emissions by 18 percent for hydrocarbons, 19 percent for CO, and 8 percent for NO_x. According to Ford (Grasetti 1997), recent data also suggest that excess sulfur impairs onboard diagnostic equipment for catalytic converters. Ford recommends a sulfur specification of 100 wt ppm to provide an average of less than 50 wt ppm, and Toyota recommends a sulfur specification of 80 wt ppm (Chris Pappas, Vehicle Marketing Department, Toyota Canada, personal communication 1997). Varying fuel composition parameters (relative to the average 1990 U.S. industry baseline gasoline) in the U.S. EPA complex model for catalyst-equipped cars reveals that sulfur reduction is one of the most effective measures in controlling NO_x emissions. Sulfur also has a significant impact on emissions of toxics. For cars not equipped with catalytic converters, sulfur has no effect on emission levels except that of SO_x, some of which forms particulate matter through further oxidation to SO_4. For all vehicle types, reducing sulfur reduces PM_{10} emissions. The cost of sulfur reduction follows a nonlinear relationship: costs increase significantly if sulfur is to be reduced to 50–150 wt ppm.

5.23 **RVP.** Reducing RVP is probably the most cost-effective way of controlling VOC emissions, including those of light olefins and benzene. This requires lowering the level of butanes, and possibly C_5 hydrocarbons. Ethanol has a high-blending RVP, further limiting the amount of C_4 and C_5 hydrocarbons that can be added to gasoline. In large parts of Europe and North America, the summer RVP is limited to 7–8 psi. Given the warm climate in many countries in Latin America and the Caribbean, and typical RVP limits of around 10–11 psi in the region, reductions of RVP should be seriously considered. The blending RVP of MTBE is about 8 psi, so that if RVP is to be below 8 psi, it would be preferable to use ethers with lower volatility, such as tertiary amyl methyl ether (TAME) or ethyl tertiary butyl ether (ETBE).

5.24 **Benzene.** The carcinogenicity of benzene has been receiving much attention recently. Other airborne toxics include acetaldehyde, formaldehyde, 1,3-butadiene, and polycyclic hydrocarbons. Reducing the amount of benzene in gasoline is a good first step in tackling toxics emissions. The addition of oxygenates reduces toxics emissions by diluting gasoline, which reduces the total amount of aromatics. Sulfur reduction decreases toxics emissions for catalyst-equipped cars by increasing hydrocarbon conversion over the noble metals.

5.25 **Parameters Affecting Ozone.** Ground-level ozone is a prevalent photochemical oxidant and an important component of smog. Ozone trends are difficult to establish because they are sensitive to year-to-year meteorological fluctuations. Ozone is not emitted directly by vehicles, but is a product of photochemical reactions among atmospheric hydroxyls, NO_x, and VOCs. Particularly photochemically reactive among VOCs are olefins, diolefins, aldehydes, and aromatics with two or more alkyl branches. Ozone abatement is complicated by nonlinear interactions among ozone precursors. To understand ozone, it is important at least to get accurate measures of the ratio of hydrocarbons to NO_x in the atmosphere, because the relative effectiveness of VOC and NO_x controls in reducing ozone in a given area depends on the ambient VOC/NO_x ratios (NRC 1991).

5.26 To control ozone, limits have been proposed for olefins and aromatics in gasoline. Among the olefins, it is the light olefins that are of concern because of their high volatility. The majority of olefins in gasoline come from light FCC naphtha. Their emission levels can be controlled by reducing RVP and minimizing C_4-C_5 olefins. The U.S. Auto/Oil Air Quality Improvement Research Program found that reducing olefins from 20 percent to 5 percent would indeed decrease the contribution of gasoline vehicles to peak ozone in the three major cities modeled, New York, Los Angeles, and Dallas-Fort Worth. The beneficial effect of light-olefin reduction was primarily the result of the large decrease in the photochemical reactivity of evaporative, running-loss, and refueling/storage emissions. The exhaust hydrocarbon emissions actually increased as a result of olefin reduction.

5.27 In the case of aromatics, however, the U.S. auto/oil industry study found that reducing aromatics from 45 to 20 percent had no effect on peak ozone in the three cities. Aromatics have low volatility and are an excellent source of octane. The growing trend to limit aromatics in gasoline has been driven by two concerns, the carcinogenicity of benzene and the photochemical reactivity of xylenes and higher aromatics. The data obtained, however, suggest that it would be more cost-effective to reduce benzene for the former, while the latter is not a concern for catalyst-equipped vehicles.

5.28 As for engine-out emissions, corresponding to exhaust emissions from cars not equipped with catalytic converters, data are sparse. Emissions tests are needed that reflect vehicle fleet characteristics as well as the traffic conditions of developing countries. The European Programme on Emissions, Fuels and Engine Technologies (EPEFE), a research program carried out jointly by the European motor industry and the European oil industry, found that increasing aromatics from 20 percent to 51 percent had no effect on engine-out emissions of hydrocarbons. There are, however, earlier unpublished European data that showed an increase of about 45 percent in engine-out hydrocarbon emissions as the aromatics content was increased from 25 to 50 percent. Further, in the absence of catalytic converters, increasing aromatics increases NO_x emissions.

Diesel Reformulation

5.29 Measures that are being considered in diesel reformulation include sulfur reduction, distillation curve control, cetane number enhancement, density control, and aromatics reduction. The benefits of sulfur reduction are reduced SO_x emissions, reduced PM_{10} emissions, and the possibility of installing catalytic converters if so desired. Catalyst technology for diesel lean-burn conditions is not as advanced as gasoline catalyst technology. In particular, three-way catalysts for NO_x reduction have not yet been commercialized. Distillation curve control has focused mainly on limiting T90, the heavier end of diesel that contributes particularly to airborne PM_{10}. Many developing countries have relatively high T90 to maximize the yield of diesel, which exacerbates the problem of air pollution from PM_{10}. PM_{10} and NO_x emission levels generally decrease with increasing cetane number, although there have been studies where increasing cetane was found to have no statistically significant effect on PM_{10} emissions. Lowering density enables the fuel-air mixture to become even leaner, because diesel engines inject a constant volume of fuel into a fixed amount of air; leaner mixtures lower PM_{10}, hydrocarbon, and CO emissions. Finally, aromatics, particularly polycyclics, have been shown in some cases to increase PM_{10} emissions.

5.30 As in the case of gasoline reformulation, it is possible to compensate for one parameter by controlling another. An example is the California program regarding NO_x emissions and diesel fuel composition. California issued specifications for diesel fuel that set a maximally permissible level of 500 wt ppm for sulfur and 10 percent for aromatics. Use of this kind of diesel would reduce NO_x emissions from a heavy-duty diesel engine by approximately 7 percent. In addition to the fuel specification, California also offered an alternative method for certifying a diesel fuel—that a fuel produce the same NO_x reduction when compared with a California reference fuel run in a Detroit Diesel Series 60 engine. The California reference fuel controlled many more parameters than the specification, and the parameters are shown in Table 5.5. Also shown in the table are diesel fuel formulations that are equivalent to the California reference in NO_x reduction. The data in the table come from several studies, and were not obtained as part of a controlled-variable study, which may make it difficult to derive correlations. The data show that the same emission limits can be met more cost-effectively by greater hydrodesulfurization and cetane enhancement than by reducing the aromatics content to 10 percent or lower, in keeping with the specification of the California Air Resources Board (CARB) reference diesel fuel.

5.31 In the absence of additives, there is a tradeoff between cetane and aromatics. Higher levels of aromatics can, however, be tolerated if cetane-improvement additives are used. This option should be considered if deemed cost-effective. It should be noted that most cetane-improvement additives contain nitrogen. Even so, cetane-improved fuels using cetane improvers can lower NO_x emissions. Currently most, if not all, diesel fuels being mandated in California have been certified by the engine procedure and contain approximately 20 percent aromatics, with varying amounts of cetane-improvement additives. This is a much more cost-effective approach than having to hydrotreat diesel fuels to a 10 percent aromatic level.

Table 5.5 Diesel Formulations Certified by CARB

		Chevron		*Arco*	
Diesel properties	*California reference*	*G2*	*D4781*	*D-25*	*D-26*
Maximum vol% aromatics	10.0	15.1	19.0	21.7	24.7
Maximum wt% polycyclic aromatics	1.4	3.6	2.2	4.6	4.0
Maximum wt ppm sulfur	500	202	54	33	42
Maximum wt ppm nitrogen	10	341	484	20	40
Minimum cetane number [a]	48.0	54.8	58.0	55.2	56.2

a. With cetane-improvement additives.

5.32 The EPEFE study found decreasing polycyclic aromatics, density, and T95 for light-duty diesel vehicles, and decreasing polycyclic aromatics for heavy-duty diesel vehicles and reduced PM_{10} emissions, respectively. As for NO_x, decreasing polycyclic aromatics for light-duty diesel, and decreasing density, polycyclic aromatics, T95, and increasing cetane for heavy-duty diesel lowered emission levels. The study also found, however, that variability in engines was more important than the effects of fuel composition. It should be mentioned that the EPEFE study did not examine the effect of varying the sulfur content of diesel.

5.33 In developing countries, T90 and sulfur levels tend to be high. While the United States and the EU have moved to an upper limit of 500 wt ppm sulfur in diesel, a number of countries still have a legally permissible sulfur level of 10,000 wt ppm. T90 (or T95) can also be several tens of degrees Celsius higher than in the United States or EU. Controlling these two parameters should lead to a significant reduction in PM_{10} emissions in these countries. Similarly, a reduction in sulfur in fuel oil will have a beneficial effect on PM_{10} emission levels. Depending on the crude processed, however, sulfur reduction could require significant capital outlays by refiners.

Harmonization of Fuel Specifications in Latin America and the Caribbean

5.34 As part of the joint initiative among the World Bank, ARPEL, and OLADE to encourage elimination of lead from gasoline and promote cleaner-burning fuels, a common set of the key technical specifications for major liquid fuels has been proposed for application throughout Latin America and the Caribbean. Although it is the prerogative of individual countries to set national standards at levels they consider appropriate, these proposed specifications are intended to set minimal standards throughout the region, provide guidance to countries that have not yet formally established fuel specifications, and, if implemented, they could allow coherent regional product markets to develop. These standards are proposed as a baseline for all countries in the region and are to be implemented over the next seven years, with some interim targets set for 2001, and final standards targeted for 2005. The proposed specifications for gasoline and diesel are given in Table 5.6 and Table 5.7, respectively. The review committee for the proposal comprises representatives from Argentina, Brazil, Chile, Jamaica, Peru, and Venezuela, in addition to ARPEL, U.S. DOE, and the World Bank.

Table 5.6 Proposed Unleaded Gasoline Specifications

Specification	*Value*
RON, minimum	91 / 95
MON, minimum	82 / 85
RVP, psi, maximum	9.0–11.5
T50, °C, maximum	120
T90, °C, maximum	190
Sulfur, wt ppm, maximum, 2001	1,000
Sulfur, wt ppm, maximum, 2005	400
Total aromatics, vol%, maximum	45
Olefins, vol%, maximum	25
Benzene, vol%, maximum	2.5
Oxygen, wt%, maximum	2.7
Lead, g/l, maximum	0.013

Table 5.7 Proposed Diesel Specifications

Specification	*Value*
Cetane number, minimum, 2001	45
Cetane number, minimum, 2005	47
T90, °C, maximum	360
Sulfur, wt%, maximum, 2001	0.5
Sulfur, wt%, maximum, 2005	0.2
Density range @15°C, kg/m^3	820–860
Total aromatics, vol%, maximum	30

5.35 The minimal RON of 91 is based on the recommendations of automobile manufacturers. Together with MON of 82, it makes the octane requirement for regular gasoline slightly less than an anti-knock index for regular gasoline of 87 in the United States. RVP is a function of the climate and is permitted to vary between 9.0 and 11.5, depending on the geographical location. In congested urban centers where ozone is a serious problem, even this range is too high, and it is recommended that much lower RVPs be mandated during the ozone season. This is indeed already the case in cities such as Santiago and Mexico City. Sulfur is reduced in two steps, going below 500 wt ppm in the year 2005. There is an upper limit on oxygen to ensure reasonable drivability; oxygenates above this level have also been associated with higher NO_x emissions in a number of tests.

5.36 With respect to diesel, a minimal cetane number rather than a cetane index was chosen to allow the addition of cetane-improvers. One problem this specification raises is that it places a burden on refiners, because engine test laboratories to determine cetane number will have to be set up to certify diesel. Sulfur is again reduced in two stages, with a maximum of 2000 wt ppm by the year 2005. Some refiners may have trouble meeting the minimal density and maximal T90, because the outlet for kerosene is rather limited in the region, and much kerosene is added to diesel.

5.37 Sulfur reduction in gasoline and diesel would not have its full intended impact on the environment if the refineries release the sulfur removed into the atmosphere. Sulfur reduction should therefore be accompanied by the installation of sulfur-recovery units at refineries.

5.38 The above specifications would make it even more difficult for small hydroskimming refineries in the region to remain viable. There will likely be some degree of rationalization of the refining industry as a result of more stringent fuel standards and greater product trade.

5.39 Finally, enforcing compliance will play a very important role in ensuring the effectiveness of the proposed specifications. If compliance is not systematically monitored at every stage in the supply chain (particularly with respect to octane when there are two octane grades, for example), those who comply will not be competitive in the market, and the fuel specification system could eventually break down. One of the key future steps in the harmonization of fuel standards is thus to set up an effective monitoring system in each country so that these standards are properly maintained.

6

Chile

Background

6.1 Air pollution in the Santiago de Chile metropolitan area has been serious for a number of years. One factor that exacerbates the problem is the topography of Santiago, which is located in a valley surrounded by mountains, leading to frequent occurrences of thermal inversion. CONAMA-RM (Comisión Nacional del Medio Ambiente de la Región Metropolitana) has been commissioned to devise a "prevention and decontamination" plan in an attempt to bring about substantial amelioration of air quality problems in the area. The plan covers all sources of pollution and includes proposals for gasoline and diesel specifications. The plan will be assessed and reformulated in 2000 and 2005. In this chapter, the discussion of the plan will be limited to its impact on mobile sources of pollution.

6.2 Chile has undergone rapid economic expansion in the last few years. This has been accompanied by gasoline and diesel consumption growth of over 8 percent annually. In 1995, Chile produced 31,500 barrels per calendar day (b/cd) of leaded gasoline and 12,000 b/cd of unleaded gasoline, and imported 1,300 b/cd of leaded and 1,700 b/cd of unleaded gasoline. In the same year, Chile produced 55,100 b/cd of diesel and imported an additional 7,380 b/cd (Alconsult 1996). The challenge is to sustain economic growth while improving air quality. More specifically, refiners in Chile must meet growing demand for refined products, develop new sources of octane to replace lead, and improve fuel quality to reduce pollutant emissions.

6.3 Against this backdrop, the National Energy Commission of Chile, with the support of the World Bank, organized a roundtable discussion in May 1997, *Automotive Gasoline, Vehicle Fleet and Air Quality Management*, to address several concerns arising from gasoline-lead elimination. In Chile, the amount of lead added to gasoline decreased from 310 metric tons in 1990 to 250 metric tons in 1995, and this amount is expected to decrease rapidly in the future. A number of refinery-upgrade projects is currently under consideration to effect the transition to unleaded gasoline and to meet other, more stringent, environmental requirements.

6.4 The roundtable discussion reviewed international trends and addressed the following questions:

- Distilling lessons from other regions, particularly the United States and EU, what would be the most cost-effective way of reformulating gasoline and diesel in Chile to improve air quality?
- In setting new gasoline specifications, how does the lack of catalytic converters in 60 percent of cars in Santiago affect the decision?
- What are the likely economic costs of reformulating motor fuels?

6.5 A panel of local and international speakers was invited to address these questions, as well as broader issues of cleaner fuels. The morning session of the first day of the roundtable focused on air quality management, the afternoon session on the impact of lead phase-out on the refining industry. In each session, a Chilean expert started the program by providing background information and outlining the current state of affairs. International industrial speakers followed, responding to the local situation and drawing lessons from other countries. Several key issues were identified and dealt with further in panel discussions. Discussions between the international speakers and local participants continued in small groups on the second day. The topics covered and names of the speakers are detailed in the roundtable program, below.

Roundtable Program

Topic	*Speaker*	*Affiliation*
Opening remarks	José Antonio Ruiz	Comisión Nacional de Energía
Current status in Santiago	Gianni López	CONAMA
Air quality		
Vehicle emissions		
Urban air quality management	Mario Carmasa	IPIECA
Performance and cost-effectiveness of stage I and stage II vapor recovery systems	William Cummings	Texaco
Emissions from cars without catalytic converters	Mario Camarsa	IPIECA
Roundtable discussion	Mario Camarsa	IPIECA
Chair: Gianni López	William Cummings	Texaco
CONAMA		

Gasoline-lead phase-out in Chile Future gasoline specifications Plans for refinery upgrades and investments	Cristóbal Norambuena	Empresa Nacional del Petróleo (ENAP)
Cleaner fuels and refinery configuration: different options for Chile	William Keesom	UOP
Worldwide fuel specifications and cost differentials	William Cummings	Texaco
Effect of gasoline composition on car components and fuel economy	Orlando Grassetti	Ford Argentina
Impact of environmental regulations on international gasoline prices	Elisa Munares	I.P. International
Roundtable discussion	William Keesom	UOP
Chair: Cristóbal Norambuena	William Cummings	Texaco
ENAP	Orlando Grassetti	Ford Argentina
	Elisa Munares	I.P. International
Closing remarks	Masami Kojima	The World Bank
	José Antonio Ruiz	Comisión Nacional de Energía

6.6 This chapter summarizes the data and proposals presented at the roundtable, the comments of international experts on the proposals in light of experience and findings elsewhere, and subsequent modifications made to the proposed fuel reformulation plans in Chile.

Air Quality in Santiago

6.7 CONAMA discussed air quality in Santiago in the context of the anticipated failure to meet the national air quality standards and emission reduction targets for the next 15 years. CONAMA also discussed to what extent the proposed decontamination plan is expected to reduce overall pollutant emissions, given that not all the targets are likely to be achieved.

Air Quality Standards versus Measurements

6.8 National air quality standards in Chile are detailed in Table 6.1. For comparison, WHO guidelines and U.S. National Ambient Air Quality Standards (NAAQS) are listed in Table 6.2 and Table 6.3, respectively. The Chilean standards for sulfur dioxide (SO_2) are identical to the U.S. federal standards and more lenient than the WHO guidelines of 125 and 50 $\mu g/m^3$ for 24-hour and annual averages, respectively. WHO currently has no guideline values for total suspended particulates (TSP) or PM_{10} on the grounds that there is no evident threshold for effects on morbidity or mortality. In the United States, the federal PM_{10} standards replaced TSP standards in 1987.

Table 6.1 Air Quality Standards in Chile

Item	*TSP*	*PM_{10}*	*O_3*	*NO_2*	*SO_2*	*CO*
Averaging time	24 h	daily	1 h		daily	1 h
$\mu g/m^3$	260	150	160 (0.08 ppm)		365	40 mg/m^3
Averaging time	annual			annual	annual	8 h
$\mu g/m^3$	75			100	80	10 mg/m^3

Table 6.2 WHO Air Quality Guidelines

Item	*TSP*	*PM_{10}*	*O_3*	*NO_2*	*SO_2*	*CO*
Averaging time	*	*		1 h	24 h	1 h
$\mu g/m^3$	*	*		200	125	30 mg/m^3
Averaging time			8 h	annual	annual	8 h
$\mu g/m^3$			120 (0.06 ppm)	40-50	50	10 mg/m^3

* No guideline values are currently set for particulate matter because there is no evident threshold for effects on morbidity and mortality.

Table 6.3 Air Quality Standards in the United States

Item	*TSP*	*PM_{10}*	*O_3*	*NO_2*	*SO_2*	*CO*
Averaging time	*	24 h	1 h		24 h	
$\mu g/m^3$	*	150	235 (0.12 ppm)		365	
Averaging time		annual		annual	annual	8 h
$\mu g/m^3$		50		100	80	10 mg/m^3

* Federal TSP standard superseded by PM_{10} standard, 1 July 1987.

6.9 Santiago has five monitoring stations of the MACAM network (la Red de Monitoreo de Contaminantes Atmosféricos) that measure PM_{10}, O_3, SO_2, nitric oxide (NO), and NO_x, and an additional eight semi-automatic stations of the Vigilancia network that measure TSP, SO_2, and NO_2 every four days. In 1995, the number of days exceeding the daily TSP standard was 40 (out of 91 days), and the corresponding number of days for exceeding ozone, PM_{10}, and 8-hour CO standards were approximately 150, 60, and 60, respectively. In the extent to which the pollutant emissions exceeded the national standards,

PM_{10} emissions were the most serious problem. Ozone exceedances occurred mainly in December (summer), while PM_{10} tended to be high from May to August (winter).

6.10 A detailed inventory of emission sources is given in Table 6.4. A breakdown by sector is given in Table 6.5. It is immediately apparent that transport is responsible for the majority of emissions of PM_{10}, NO_x, and CO. In the case of PM_{10}, the bulk of the emissions come from street dust. If street dust is excluded, transport contributes to slightly less than one-third of the total PM_{10} emissions. CONAMA's emission targets are listed in Table 6.6. The goal is to halve emissions levels by 2011. Table 6.7 gives estimates of emissions levels in 2005, first assuming no further control measures, and second assuming that the proposed decontamination plan is fully implemented.

6.11 The decontamination plan tackles emissions from transportation, industry/commerce/construction, agriculture, and domestic use of energy. For transportation, the plan proposes specific measures for vehicular emission reduction: facilitating fleet renewal, introducing more stringent standards for new vehicles and control (including inspection and maintenance) of in-use vehicles, requiring further fuel reformulation, and paving more roads. Further, it proposes steps to reduce the total distance traveled by vehicles, as well as the time spent traveling. These steps include the addition of environmental dimensions to territorial planning, halting urban expansion, improving the quality of public transportation, introducing incentives for the rational use of automobiles, and curtailing new motor traveling.

6.12 The plan represents a significant step forward in the area of air quality management in Chile. It aims to reduce emission levels by 20 to 55 percent relative to the "no plan" scenario. The ambitious nature of the targets notwithstanding, the reduction relative to the 1997 emission levels is significant only for SO_2, and emission levels will actually increase for VOC, even if the plan is successfully implemented. The target emission levels will not be achieved with any of the pollutants in spite of the decontamination plan, with the exception of SO_2.

6.13 As for diesel, sulfur will be limited to 0.1 wt% in the year 1999, and 0.05 wt% in 2001. The latter is identical to the current limit in the EU and the United States. The minimum cetane number required will be 50, density is to fall within the range 0.83–0.85 kg/liter, and T90 will be limited to 338°C in the year 1999, and 320 in 2001. Two prominent features are the limit of 10 vol% aromatics and 1.4 vol% polycyclic aromatics to become effective in the year 2001. They are identical to those of the "reference" diesel in California listed in Table 5.5. As mentioned in Chapter 5, because the refiner can opt for emission-based specifications, diesel in California typically contains far in excess of 10 vol% aromatics and 1.4 vol% polycyclic aromatics. The proposal for the EU for the year 2000 specifies a limit of 11 vol% polycyclic aromatics in diesel, higher than the proposed Chilean limit for total aromatics. The 2001 Chilean specifications will require severe hydrotreating options.

Table 6.4 Estimated Inventory of Emissions in Santiago in 1997
(tons annually)

Source		PM_{10}	SO_2	NO_x	*VOC*	*CO*
Mobile	Private vehicles	225	277	9,478	10,164	113,123
	Commercial vehicles	326	411	5,292	5,660	62,810
	Taxis	54	111	1,947	2,237	25,628
	Trucks	953	1,348	8,727	2,759	18,859
	Buses	1,173	1,010	5,490	1,322	4,854
	Motorcycles			9	229	718
Subtotal, mobile		2,730	3,157	30,943	22,371	225,992
Fixed	Industrial processes	1,467	7,827	5,391	65	1,222
	Industrial boilers	1,486	8,735	5,075	165	2,791
	Heating boilers	190	427	418	9	241
	Bakeries	33	49	75	1	49
Subtotal, fixed		3,175	17,037	10,959	241	4,303
Street dust	Paved	28,524				
	Unpaved	4,462				
Subtotal, street, dust		32,986				
Other sources	Residential combustion	1,359	975	1,567	3,543	5,134
	Evaporative VOC emissions				14,076	
	Use of domestic solvents				1,316	
	Fuel distribution				4,959	
	Evaporation from vehicles				6,046	
	Biogenic emissions			218	8,722	
	Forest fires	1,467		140	873	9,083
	Registered and illegal Burnings of forests	65		1	74	410
Subtotal, other sources		2,891	975	1,926	39,609	14,627
Total		41,782	21,169	43,828	62,221	244,921

Note: Running losses appear under *mobile*; refueling losses appear under *fuel distribution* (2/3 from vehicles, 1/3 from storage tanks); hot soak and diurnal appear under *evaporation from vehicles*. Utility emissions are included in *industrial boilers*.

Table 6.5 Estimated Inventory of Emissions, by Sector, in 1997
(tons annually)

	PM_{10}	SO_2	NO_x	VOC	CO
Transport	35,716	3,157	30,943	28,417	225,992
Industry, commerce, & construction	3,175	17,037	10,959	19,276	4,303
Agriculture	1,532		359	9,669	9,493
Domestic	1,359	975	1,567	4,859	5,134
Total	41,782	21,169	43,828	62,221	244,921

Table 6.6 Emission Targets
(tons annually)

	PM_{10}	SO_2	NO_x	VOC	CO
1997	41,782	21,169	43,828	62,221	244,921
Target for 2000	38,648	19,581	40,541	57,554	226,552
Target for 2005	31,336	15,877	32,871	46,666	183,691
Target for 2011	20,891	10,585	21,914	31,110	97,968

Table 6.7 Emission Projections
(tons annually)

	PM_{10}	SO_2	NO_x	VOC	CO
1997 baseline	41,782	21,169	43,828	62,221	244,921
2005 forecast without plan	53,959	23,216	54,974	83,273	312,253
2005 forecast with plan	41,891	10,734	41,276	67,143	218,212
Percentage reduction in 2005 relative to forecast without plan	22	54	25	19	30
Percentage reduction in 2005 relative to 1997	0	49	6	–8	11

Fuel Specifications

6.14 As part of the above decontamination plan, CONAMA drafted proposals for future gasoline and diesel specifications to reduce vehicular emissions, which were presented at the roundtable. The current specifications for gasoline and diesel are listed in Table 6.8 and Table 6.9, respectively.

Table 6.8 Current Gasoline Specifications

Item	*Specifications*		*Observed values, 1995*
	Class I (summer)	*Class II (winter)*	
T10, °C, maximum	70	70	55
T50, °C, maximum	121	121	
T90, °C, maximum	190	190	170
End point, °C, maximum	225	225	
RVP, maximum	69 kPa (10 psi)	86 kPa (12.5 psi)	9.7 psi
Lead in leaded, g/l, maximum	0.6	0.6	0.26
Lead in unleaded, g/l, maximum	0.013	0.013	<0.003
Sulfur in leaded, wt%, maximum	0.15	0.15	0.05
Sulfur in unleaded, wt%, maximum	0.1	0.1	0.02
Benzene, vol%, maximum	5	5	1.5–2.6
Stability in minutes	240	240	
Copper corrosion, maximum	1	1	1

6.15 The proposed unleaded gasoline specifications for the year 2000 place a limit of 25 vol% on aromatics, 1 vol% on benzene, and a minimal oxygen content of 2 wt%. These requirements are more restrictive than those in place in the United States, and much more stringent than the gasoline specifications for the EU proposed by the European Commission for the year 2000. In the United States, the 1990 Amendments to the Clean Air Act specifying reformulated gasoline do not currently, nor will they in the future, impose a direct limit on the aromatics content in gasoline. Beginning in 1998, reformulated gasoline in the United States will be controlled by the complex model that will allow any composition, as long as the emission specifications and the specifications for oxygen and benzene are met. The proposed specifications in Chile, however, do not address sulfur, and summertime RVP is limited to 8.5 psi, wintertime RVP to 11 psi. Refiners will be required to report vol% olefins in gasoline.

Table 6.9 Current Diesel Specifications

Item	Specifications		Observed values, 1995
	Type A	*Type B*	
Flash point, °C, minimum	52	52	60
Pour point, °C, maximum	–1	–1	–6
Water & sediment, vol%, max	0.1	0.1	0.04
Carbon residues			0.1
Ramsbottom carbon	0.21	0.35	
Conradson carbon	0.2	0.34	
Ash, wt%, maximum	0.01	0.01	
T90, °C, maximum	282 min–349 max	282 min–357 max	350
Density at 40°C, centistokes	1.9 min–5.5 max	1.9 min–5.5 max	3.4
Sulfur, wt%, maximum	0.3 [a]	0.5 [b]	0.2
Copper corrosion, maximum	2	2	1
Cetane number, minimum	45	45	49
Density at 15°C, kg/l	0.85 ± 0.02	0.85 ± 0.02	0.85

Note: Type A: Metropolitan Region (which includes Santiago; Chile is divided into 13 regions). Type B: rest of the country. Density in Region XII is 0.815 kg/l.

a. To change to 0.2 beginning 3 May 1998.
b. To change to 0.3 beginning 3 May 1998.

Refinery Modification Plans

6.16 In order to complete the phase-out of lead in gasoline, ENAP has a number of refinery upgrading plans to meet the octane shortfall. They are presented in Table 6.10, and include the expansion of reformers and the addition of alkylation, isomerization, and etherification units. The plans for the installation of CCR (continuous catalyst regeneration) reforming units are currently on hold in light of the proposed limits on aromatics and benzene.

Table 6.10 Refinery Modification Plans for Lead Phase-Out

Modification	*Year*	*Capacity, b/d*	*Investment, million US$*
RPC Refinery			
Semi-regen.	1996	10,000	33.7
Semi-regen. expansion	1997	2,000	7.3
Conversion to CCR	1999	1,800	20.4
Isomerization	1997	5,000	14.1
DIPE (di-isopropyl ether)	1998	60,000 t/y	21.8
HF (hydrofluoric acid) alkylation	2005	3,000	31.8
MTBE	2001	30,000 t/y	11.6
Petrox Refinery			
Semi-regen.	1998	14,000	45.6
Conversion to CCR	2000	2,100	20.4
Isomerization	1998	5,000	13.1
HF Alkylation	2005	3,000	29.6
MTBE	2001	30,000 t/y	11.6

Note: b/d: barrels per day; t/y: metric tons per year.

Control Options

6.17 The international speakers emphasized the importance of basing regulatory decisions for urban air quality management on an objective assessment of science and technology. Given that Chile's specific circumstances differ from those of the United States and the EU, the control measures adopted in North America and Europe may not necessarily be cost-effective in Chile. There was a unanimous consensus among the international speakers that catalytic converters should receive the highest priority: by far the most effective measure for reducing the emissions of VOC, CO, and NO_x from gasoline-fueled vehicles is the installation of catalytic converters. What can be achieved by fuel reformulation pales in comparison with the 70–95 percent reduction of exhaust emissions that can be realized by catalytic converters.

Vapor Control

6.18 For VOC emissions control during distribution, stage I and stage II vapor control has been implemented in some countries. Stage I vapor recovery covers tank truck and terminal operations, where uncontrolled emissions are estimated to be approximately 7.3 pounds for every 1,000 gallons of fuel in the United States, and can operate with 95 percent efficiency. Stage II vapor recovery covers vehicle refueling at service stations.

Uncontrolled emissions are a function of the ambient temperature and the RVP of gasoline. With an RVP of 8.6 psi, uncontrolled emissions are on the order of 10 pounds for every 1,000 gallons of gasoline. The efficiency target is 90 percent, but small service stations tend to be exempted. The estimates of the cost-effectiveness of stage II recovery, which depend on the extent of exemptions, range between US$180 and US$1,330 per ton of VOC.

6.19 In Europe, where approximately 60 percent of cars are equipped with catalytic converters, vapor loss during refueling is less than 2 percent of total hydrocarbon emissions. In countries where the percentage of cars equipped with catalytic converters is lower, the figure of 2 percent is expected to be even lower. Because of volume-related exemptions, only 1 percent of the total VOC emissions is addressed by stage II recovery. With in-use efficiency of 60–70 percent, a reduction of 0.5–0.6 percent is actually achieved.

6.20 An alternative to stage II recovery is the installation of on-board refueling-vapor-recovery systems in vehicles. They absorb vapors with 95 percent efficiency during refueling, desorb absorbed hydrocarbons onto the engine where the hydrocarbons are burned later, cost on the order of US$40 to US$50 for each vehicle, last the life of the car, and are essentially maintenance-free. In the United States, on-board refueling-vapor-recovery systems will be mandated beginning in 1998. Stage II vapor control will eventually become redundant, and it could be abolished when all cars are equipped with on-board refueling-vapor-recovery systems. This technology controls emissions from the entire fleet, as opposed to stage II, which partially controls the fleet.

Fuel Reformulation

Gasoline Reformulation

6.21 In order to take advantage of vehicle control technology such as catalytic converters, contaminants that impair the operation of control systems should be minimized or eliminated. The two most critical contaminants are lead and sulfur. Lead poisons catalytic converters permanently, mainly through pore-mouth plugging, and should be removed altogether from gasoline. Sulfur reduces the conversion of pollutants over the catalyst, and should be kept below 500 wt ppm. The efficiency of the catalyst increases dramatically, particularly at very low levels of sulfur in the fuel. Phosphorus is another catalyst poison that should be eliminated. In response to the proposed gasoline fuel specifications, the international panelists emphasized the cost-effectiveness of reducing sulfur and RVP rather than imposing a stringent limit on aromatics. Specifically, the speakers suggested that a 25 percent limit on aromatics be postponed, and instead that stricter limits on RVP be imposed and a limit on sulfur be introduced. The need to evaluate carefully the data obtained in the U.S. and European auto/oil industry studies was stressed.

Diesel Reformulation

6.22 There was a consensus among the international speakers that meeting the new diesel specifications would be extremely costly. They pointed out that the refiners in

California avoided high capital expenditures by increasing the cetane number, often by means of cetane-improvement additives, rather than reducing mononuclear and polycyclic aromatics. Because all the diesel formulations presented in Table 5.5 meet the same emission standards, there is no environmental benefit to be gained by opting for a more costly option. They recommended that the matter be investigated further to seek the least-cost solution.

Economic Considerations

6.23 Depending on the extent of reformulation, improving the quality of gasoline and diesel could be costly. To assess the impact on consumers, however, it is important to bear in mind that in international markets changes in product prices have not necessarily been driven by higher product costs that arise from compliance with more stringent environmental regulations; that is to say, cost increases are often not reflected in prices. An example is the U.S. experience with the introduction of reformulated gasoline; the differential between conventional and reformulated gasoline has not corresponded to the incremental cost of producing the latter, but has varied according to the demand and supply relationship. Therefore, if Chile and other countries in the region continue to open their domestic markets to international suppliers of refined products, domestic refiners will face increasingly tough competition from importers.

6.24 Experience elsewhere has shown that it is difficult to justify investments made to meet more stringent environmental regulations purely on business grounds, because refiners do not typically recover the cost of investments made. It is therefore imperative that refinery operations remain economically viable, and that cost-effectiveness be one of the key criteria in defining future pollution abatement strategies.

Summary of the Roundtable Discussion

6.25 The World Bank summarized the presentations made and the discussions that followed at the roundtable in the concluding remarks. These remarks were subsequently issued in English and Spanish. They are reprinted below.

Automotive Gasoline, Vehicle Fleet, and Air Quality Management

Aide-memoire: Roundtable Discussion held in Santiago de Chile, 12 May 1997

The National Energy Commission of Chile, jointly with the World Bank, organized a roundtable discussion in Santiago on 12 May 1997 to discuss issues arising from elimination of lead in gasoline and, more broadly, to deal with the on-going debate in Santiago on how best to reformulate transportation fuels. The quantity of lead added to gasoline in Chile decreased from 310 metric tons in 1990 to 250 tons in 1995, and this amount will continue to decrease in the future. There are several refinery projects in progress or under consideration to enable the transition to unleaded gasoline. At the same time, there is growing concern over air quality in Santiago and other major cities in Chile, and the recognition that lead removal must be accompanied by sound fuel reformulation.

The roundtable was called to review international trends and examine the following issues:

- How do we make up for the octane loss from lead removal in such a way that other air pollution problems do not arise, given that a large fraction of cars in Chile are not equipped with catalytic converters?
- Considering international trends in changing fuel specifications, how should the refining sector in Chile respond to gasoline lead removal, and what are the likely economic costs?

Local and international speakers were invited to address various aspects of transportation fuel reformulation, and its anticipated impact on air quality. The roundtable was attended mainly by representatives from the Chilean Environmental Agency (CONAMA) and the refining industry (ENAP). A Chilean speaker opened each session, outlining the local situation, and international industrial speakers followed, drawing lessons from experiences from around the world.

Background

The roundtable discussion underscored the importance of urban air quality management in Santiago. There are serious problems, particularly with respect to ozone and particulates, with the situation worsening between 1995 and 1996. Transport is one of major contributors to air pollution. Forty percent of cars in Santiago are equipped with catalytic converters, sixty percent are not. Thirty percent of vehicles are 15 years or older. The government of Chile has mandated catalytic converters for new cars, and in the city of Santiago, the circulation of cars not equipped with catalytic converters is banned on days exceeding predetermined pollutant levels.

CONAMA Proposal

It is against this background that CONAMA is working toward formulating a decontamination plan, including new transportation fuel specifications. Although much can be learned from international experience, there is a need to identify realistic emission factors representative of the vehicle fleet in Chile, and tests are in progress. CONAMA is in the process of conducting a cost/benefit analysis for each pollutant to identify least-cost solutions. The plan that CONAMA is proposing will call for a 35–50 percent reduction in pollutant emissions, but even a 50 percent reduction is unlikely to enable Santiago to meet the national air quality standards. The CONAMA proposal includes stringent gasoline and diesel specifications with respect to aromatics and other parameters.

Need for an Integrated Solution and Cost-Effectiveness

The international speakers responded to various aspects of the proposed air pollution abatement strategy and new fuel specifications. While they came from different parts of the world (Europe, the United States, and Latin America), a strong consensus emerged in their presentations. They emphasized the need, first and foremost, for an *integrated solution* to look at all different sources of pollution, stationary as well as mobile. The least-cost solution is unlikely to involve proportionality whereby all pollutants are reduced by the same percentage, or where different sectors of the economy are required to achieve the same percentage reductions, but the speakers recognized the political difficulties involved in moving away from the principle of proportionality currently embodied in the Chilean legislation.

Catalytic Converters

Concentrating mainly on mobile sources, the international speakers were unanimous in their assessment that by far the most effective solution for gasoline-fueled vehicles is the *use of catalytic converters*. The role of fuel reformulation is secondary, as any reductions in exhaust emissions arising from fuel reformulation pale in comparison to that which can be achieved by new vehicle technology. In the case of gasoline, this is true particularly with respect to NO_X emissions which are relatively insensitive to fuel composition.

Emission-Based Regulations

The international speakers spent a considerable amount of time addressing fuel reformulation and its impact on the refining industry. They pointed out that we should not lose sight of the fact that what we want to achieve ultimately is emissions reduction, not fuel reformulation *per se*. They cautioned against composition-based regulations which give little flexibility to refiners and which, when taken from regulations implemented in other countries, may be ill-suited for the local situation in Chile. Emission-based regulations, which offer greater flexibility to refiners, were considered more cost-effective.

Key Gasoline Parameters: Sulfur and RVP

One of the objectives for gasoline reformulation should be to enable efficient operation of catalytic converters. To this end, lead removal and sulfur reduction are needed. The response of catalytic oxidation/reduction to sulfur is nonlinear, and catalyst efficiency increases dramatically particularly at low levels of sulfur. For controlling hydrocarbon emissions including light olefins (and hence ozone), reducing RVP was considered the most cost-effective measure.

Aromatic Content and Old Vehicles

In contrast, emission tests, carried out in the U.S. Auto/Oil Air Quality Improvement Research Program, in which aromatics were increased from 20 to 45 percent showed that the effects were negligibly small for cars equipped with catalytic converters. The data on cars not equipped with catalytic converters are sparse and no firm conclusions could be drawn. In this respect the emission tests currently being conducted in Chile would yield useful information. In addressing ozone, the international speakers cautioned against targeting primarily VOC, and instead called for a balanced reduction of NO_X and VOC. For controlling airborne toxics, limiting benzene, but not aromatics, was considered worthwhile. The use of unleaded gasoline will grow as new cars with catalytic converters replace old vehicles. The speakers indicated that there were no serious concerns in using unleaded gasoline in cars not equipped with catalytic converters, provided that RVP is lowered sufficiently and the level of benzene remains within a reasonable range.

Diesel Specifications

Responding to the new diesel specifications, the U.S. speakers pointed out that even in California, refiners have the option of trading off aromatics for other parameters, and the actual level of aromatics is in the vicinity of 20 percent rather than 10 percent. This is because it is extremely costly to produce diesel containing only 10 percent aromatics, and the same emissions standards can be met by using cetane enhancing additives and other means which are substantially less expensive. Therefore, by imposing a 10 percent limit on aromatics in diesel as suggested in the CONAMA proposal, Chile may be in danger of isolating itself from the rest of the Americas and, in the event of supply shortage, of not being able to import diesel of the required specifications readily. The speakers urged that Chile look into cost-effective alternatives to the current proposal for reducing particulate and NO_X emissions from diesel-engines.

Effective Inspection/Maintenance Program

Finally, to maintain the value of the substantial investments that the above program is likely to entail both in refining and vehicle technology, the speakers urged that an effective I/M program continue to be implemented. The combined effects of well-maintained engines and catalytic converters, together with suitably reformulated motor fuels, will go a long way towards improving air quality in Chile.

Revised Fuel Specifications

6.26 CONAMA published revised fuel specifications, which are listed in Table 6.11–Table 6.13, in July 1997. The most significant change in the revised specifications is the stipulation for a study to be undertaken by the end of December 1998 to define some of more controversial parameters in the previous proposal, such as polyaromatics, aromatics, and nitrogen in diesel. In addition, sulfur in gasoline is controlled.

Table 6.11 Revised Specifications for Leaded Gasoline

Item	*1997*	*9/2000*	*9/2002*
Aromatics,vol%, maximum	report	35 [a]	30 [a]
Benzene, vol%, maximum	4	2	2 [a]
Oxygen, wt%	report	report	report
Olefins, vol%, maximum	report	30 [a]	20 [a]
Sulfur, wt%, maximum	0.1	0.1	0.1
Lead, g/liter, maximum	0.4	0.4	0.4
RVP, psi, maximum	9 (11.5)	8 (10)	7.5 (10) [a]

Note: RVP values in parentheses are to apply from 1 April to 30 August.
a. Parameters will be defined in accordance with M3CMB9, which stipulates that a study be completed by 31 December 1998 with participation of refiners and refined-product importers.

Table 6.12 Revised Specifications for Unleaded Gasoline

Item	*1997*	*9/2000*	*9/2002*
Aromatics, vol%, maximum	report	40 [a]	35 [a]
Benzene, vol%, maximum	4	2	2 [a]
Oxygen, wt%, maximum	report	2	2
Olefins, vol%, maximum	report	30 [a]	20 [a]
Sulfur, wt%, maximum	0.1	0.05 [a]	0.02 [a]
RVP, psi, maximum	9 (11.5)	8 (10)	7.5 (9.5) [a]

Note: RVP values in parentheses are to apply from 1 April to 30 August.
a. Parameters will be defined in accordance with M3CMB9, which stipulates that a study be completed by 31 December 1998 with participation of refiners and refined-product importers.

Table 6.13 Revised Specifications for Diesel Grade A1

Item	*4/2000*	*4/2002*
Sulfur, wt%, maximum	0.1	0.05
Cetane number, minimum	48	50
T90, °C, maximum	338	338 [a]
Density, kg/l	0.84±0.01	0.84±0.01
Aromatics, vol%, maximum	a	a
Polycyclic aromatics, vol%, maximum	a	a
Nitrogen, ppm, maximum	a	a

a. Parameters will be defined in accordance with M3CMB9, which stipulates that a study be completed by 31 December 1998 with participation of refiners and refined-product importers.

6.27 These new specifications should allow Chile greater flexibility in meeting emission standards, such as the use of cetane-improvement additives to compensate for higher aromatics in diesel.

7

El Salvador

Background

7.1 In elimination of lead in gasoline and in the formulation and execution of an integrated program for air quality management, El Salvador presents an example of best practice for small countries. In 1995, unleaded gasoline constituted a mere 6 percent of the total gasoline market in El Salvador. Yet by August 1996, lead in gasoline was totally eliminated in the country. This chapter reviews the process of gasoline lead elimination in El Salvador, identifies the factors that enabled such a rapid transition to unleaded gasoline, and gives an overview of the activities to improve urban air quality that accompanied the move to remove lead from gasoline.

7.2 Following the devastation of the civil war, El Salvador has made a rapid economic recovery in the past five years. Between 1992 and 1995, El Salvador maintained an average annual GDP growth rate of 6.8 percent. Between 1994 and 1996, total oil consumption grew at an annual rate of 2.1 percent. During the same period, gasoline consumption grew at 7.4 percent a year, diesel consumption at 5.6 percent. The entire petroleum sector in El Salvador is in private hands. El Salvador is actively participating in the ongoing Central American regional efforts for regional integration. These efforts include the harmonization of fuel specifications and vehicular emissions standards.

7.3 The growth of the economy and of transportation fuels has paralleled rapid urbanization and motorization, thereby increasing environmental and public health concerns, which are now receiving high priority from the government of El Salvador. Since 1993, respiratory diseases have replaced diarrhea as the most serious public health concern, with particulate emissions from fuel combustion making a significant contribution. Up until now, there has been no overseeing body to coordinate activities undertaken in the area of pollution mitigation for coherent policy formulation and effective enforcement of environmental regulations in El Salvador. Without an overall conceptual and institutional framework, the government of El Salvador has nevertheless gone ahead with gasoline lead elimination, establishing vehicular emissions standards, and a national vehicle inspection and maintenance (I/M) program. Furthermore, air quality has been monitored systematically in the city of San Salvador since 1996.

Gasoline Supply and Lead Elimination

7.4 There is one refinery in El Salvador, owned jointly by Esso (65 percent) and Shell (35 percent). It is a small hydroskimming refinery with a design capacity of 20,000 b/cd. The average throughput is on the order of 15,000 b/cd. For gasoline production, it has a 3,000 b/cd semiregenerative reformer using a monometallic catalyst producing reformate of 95 RON. El Salvador imports more than a quarter of its refined petroleum product demand, with transportation fuels coming from the United States, the Caribbean, and certain Latin American countries including Venezuela and Brazil. The refinery also exports fuel oil and asphalt to other Central American countries.

7.5 In January 1994, the Ministry of Economy liberalized petroleum product prices and made restrictive practices (for example, monopoly, price collusion) in the sale of refined products, including imports and exports, illegal. Since that time, all petroleum product prices have been set in relation to import parity prices, with other margins set by market competition. The reference quotations used, including prices of leaded gasoline, are those prevailing in the U.S. Gulf Coast. When product prices were liberalized in 1994, retail prices fell from US$1.75 to $1.55/gallon for premium and from $1.53 to $1.40/gallon for regular gasoline. Because gasoline prices were determined by those of U.S. Gulf Coast unleaded gasoline, there was no change in the pump price of gasoline when lead was eliminated in August 1996.

7.6 Diesel is used extensively as a transportation fuel but carries much lower taxes than gasoline. In August 1997, pump prices for gasoline varied within the range 15–16 Colones a gallon for regular 87 RON and 18–19 Colones a gallon for premium 95 RON. In contrast, the corresponding figure for diesel was only 9–10 Colones (US$1.00 = 8.75 Colones).

7.7 A nominal import tariff of 1 percent is imposed on crude oil and all oil products. Although there are no legal restrictions on product imports today, Esso/Shell has been the sole importer of gasoline until now. Texaco is expected to start importing gasoline by 1998. Other distributors of petroleum products include Coastal and the national electricity company.

7.8 The government began serious discussions on gasoline lead elimination in 1994. Beginning in January 1995, a series of meetings was held with key players in the downstream petroleum sector to discuss phasing out lead.

7.9 The refinery processes spiked crude consisting of 80 percent Oriente crude and 20 percent Peruvian naphtha. When the use of TEL was permitted, the gasoline stream consisted of butane, light straight-run naphtha, heavy straight-run naphtha, reformate, and

TEL. After lead removal, the refinery adjusted the amount of Peruvian naphtha blended into crude so as to minimize the amount of heavy straight-run naphtha, and in its place blended imported gasoline blending components with an anti-knock index (AKI), (R+M)/2, of 93. The severity of reformer operations was not increased because shortening the cycle period between shutdowns to increase RON marginally was not deemed economic. No anti-valve-seat-recession additives have been added to unleaded gasoline. The refinery will begin adding MMT to gasoline in the near future.

7.10 The refinery estimated that six weeks would be needed to flush the product storage tanks of residual lead. Three volume turnovers were found to be sufficient to lower the amount of lead in unleaded gasoline to below 0.013 g/liter. The unleaded gasoline used to flush out the storage tanks was sold as leaded gasoline. The refinery built one blend stock tank in preparation for lead removal. Because the imported 93 AKI blend contains a varying amount of MTBE, the refinery changed hoses and installed a special seal in the storage tank.

7.11 The refinery estimates the cost of lead removal to be approximately $2 a barrel, or 1 U.S. cent a liter. No financial assistance was provided by the government for gasoline lead removal, nor was there an increase in the price of gasoline at the pump at the time of lead elimination, thanks to the pricing strategy adopted by the government. Further, although no anti-valve-seat-recession additives have been added to gasoline, there have been no reports of engine complaints from consumers.

7.12 The transition period was short, and not all retail outlets sold unleaded gasoline during that period. This strategy had a significant cost advantage of not having to invest heavily in a dual distribution system. Those retail outlets that sold leaded and unleaded gasoline typically had three pumps: one for regular leaded, another for premium unleaded, and the third for premium leaded. In 1996 several months were set aside to flush the entire distribution system of residual lead. During these months, only unleaded gasoline was allowed in the distribution system, although lead removal was not officially completed until August 1996.

New Fuel Specifications

7.13 The Ministry of Economy began working on new fuel specifications in 1996. Meetings were held with industrial concerns within El Salvador, as well as with other Central American countries, to discuss regional harmonization of fuel standards. Despite small differences in the fuel standards adopted or proposed by each country, there is considerable uniformity among the countries in the region. In El Salvador, the Minister of Economy is expected to approve the proposals before the end of 1997.

7.14 The proposals for gasoline and diesel are given in Table 7.1 and Table 7.2, respectively. Gasoline lead is limited to 0.013 g/l as expected. The boiling point distribution is essentially the same as that set by the American Society for Testing and Materials (ASTM). The maximum permissible level of sulfur in gasoline is 1,500 wt ppm, which is high compared with the maximum level of 500 wt ppm or lower recommended by auto manufacturers to ensure efficient operation of catalytic converters. At present, typical levels of sulfur in gasoline are nearly an order of magnitude lower than the legal limit, so that levels of emissions from gasoline-fueled vehicles equipped with catalytic converters should be low because of high conversion over the catalyst. Given the warm climate in El Salvador, the RVP limit of 10 psi may be high. While typical RVP values of gasoline sold on the market today are in the neighborhood of 8.5 psi, the refinery has invested US$1 million to optimize its blending operations so that future RVP levels will be much closer to the legal limit. Lowering the maximum RVP should be seriously considered in the future.

Table 7.1 Proposed Gasoline Specifications

	Specifications
RON, minimum	95 / 85
MON, minimum	87 / 77
E67 (°C), minimum	10%
E77 (°C), maximum	50%
E121 (°C), minimum	50%
E190 (°C), minimum	90%
End point,°C	225
RVP, maximum	69 kPa (10 psi)
Lead, g/l, maximum	0.013
Sulfur, wt%, maximum	0.15
Stability in minutes, minimum	240
Copper corrosion, maximum	1

7.15 For diesel, the most significant change is the reduction of sulfur content from the current 0.9 weight percent to 0.5 weight percent. T90 is given a rather broad range, 272°C to 363°C. The upper limit of the range is high and is likely to result in high PM_{10} emissions. The further tightening of diesel sulfur and T90 specifications in the future should help to lower PM_{10} levels and improve urban air quality.

7.16 The maximum sulfur content of fuel oil for on-land use is 3 wt%. Typical values at present do not exceed 2 wt%. Given the widespread incidence of respiratory infections, a reduction in the sulfur content of fuel oil should also be considered in the future.

Table 7.2 Proposed Diesel Specifications

	Specifications	
	Automotive	*Industrial*
Flash point, °C, minimum	52	52
Water & sediment, vol%, maximum	0.05	0.05
Conradson carbon in 10% residue, wt%, maximum	0.1	0.35
Ash, wt%, maximum	0.01	0.01
T90, °C, maximum	282 min–363 max	282 min–363 max
End point, °C, maximum	report	399
Viscosity at 40°C, centistokes	1.9 min–4.6 max	2.0 min–5.8 max
Sulfur, wt%, maximum	0.5	0.5
Copper corrosion, maximum	1	1
Cetane index, minimum	45	40
Density at 60°F, °API, minimum	report	30

Air Quality Monitoring

7.17 The monitoring of air quality in El Salvador began in 1970. Under the Pan Air program, several pollutants in key cities were measured between 1970 and the mid-1980s, when the program was disrupted by the civil war and was abandoned. Air quality monitoring presumed in the 1990s. In the early 1990s a number of studies, many carried out by university researchers, showed that the levels of particulates, lead, NO_x, and SO_x were high. In particular, the Swiss Foundation for Technical Cooperation (Swisscontact) ProEco, operating in Central America, found that the level of airborne lead in San Salvador was one of the highest in the region. With the assistance from Swisscontact ProEco, Fundación Salvadoreña para el Desarrolo Económica y Social (FUSADES) began monitoring lead, ozone, NO_x, and PM_{10} in San Salvador on a systematic basis in 1996. Eight monitoring stations with varying levels of traffic were selected. Benzene/toluene/xylene (BTX), CO, and TSP were added to the list in 1997. There is a plan to start monitoring SO_2 in the near future.

7.18 After gasoline-lead elimination, the level of airborne lead fell to less than 0.1 $\mu g/m^3$. Although no data on airborne lead are available from 1995, when most gasoline sold in San Salvador was leaded, earlier data obtained by Swisscontact ProEco showed that airborne lead levels were quite high, suggesting immediate health benefits from gasoline lead removal.

7.19 The levels of ozone, PM_{10}, and NO_2 measured at various sites are not particularly high, although TSP levels are significant, as discussed below. Table 7.3 shows data obtained at one of the El Sol supermarkets located in an area where the traffic density is high.

Table 7.3 Air Quality Data in μg/m³

	4/96	*6/96*	*8/96*	*10/96*	*12/06*	*2/97*	*4/97*	*6/97*
NO_2	117	66	101	41	59	120	112	83
O_3	35	33	55	87	64	62	25	96
PM_{10}	67	43	44	44	26	44	24	46
Lead	–	1.5	0.1	0.0	0.0	0.0	0.0	–

Note: NO_2 measured continuously for 30 days every month, two samples taken per site; O_3 measured once a month, continuously for eight days at a time, two samples taken per site; PM_{10} measured twice a month for 24 hours at a time; lead analyzed from PM_{10}; TSP measurements not available as of June 1997.

7.20 Some questions about the data are being investigated. While measured PM_{10} levels are relatively low, TSP levels where measurements are available have been found to be extremely high—on average, 9 times higher than PM_{10} levels (in one case, 30 times higher). The high ratio of TSP to PM_{10} observed is at variance with data obtained in other countries, where the ratio is typically in the vicinity of 2. Because of the high levels of TSP not only in El Salvador but throughout Central America, Swisscontact ProEco has a plan to carry out compositional analysis of TSP in each country. High TSP levels, and not relatively low PM_{10} levels, are consistent with the high incidence of respiratory illness in El Salvador. BTX measurements obtained so far show exceptionally high levels of these aromatics. Benzene, for example, has been recorded at 1–5 ppm, seemingly three orders of magnitude higher than anticipated. Instrumentation, calibration, and equipment operations need to be examined to address these questions. If TSP measurements are correct and the actual levels of PM_{10} are considerably higher, then the levels of airborne lead would also be correspondingly higher, although still lower than 0.5 μg/m³.

7.21 Swisscontact ProEco, which has been providing financial and technical assistance for air quality data collection, is completing its three-year program in 1998. The sustainability of data collection, in terms of equipment maintenance and personnel training, is somewhat in question at this stage. Further, there is a need to expand data collection beyond San Salvador to the rest of the country. These concerns, together with the need to include SO_2 in the database and answer questions about BTX and TSP/ PM_{10}, are some of the issues that need to be addressed in the coming years.

Vehicular Emissions and I/M

7.22 Until recently, regulations governing traffic were old laws dating back to 1946 that contained no provisions for limiting vehicle emissions. The new transportation law that came into effect in August 1996 for the first time set limits on emission levels of CO and hydrocarbons for gasoline-engine vehicles and percent opacity for diesel engine vehicles. The emission standards, shown in Table 7.4, are based on those established for the rest of Central America and are set for new imports, secondhand imports, and in-use vehicles. The law effectively requires that, beginning in January 1998, all cars entering the vehicle fleet in El Salvador, whether new or used, be equipped with catalytic converters.

Table 7.4 Vehicular Emissions Standards

	Effective date	*CO (vol%)*	*HC* [a] *(ppm)*	*Opacity (%)*	*Equivalent K*
Ignition-engine vehicles, in-use	1/98	4.5	600		
New addition to the fleet (new or used), ignition-engine vehicles	1/98	0.5	125		
Diesel-engine, < 3 metric tons	1/98			70	2.8
Diesel, < 3 t turbocharged, or > 3 metric tons	1/98			80	3.5
New addition to the fleet, diesel-engine, <3 metric tons	1/99			60	
New addition to the fleet, diesel, <3 t turbocharged, or > 3 t	1/99			70	2.8

a. HC ≡ hydrocarbons.

7.23 In November 1996 Swisscontact ProEco, which has been active in giving technical and legal advice for the new vehicular emissions standards and I/M program, launched the "Week of Clean Air" to raise public awareness about the degradation of air quality in San Salvador. During the five-day campaign, vehicle owners were encouraged to bring their vehicles for free inspection of emission levels. In cases of emission levels exceeding the standards shown in Table 7.4, these owners were given free advice. A total of 6,024 vehicles were tested (765 diesel-engine and 5,259 gasoline-engine vehicles); 1,608 of the cars tested were equipped with catalytic converters. The results, tabulated in Table 7.5, showed that approximately half of the vehicles on the road in San Salvador met the new emission standards.

Table 7.5 "Week of Clean Air" Emission Test Results

	No. of diesel vehicles	*Passed (%)*	*Failed (%)*	*No. of gasoline vehicles*	*Passed (%)*	*Failed (%)*
Cars	218	49	51	3,539	53	47
Buses	390	49	51	91	44	56
Trucks	73	36	64	4	25	75
Jeeps	23	57	43	6	67	33
Minibuses	0	–	–	195	59	41
Pick-ups	61	46	54	1,182	59	41
Taxis	0	–	–	242	72	28

7.24 The enforcement of the emission standards will be centralized and carried out by a private firm, and a tendering process for selecting the firm is currently in progress. All vehicles will be required to report to inspection stations once a year. These inspection stations will check not only the emission levels but also the mechanical integrity of the entire vehicle. European organizations, including Swisscontact, have provided technical training to auto mechanics in car repair shops to ensure better compliance with the new regulations. Vehicles passing the tests will be issued stickers. In addition, to combat potential corruption, another private concern, financed entirely by the fines collected from vehicles not meeting the emission standards, will be established to carry out spot checks on vehicles on the road, including those displaying certification stickers. Further, fifty "transit delegates" under the Ministry of Public Works, Transport, Housing, and Urban Development have also been trained to date so as to be able to check emission levels of vehicles on the road.

7.25 The I/M program and spot checks conducted by transit delegates were scheduled to start in January 1998. However, owing to a shortage of personnel, the I/M program is likely to be fully in place only in 1999.

Air Quality Standards

7.26 The Ministry of Public Health, on the basis of information given by various organizations on emissions from mobile and stationary sources, and comparing standards in the United States, Mexico, and Costa Rica as well as the WHO guidelines, has proposed air quality standards for El Salvador. The proposals were scheduled to be presented in late August 1997 and are in the form of a working paper. They suggest ranges rather than single numbers for the new standards, so as to invite comments and discussions from various key players before settling on specific standards.

7.27 In the 1980s, diarrhea was the most serious public health concern in El Salvador, followed by respiratory-related illness. Between 1990, when a cholera epidemic broke out in the region, and 1993, when the fear of cholera subsided, much was done to eradicate the epidemic. Since 1993, respiratory infections have overtaken diarrhea as the most serious public health concern, with approximately 900,000 cases of critical respiratory infections reported in 1996. In major cities the combustion of fuels is believed to contribute to respiratory illness. In the countryside, it is the burning of wood for cooking inside houses and the burning of sugarcane that are believed to affect public health adversely. In light of the concern about respiratory illness, it is all the more important to obtain accurate measurements of PM_{10} and TSP and to set suitable standards.

Air Quality Management

7.28 There have been many initiatives coming from different quarters to tackle air quality management in El Salvador. There is a widely acknowledged need to consolidate all the data collected, analyze them, define what still remains to be done, draw up inventories of pollutant emissions, carry out cost/benefit analyses, and formulate an integrated pollution abatement strategy. The newly created Ministry of Environment and Natural Resources may play the coordinating role, giving directions for future environmental policies.

7.29 In the near term, there is a project funded by the Inter-American Development Bank to review and consolidate all the work carried out to date, forecast future trends based on modeling of the data, and make recommendations with specific tasks and cost estimates to the Ministry of Environment and Natural Resources by the end of 1997.

Lessons from El Salvador

7.30 Several factors facilitated the elimination of gasoline lead in El Salvador. Because not all gasoline is produced domestically, it was not necessary to wait for the refinery to be upgraded before complete lead removal. Prices were already liberalized, so that prices of unleaded gasoline were determined by import-parity prices. Since the entire petroleum sector was in private hands, the government did not feel constrained to protect any state enterprise in the process. By choosing to eliminate gasoline lead rapidly, El Salvador minimized the investment needed in the infrastructure to distribute leaded and unleaded gasoline simultaneously.

7.31 Without waiting for comprehensive air quality data and emission inventories to be made available, the government of El Salvador has taken certain steps: gasoline lead removal, setting basic vehicular emissions standards, and setting up the framework for implementing an I/M program. The setting of fuel specifications and vehicular emissions standards was facilitated by the discussions carried out with other neighboring countries for the harmonization of standards. The important point is not so much that every step taken along the way had to be absolutely correct, but that the steps taken, based on the lessons distilled from the collective experience of other countries, would not reverse the decisions made earlier. This is certainly the case with gasoline lead removal, where no country that has eliminated lead has gone back and reintroduced it.

Future Tasks

7.32 The tasks that need to be carried out in the future in El Salvador for air quality management include:

Institutional

- Establishing an overall institutional framework to coordinate and integrate all activities for developing, implementing, and enforcing environmental regulations
- Securing the sustainability and expansion of the network of air quality monitoring stations.

Abatement strategy selection

- Setting up inventories of pollutant emissions from all sources in major cities
- Identifying least-cost solutions.

Air quality monitoring

- Ensuring data accuracy for BTX and TSP/PM_{10}
- Ensuring long-term sustainability of air quality monitoring, including funding
- Expanding the air quality database to include SO_2.

Fuel-related improvements

- Lowering the gasoline sulfur content and RVP
- Ensuring that levels of benzene, olefins and aromatics in gasoline do not become unacceptably high
- Lowering diesel sulfur and T90
- Lowering sulfur in fuel oil
- Eliminating the price subsidy for diesel.

7.33 Air quality management is an interactive process. The above steps, as well as future economic growth, will bring El Salvador to modify the environmental standards again. As long as the government continues to involve, and gives enough lead time to, all the key industrial stakeholders, this need not be a disruptive process. Within five years of reaching a peace settlement, El Salvador has made significant progress in air quality management.

8

Jamaica

Background

8.1 At the Summit of the Americas held in December 1994, heads of state from countries in the Western Hemisphere, including Jamaica, made a commitment to phase out lead in automotive gasoline. A subsequent meeting of technical experts recommended that each country prepare a national action plan for phasing out lead in gasoline, by the year 2001 if possible.

8.2 Arising out of a meeting of potential stakeholders in Jamaica held in response to the Summit Action Plan signed in December 1994, the Petroleum Corporation of Jamaica (PCJ) assumed leadership for arranging preparation of the national action plan for gasoline lead elimination. It was also agreed that the Natural Resources Conservation Authority (NRCA) would coordinate future meetings and provide support to PCJ. The World Bank provided funding to the NRCA for the preparation of the national action plan, and BOVAR Environmental was retained to undertake a study. This chapter is based on the report prepared by BOVAR Environmental after extensive consultation with all the key stakeholders. In particular, a series of meetings were held in Kingston on 27-29 May 1997 to arrive at a consensus on the proposed action plan, including a meeting with representatives from the NRCA; the Consumer Affairs Commission; PCJ; Petrojam; Shell; Jamaica Gasoline Retailers' Association (JGRA); the Automobile Dealers of Jamaica; Jamaica Bureau of Standards (JBS); the Ministry of Public Utilities, Transport, and Energy (MPUT); the Ministry of Finance and Planning; and the Environmental Control Division of the Ministry of Health.

8.3 Lead emissions from the Jamaican on-road automobile fleet in 1993 were estimated to be 149 metric tons. On the basis of a 15 percent increase in the consumption of leaded gasoline between 1993 and 1995, lead emissions from the on-road Jamaican fleet were estimated to be 206 tons in 1995. It is expected that the increase in the use of unleaded gasoline and the obligatory reduction of the lead content in the leaded gasoline will result in a substantial decrease in the level of environmental lead emissions in the future.

Objectives and Methodology of the Study

8.4 The objectives of the study were to (1) prepare a plan for the phased elimination of lead in gasoline in Jamaica by the year 2001 or earlier, taking into account potential health, social and economic aspects; (2) identify public and private sector institutions and the roles they should play in the phase-out process; and (3) make policy recommendations for the timely execution of the national action plan.

8.5 The study entailed making use of existing information and documentation to summarize the environmental and human effects of lead and its replacements and to present an analysis of the current situation in Jamaica. Meetings were held with key stakeholders to provide first-hand knowledge of their positions and to obtain locally available information. Subsequently, the draft report was critically reviewed and was instrumental in reaching a consensus for key actions and their implementation.

8.6 The analysis included an examination of the current capabilities of the Petrojam refinery; the current (1995) and projected (2001) Jamaican motor vehicle fleet and gasoline consumption; estimates of current emissions of lead from leaded gasoline use in Jamaica; and an evaluation of the technical and economic merits of changing the octane grades of gasoline and, in general, of the proposed action plan. Political decisions to implement the proposed plan were able to proceed immediately, given the broad consensus reached by all the stakeholders.

The Situation in Jamaica: Gasoline Supply and Car Fleet

8.7 The current supply of petroleum products in Jamaica centers around the 35,000 barrels per day (b/d) nameplate capacity Petrojam refinery that was constructed by Esso in 1963/64 and purchased in 1984 by Petrojam, at the time a Jamaican government-owned company. Production in 1995 was only about 16,000 b/d. The refinery is a simple hydroskimming plant whose design is consistent with a low gasoline/distillate market ratio with considerable heavy fuel oil demand and the availability of lead alkyl antiknock additives to achieve required gasoline octane numbers. The current legal limit for lead in gasoline is 0.84 g/l. A 1996 survey conducted under the auspices of this project showed that leaded gasoline sold in Jamaica typically contained 0.77 g/l (World Bank 1997). Leaded gasoline accounts for 36 percent of the total gasoline market today.

8.8 The only gasoline octane upgrading unit at Petrojam is a 3,500 b/d catalytic reformer, Powerformer. The unit is limited to producing reformate of about 93 RON. Relatively large amounts of lead and/or MTBE are needed to produce the 95 RON premium leaded and unleaded gasolines currently marketed in Jamaica. The refinery must either make investments in process-upgrading equipment or face increasingly challenging operating conditions. The investment options are currently complicated by the possibility of the sale of the refinery to private investors.

8.9 An immediate upgrade option involves the expansion of reforming capacity or the addition of an isomerization unit (or both) and is relatively low in cost. For example, expanding the reformer capacity is estimated to cost on the order of US$5 million because of the availability of spare vessels and fractionators. If a high-severity reformer capable of operating up to 100–102 RON were to be installed (at additional cost), it would result in considerable improvement of octane in the Petrojam gasoline pool. An isomerization unit (output typically 82–84 RON without unconverted feed recycle) would require additional octane support. Another option is a major refinery revamp costing on the order of US$150 million, including the installation of an FCC unit and associated equipment. Such a step would increase the complexity and flexibility of the refinery operations. A 15,000 b/d FCC unit would produce substantially more gasoline than the current total gasoline demand in Jamaica. These options are being given careful consideration by Petrojam management.

8.10 The Jamaican on-road vehicle fleet increased from an estimated 171,082 units in 1993 to about 264,100 in 1996. The 1993 estimate is 37.5 percent higher than the reported number of Certificates of Fitness issued to account for the 15-month validity period of the certificate, vehicles without certificates, and vehicles with temporary licenses. Estimates of the fleet in 2001 range from 344,100 (an increase of 30 percent over the 1996 level) to 414,100 (an increase of 57 percent over the 1996 level). The estimates are based on projections of annual imports of 16,000 to 30,000 units up to 2001. One estimate of the demand for gasoline and diesel fuel in the year 2001 showed a 50 percent increase over 1996 volumes.

The National Action Plan

Changing the Octane Grade(s)

8.11 The current octane level (95 RON) of leaded and unleaded gasoline exceeds the octane requirements of most engines in the Jamaican vehicle fleet. The fleet increasingly consists of Japanese vehicles, nearly all of which are designed for 90 RON unleaded gasoline. Since no performance benefit is derived from using 95 RON gasoline, a reduction in the octane level of gasoline is recommended. Based on the anti-knock index, (R+M)/2, which is more frequently used to reflect city and motorway driving cycles, and referring to the most traded gasoline octane grade in the U.S. Gulf Coast, the study recommends an 87 (R+M)/2 octane grade for regular gasoline in Jamaica, identical to the U.S. regular grade. This gasoline, which will satisfy the octane requirements of most cars, would initially be made available as leaded and unleaded.

8.12 A small percentage of cars in Jamaica require higher-octane gasoline. At the meeting with stakeholders it was recommended that in addition to the above two types of gasoline—a premium unleaded grade, equivalent to (R+M)/2 of 91 or higher—be marketed. The use of regular grade 87 (R+M)/2 gasoline in countries such as the United States and Canada, however, takes place in a multigrade unleaded gasoline market where there are options for using higher-octane gasolines, for example, 89, 92, 93, and in some cases up to 94 (R+M)/2.

8.13 The first steps in the recommended plan constitute a change from a single-octane gasoline market to a multioctane grade market. This involves:

- A reduction in the octane level of the regular gasoline supplied to the Jamaican market (during the phase-out period, regular gasoline will be available in leaded and unleaded grades)
- The introduction of one or more higher-octane grades addressing the requirements of a minority of modern car engines.

Phase-Out of Leaded Gasoline

8.14 The agreed plan includes a reduction in the lead content of the leaded 87 (R+M)/2 regular gasoline from the current limit of 0.84 g/l to 0.6 g/l effective 1 January 1998, followed by a further reduction to 0.4 g/l effective 1 January 1999, and finally a complete phasing-out of this leaded gasoline from the market from 1 January 2001.

8.15 With respect to related health studies on lead, studies on exposure to lead in soil from waste disposal of batteries and abandoned lead mines have been conducted, and measurements of lead in the ambient air are planned.

New Gasoline Specifications and Monitoring Capability

8.16 In addition to lead reduction, the plan calls for enacting new gasoline specifications (Table 8.1). The new specifications include restrictions on volatility, sulfur, benzene, and aromatics content; making obligatory the reporting of the olefin content; and allowing for the use of detergent additives and a higher percentage of oxygenates than in the current specifications.

Table 8.1 Proposed Specifications for Unleaded Gasoline in Jamaica

	Minimum	*Maximum*
Sulfur, wt%		0.10
Lead, g/l		0.013
RVP, psi		9.0
Aromatics, vol%		45
Benzene, vol%		5
Olefins, vol%		To be reported
(R+M)/2 – Premium	91	
(R+M)/2 – Regular	87	

8.17 It is important to develop within the government (that is, Bureau of Standards and other government bodies) the required capability for monitoring the quality of the gasolines delivered to the market.

Refinery Upgrading

8.18 A key aspect of the national action plan for the phasing-out of leaded gasoline concerns the Petrojam refinery. The recommended strategy for the phase-out involves a reduction in the octane level from the current 95 RON to the internationally available U.S. regular grade, 87 (R+M)/2. At the same time, there will be successive reductions in the maximally allowable lead content of regular leaded gasoline from the current 0.84 g/l to 0.6 g/l, 0.4 g/l, and, finally, to 0.013 g/l (complete lead removal). It is imperative that there be a simultaneous and equal reduction in the octane level of unleaded and leaded gasoline.

8.19 Alternative upgrade schemes being considered for the Petrojam refinery are:

- Investment on the order of US$5 million for expanding/upgrading the catalytic reformer
- A US$150 million investment for a major refinery revamp, including the addition of an FCC unit.

The detailed economics of various alternative processes must be determined by Petrojam management. The expansion of reformer capacity is designed specifically to produce unleaded gasoline of 87 and 91 or higher (R+M)/2 grades in a cost-effective manner. The revamp under the second option would provide greater flexibility in refinery operations and would affect a wider range of refinery products.

Economic and Logistical Implications

8.20 Recent pump prices of unleaded gasoline were reported to be approximately 3 percent higher than those of leaded gasoline because taxes for unleaded gasoline were 5.9 percent higher than for leaded gasoline. The higher pump price of unleaded gasoline notwithstanding, the market share of unleaded gasoline, which was first introduced in 1990, has increased steadily to the current level of about 64 percent.

8.21 The proposed plan involves the introduction of regular-grade gasoline, meeting the octane requirements of the majority of cars, with the same pump price for unleaded and leaded, possibly a few cents lower initially than the current 95 RON gasoline. This may be possible on account of the lower cost of producing gasoline with a lower octane number. In addition, premium gasoline will be available on the market, with a price that may be 15 to 25 percent higher, depending on the octane grade, than that of the new regular gasoline. The overall plan could be implemented with an increase in tax revenues exceeding the estimated annual growth of gasoline consumption. The current gasoline pricing and taxation structure is given in Table 8.2. Table 8.3 gives an illustration of estimates of consumer gasoline prices and corresponding tax collection for 1998/99. The calculations assume growth in total consumption from 3.7 million barrels to 4.0 million barrels of gasoline, equivalent to a growth rate of 7.8 percent. This table represents only one of the possible scenarios and is only illustrative. The final decision on taxation policy and pricing levels will be made by the Ministry of Finance and marketing companies.

8.22 The "product cost" in the tables refers to the ex-refinery price rather than the cost of production. For the current gasoline grades the product cost was estimated as the average of survey pump prices minus the total taxes. The current product cost may be converted to the 89 (R+M)/2 gasoline grade and the product costs for the 87 and 91 (R+M)/2 were estimated on the basis of US$0.01/gallon for one (R+M)/2 octane. The ex-refinery prices of 87 (R+M)/2 leaded and unleaded gasoline were arbitrarily taken to be equal. The taxes proposed for regular gasoline are designed to ensure the same pump prices in the future so as to discourage the use of leaded gasoline by eliminating the price differential between leaded and unleaded regular gasoline. In reality the ex-refinery price of unleaded gasoline would be expected to be higher than that of leaded, so that the tax on unleaded gasoline would have to be less to equalize the pump prices. The example shown in Table 8.3 gives an increase in tax revenues of approximately 18 percent. Even after taking into account the higher ex-refinery price of unleaded gasoline, the increase in tax revenues is likely to exceed the rate of growth of gasoline consumption under this scenario.

Table 8.2 Current Gasoline Pricing and Taxation
(J$/gallon)

Item	*Leaded, 95 RON*	*Unleaded, 95 RON*	*Total*
Product cost	11.33	11.38	
Taxes	2.24	2.37	
Consumer price	13.56	13.76	
Total volume (million bbls)	1.33	2.38	3.71
Tax collected (million J$)	472	899	1,370

Table 8.3 Sample Future Gasoline Pricing and Taxation (illustration only)
(J$/gallon)

Item	*Leaded 87 (R+M)/2*	*Unleaded 87 (R+M)/2*	*Premium 91 (R+M)/2*	*Total*
Product cost	11.14	11.14	11.51	
Taxes	2.37	2.37	4.03	
Consumer price	13.51	13.51	15.54	
Total volume (million bbls)	1.1	2.5	0.4	4.0
Tax collected (million J$)	414	942	256	1,612

8.23 The action plan during the phase-out period calls for a major coordination effort among the companies involved in the transport and distribution of gasoline. It is important that investment be kept to a minimum while three grades of gasoline are being marketed. Some retail outlets will have to decide how to limit their operations to two gasoline types (87 leaded and unleaded, or 91+ and 87 unleaded). During the coordination meetings, the industry representatives appeared fully in agreement with the need to handle the transition in a cost-effective manner.

Consumer Education

8.24 A nationwide information campaign should be developed to inform consumers of the advantages of using unleaded fuel, the savings to be made by the reduction of the gasoline octane grade for most vehicle owners, good energy conservation driving habits, and overall air quality benefits to be attained by using the right fuel and driving properly tuned-up vehicles.

The Action Plan

8.25 The key policy actions required for the implementation of the action plan are an amendment of regulations for gasoline specifications under the Petroleum Quality Control Act, the implementation of motor vehicular emissions standards, and the phased implementation of an in-use motor vehicle I/M program.

8.26 The action items in the plan, with an indication of the lead and supporting agencies, are summarized in Table 8.4. Although there has been some delay since this study was undertaken by BOVAR, the stakeholders are working together to update and implement the action plan.

Air Quality Improvement

8.27 The improvements in fuel quality must be accompanied by the introduction of vehicular emissions standards and the enforcement of an adequate I/M program in order for fuel reformulation to be truly effective. A consultant's report that proposes motor vehicular emissions standards for new and used imported vehicles has been prepared for the NRCA. The report estimated the emissions from various categories of vehicles and recommends the phased implementation of a motor vehicle I/M program. It is the combination of measures dealing with both vehicular emissions and fuel quality that will reduce vehicular emissions and improve air quality.

Table 8.4 Action Items For the Phase-Out of Leaded Gasoline in Jamaica

Action item	*Comments*	*Lead and supporting roles*
Review of the study	Confirm phase-out strategy (87 and 91 (R+M)/2 and proposed phased lead reductions to get there); decisions on logistics of distribution system (such as need for a nozzle change)	**Petrojam**, all stakeholders
Decide on the refinery upgrade scheme	Schedule will be critical	**Petrojam**, GOJ, PCJ
Revise gasoline specifications	Establish final specifications	**MPUT**, Jamaica Bureau of Standards, Petrojam, PCJ
	Plan for upgrade of analytical capabilities (benzene, aromatics, olefins)	**JBS**, Petrojam
Develop new taxation/pricing and other economic measures during phase-out		**Ministry of Finance**, MPUT
Develop public education campaign	Coordinate/piggy back on existing public education programs	**JPC**, NRCA
Formulate logistics for phase-out		**JGRA**, Marketing companies, Petrojam
Develop regulations for: Fuel Vehicle emissions Importation of vehicles	Include other supporting regulations (motor vehicular emissions standards, inspection and maintenance)	**MPUT**, NRCA, Ministry of Trade and Industry, Ministry of Environment
Implement phase-out	Octane and lead reduction	**Petrojam**, Marketing companies
Monitor market		**JBS**, Petrojam, marketing companies, consumer groups

9

Peru

Background

9.1 The deep recession and violent terrorist movements that took place in Peru during the 1980s had severe social consequences, including the migration of a large percentage of the population from the affected Andean areas to coastal cities, in particular to the capital city of Lima. Economic recovery began in 1990; one consequence was unrestricted importation of secondhand vehicles, which has resulted in rapid motorization, greater traffic congestion, and a consequent significant deterioration of urban air quality. The government's policy agenda, hitherto focused on ensuring the peace process and the continuation of growth, is starting to include new priorities—among them the environment in general, and the improvement of air quality in Lima and other major cities in particular.

9.2 Following the decision of the heads of state at the December 1994 Summit of America in Miami to implement pollution prevention programs and to support national plans to phase out lead, the government of Peru defined urban air quality improvement and gasoline lead elimination as a national objective. The Vice-Minister of Housing and Construction was appointed as the national focal point to oversee the planning and execution of the program. To assist the Vice-Minister, the government requested the World Bank to provide technical assistance for preparing a plan for phasing out lead from gasoline, improving the regulatory framework, and strengthening institutional capacities for monitoring related health and air quality parameters and enforcing standards.

9.3 With the participation of major stakeholders from the public and private sector, a Steering Committee has been established and has prepared an ambitious *Program for the Improvement of Air Quality and the Elimination of Lead from Gasoline.* The program is intended to consolidate efforts undertaken in Peru to protect health and the environment, particularly in urban areas, in accordance with the overall government objective of achieving sustainable development. A multisectoral commission was created on 25 May 1997 by Supreme Decree No. 057-97 MTC and made responsible for the management and coordination of the program. This commission, under the chairmanship of the Vice-Minister of Housing and Construction, is currently executing the first phase of the program.

9.4 The World Bank has actively assisted the multisectoral commission. In particular, the Bank is funding a local technical project coordinator to ensure continuity of the program. Furthermore, the activities of the committee are executed in conjunction with a World Bank Urban Transport Project aimed at assisting the municipalities of Lima and Callao in much needed improvements in public transport, traffic safety, and environmental quality.

Current Situation

Gasoline Supply and Demand

9.5 Gasoline in Peru is produced in six refineries. Two large refineries that represent 97 percent of total primary capacity are La Pampilla (102,000 b/d) and Talara (62,000 b/d), both equipped with FCC units. The other four are simple topping refineries with small nominal capacities: Conchan (8,000 b/d), Iquitos (10,500 b/d), Pucallpa (2,500 b/d), and El Milagro (1,600 b/d). These refineries altogether produce a total of 27,900 b/d of motor gasolines. La Pampilla is the only refinery equipped with a catalytic reformer.

9.6 As part of the sectoral reform, La Pampilla Refinery has been privatized and is operated by the Spanish firm Repsol, the largest private stakeholder in the consortium that now owns the refinery. The refinery of Pucallpa has been given in a long-term concession to a private consortium led by Maple; Maple is in charge of a regional gas-condensate development project including the Aguaytia field. The other refineries are still operated by Petroperu, although the government's intention is to complete privatization of the entire sector in the medium term the.

9.7 Gasoline demand has shown a moderate annual growth rate of 2.5 percent in recent years. Most of the growth in demand in the transport sector is reflected in diesel consumption, a product with a significant lower price. There are four grades of gasoline available on the market (Table 9.1): two leaded grades of 84 and 95 RON, and two unleaded grades of 90 and 97 RON. In 1996, leaded gasolines represented 77 percent of total consumption. In response to the renewal of the vehicle fleet, however, there has been a gradual shift in consumption from lower-octane to higher-octane gasolines and a reduction in the use of the leaded 95 RON grade, resulting in an increase in the demand for the unleaded 90 and 97 RON grades.

Table 9.1 Gasoline Demand in 1996

	b/d	*Percent*
97 RON - unleaded	2,900	10.4
95 RON - leaded	1,600	5.7
90 RON - unleaded	3,300	11.8
84 RON - leaded	20,100	72.7
Total	27,900	100.0

9.8 To satisfy the octane specifications, the refineries complement local gasoline production with the importation of reformate, MTBE, and TEL, and export surplus low-octane straight-run naphtha.

9.9 The amount of TEL added to gasoline has fallen recently, from the historic value of 1,200 tons of anti-knock compounds a year to 950 tons last year. The latter is equivalent to 374 tons of lead and is a result of processing-unit improvements achieved in the two large refineries. In La Pampilla, the catalytic reformer was brought back into operation, and the FCC unit was upgraded with some capacity gain. In the Talara Refinery, significant changes were made to the FCC unit.

9.10 The largest use of lead additives is in the production of the 84 RON gasoline. The highest lead concentration (1.1 g/l) is found in the 95 RON gasoline, in which lead is added directly to straight-run naphtha without further processing by the small refineries. The current gasoline specifications do not include limits on benzene, aromatics, olefins, or oxygen.

9.11 Diesel demand has been growing at a sustained rate of 3 percent a year, owing to the start-up of several diesel power generation plants and the addition to the vehicle fleet of new and secondhand diesel units. The demand for diesel is met by local refineries and growing diesel imports. In 1996 total diesel demand was 56,000 b/d, while local production was only 34,000 b/d.

9.12 The current specifications for gasoline and automotive diesel (No. 2 diesel) are presented in Table 9.2 and Table 9.3, respectively. The typical sulfur content in domestically produced diesel is relatively low because of the availability of sweet (that is, low-sulfur) local crude oils.

Table 9.2 Current Gasoline Specifications

Specification	*84*	*90*	*95*	*97*
RON, minimum	84	90	95	97
Color	Yellow	Violet	Blue	None
T10, °C, maximum	70	70	70	70
T50, °C, maximum	118	118	118	118
T90, °C, maximum	190	190	190	190
End point, °C, maximum	225	225	225	225
RVP, psi, maximum	9.9	9.9	9.9	9.9
Sulfur, wt%, maximum	0.15	0.1	0.15	0.1
Lead, g/l, maximum	1.1	0.013	1.1	0.013

Table 9.3 Current No. 2 Diesel Specifications and Typical Values

	Specifications	*Observed values*
°API gravity		33
T90, °C, maximum	357	348
End point, °C, maximum	385	373
Viscosity, centistokes at 37.8°C, min./max.	1.83/5.83	4.0
Cetane index, minimum	45	49.4
Sulfur, wt%, maximum	0.7	0.48

Vehicle Fleet

9.13 According to 1996 statistics, the total vehicle fleet of Peru comprised 936,428 vehicles (Table 9.4). Over the period 1990–96, the fleet increased by 330,858 vehicles, equivalent to an annual growth rate of 6.4 percent.

9.14 The majority of vehicles are concentrated in Lima (636,864 vehicles, equivalent to 68 percent of the total fleet). The fleets of other Departments are: Arequipa (51,140), Junín (33,519), La Libertad (32,559), Lambayeque (29,894), and Piura (27,123). It is estimated that 75 percent of the fleet corresponds to vehicles older than ten years. The rate of vehicle replacement is low, and that of vehicle scrappage is only 1.9 percent a year. The growth of the fleet has produced serious traffic problems—especially in Lima, where reducing traffic congestion requires the implementation of major traffic reordering and rationalization measures.

Table 9.4 Composition of the Vehicle Fleet in Peru in 1996

Vehicle type	*Number of units*	*Percentage*
Private passenger cars	483,413	51.6
Station wagons	73,629	7.9
Pick-up, light-duty vehicles	133,704	14.3
Medium-duty vehicles	88,193	9.4
Minivans	11,179	1.2
Passenger buses	43,174	4.6
Heavy duty trucks	83,084	8.9
Trailer trucks	20,052	2.1
Total	936,428	100.0

Fuel Prices and Taxes

9.15 The taxation structure on petroleum products is not uniform. Gasolines have higher taxes than other fuels. This has led to a higher demand for diesel, in particular for public passenger transportation. Moreover, among gasolines there is an undesirable tax incentive favoring the use of the 84 RON leaded grade.

9.16 There is a program, still in the initial stage, to provide incentives for the penetration of LPG in the transport sector. The current excise tax on LPG is lower than that on diesel and gasoline. However, until the Camisea Project, a major LPG project, comes on stream, all additional LPG consumption will have to be satisfied by imports.

9.17 Table 9.5 presents the current ex-refinery prices and taxes. Ex-refinery prices are set in relation to import-parity values plus maritime transport. Consumer prices include distribution and retail margins, which are set by the market, in addition to the ex-refinery price and taxes. Thus, consumer prices vary depending on the gasoline station and the fuel delivery point. The tax structure needs to be reviewed in order to provide incentives for the use of more abundant alternative fuels and to reduce the consumption of poor-quality fuels that are damaging the environment.

Table 9.5 Fuel Prices and Taxes (as of 12 December 1997)

	Ex-refinery price (US$/gallon)	*Total taxes (US$/gallon)*	*Rodaje (%)*	*ISC (US$/gallon)*	*IGV (%)*
LPG	1.15	0.39	0	0.232	18
Gasoline 84 RON	1.87	0.89	8	0.605	18
Gasoline 90 RON	2.25	1.12	8	0.793	18
Gasoline 95 RON	2.45	1.24	8	0.875	18
Gasoline 97 RON	2.74	1.36	8	0.963	18
Kerosene	1.15	0.33	0	0.170	18
No. 2 diesel	1.53	0.59	0	0.391	18

Note: Prices, total taxes, and ISC are presented in US$/gallon (US$1.00 = 2.70 Soles); Rodaje = municipal tax applied only to gasoline; ISC = excise tax (*Impuesto Selectivo al Consumo*) set as a fixed Soles/gallon value; IGV = general ad-valorem sales tax (*Impuesto General a las Ventas*).

Impact on the Environment

9.18 There are no permanent air quality monitoring stations in Peru. Since 1988, the Direction-General for Environmental Health in the Health Ministry (DIGESA, Dirección General de Salud Ambiental) has been measuring TSP, CO, SO_2, NO_x, and heavy metals in two locations in downtown Lima, CONACO (Concejo Nacional de la Construcción) and DIGESA. The results are summarized below.

- Eight-hour average CO measurements in selected points with high traffic congestion have ranged between 18 and 25 ppm. The WHO recommends a maximum of 9 ppm over an eight-hour period.
- Average measurements for TSP, recorded at the CONACO station in 1996, were between 249 and 342 $\mu g/m^3$, considerably higher than the recommended annual average maximum (in the neighborhood of 100 $\mu g/m^3$).
- Twenty-four-hour SO_2 measurements at the CONACO station have averaged 0.06 ppm. The WHO guideline is 0.05 ppm, while the limit in the United States and Chile is 0.14 ppm.
- Twenty-four-hour average NO_x measurements have shown increasingly higher values, currently in the neighborhood of 115 $\mu g/m^3$. The WHO guideline is 150 $\mu g/m^3$.
- Airborne lead measured at the two monitoring stations has been as high as 1.1 $\mu g/m^3$, with a twenty-four-hour average in the neighborhood of 0.4 $\mu g/m^3$. The WHO recommends a maximal annual average of 0.5 $\mu g/m^3$.

Program for the Improvement of Air Quality and the Elimination of Lead from Gasoline

Program Objective

9.19 The Steering Committee was set up with the mandate to carry out actions that will preserve and improve public health and the environment. More specifically, the objectives of the program under execution are:

- To improve air quality, taking as pilot cases the cities of Lima, Arequipa, and Iquitos in the first stage, and the cities of Cuzco, Trujillo, and Chiclayo in the second stage.
- To determine the actions required to achieve rapid phase-out of lead from gasoline in order to eliminate the damage to the health and mental integrity of the exposed population.

9.20 To accomplished these objectives, the following activities are undertaken in parallel:

- Review of the technical specifications of fuels and reduction of the use of lead in gasolines, considering the conversion capacity in the large and small refineries
- Review of the existing regulations on air quality
- Study of the car fleet and establishing vehicle emissions standards for old and new vehicles, including mandatory use of catalytic converters for the latter
- Monitoring of key environmental parameters, in particular air quality in major cities
- Monitoring of the blood-lead level in the exposed population, especially children
- Infrastructure improvements and rationalization of the urban transport system, including street lighting, traffic signals, and elimination of traffic bottlenecks
- Studies on the impact of lead on human health and the fauna and flora
- Improvement of free urban spaces, including tree planting projects and recovery of public gardens and urban green areas
- Development of alternative fuels such as LPG.

Organization and Scope of Work

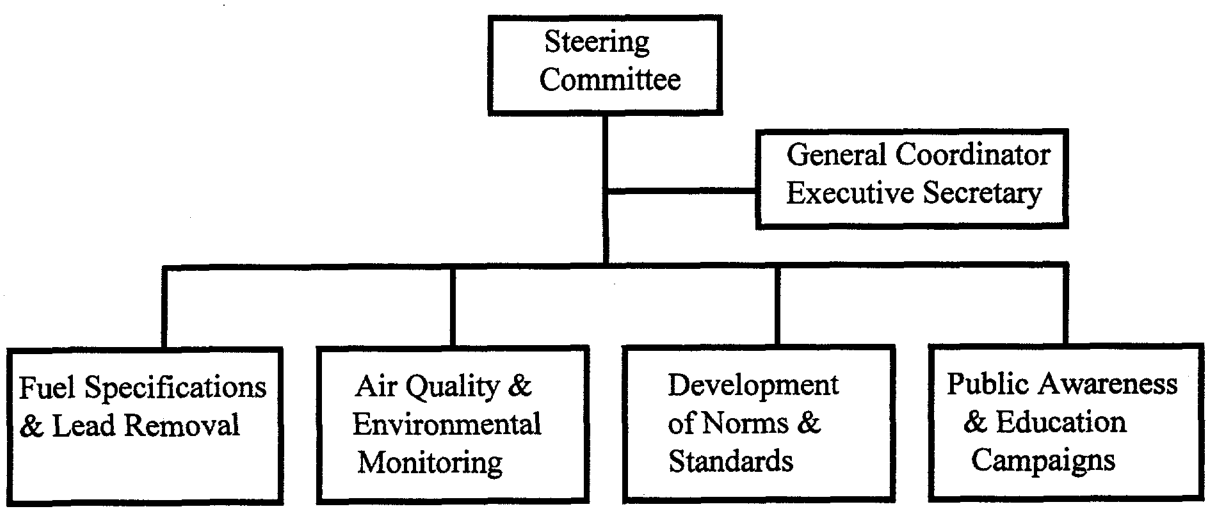
9.21 To execute the program, a Steering Committee has been formed to coordinate the work of three Technical Committees; (1) *Fuel Specifications and Lead Removal*, (2) *Air Quality and Environmental Monitoring*, and (3) *Development of Norms and Standards*, and to manage directly the activities of a fourth committee in charge of developing *Public Awareness and Education.* The overall organization of the program is show in Figure 9.1.

9.22 The *Steering Committee* consists of the following government officials:

- The Vice-Minister of Housing and Construction, who is the Committee Chairman
- The Director-General for Hydrocarbons
- The Director-General for Environmental Health
- The Director-General for Road Transportation.

In addition, this committee includes two local consultants, one acting as general coordinator and the other as executive secretary. The Steering Committee meets periodically to plan and supervise the progress in the different activities of the program.

Figure 9.1 Organization of the Project



9.23 The *Technical Committee on Fuel Specifications and Lead Removal* includes representatives from

- The Direction General for Hydrocarbons
- PetroPeru
- La Pampilla Refinery
- The Association of Automotive Representatives of Peru
- The National Institute for Consumer Defense and Competition (INDECOPI)
- The National University for Engineering.

In the first phase, this committee is in charge of the gasoline lead phase-out program and establishing minimally acceptable specifications for gasoline, in particular for lead content. During the second phase, the committee is to propose a complete set of national quality standards for petroleum products.

9.24 The main tasks of *Technical Committee for Air Quality and Environmental Monitoring* are to propose general standards for air quality; standardize the methodology for analyzing air quality; and recommend and establish an organization and respective management system for monitoring air quality. In addition, the committee oversees the survey of lead in blood, commissions a network of air quality monitoring stations, and develops the necessary public education and information campaigns. Representatives from the following institutions are on this committee:

- The Direction-General for Environmental Health
- The Direction-General for Environmental Matters from the Ministry of Transport and Constructions
- The Direction-General for Environmental Matters from the Ministry of Energy and Mines
- The Direction General for Environmental Matters from the Ministry of Industry, Tourism, Integration, and Trade
- Municipality of Lima
- Municipality of the Province of Callao
- The National University of San Marcos
- The National Commission for the Environment (CONAM).

9.25 The principal responsibility of the *Technical Committee for the Development of Norms and Standards* is to review the current environmental legislation and regulatory framework and to propose modifications to ensure, from the legal point of view, that urban air quality is adequately preserved. The committee consists of representatives from the following institutions:

- The Direction General for Road Transportation
- The Direction General for Hydrocarbons
- The Direction General for Environmental Health
- Municipality of Lima
- Municipality of the Province of Callao
- The National University for Engineering
- CONAM
- The Association of Automotive Representatives in Peru (ARAPER)

- The National Institute for Transport Research of the Ministry of Transport and Construction (INAIT-MTC)
- The Ministry of Justice.

This committee is responsible for surveying emissions from vehicles; providing technical support for pollution regulations, including emissions standards for new and old vehicles, and in particular making the installation of catalytic converters mandatory in new cars; developing a vehicle inspection and maintenance program; proposing regulations for the use of LPG in transport; and recommending modifications on taxes of transportation fuels.

9.26 The Steering Committee has the responsibility of managing directly the activities of the fourth committee in charge of public awareness and related education campaigns. In this respect, the Steering Committee intends to develop a strategy for informing the public and enhancing general awareness of the adverse effects of lead and the need to improve urban air quality.

Progress in the Execution of the Program

9.27 The program is expected to be executed in two phases. In the first, initial efforts focus on launching the technical committees activities and revising the current regulations. In the second phase, efforts will be channeled into commissioning an environmental monitoring network in major cities and implementing all the measures envisaged for improving air quality.

9.28 In this report, some of the progress made in undertaking the first phase of the program will be presented. This includes activities that require minor expenses and could be undertaken using technical assistance grants from multilateral agencies. The main activities under execution are indicated in Table 9.6.

9.29 Much of the preparatory work, including information sharing and the building of consensus among the stakeholders, took place at two workshops. One, organized by the U.S. Environmental Training Institute together with the World Bank in March 1997, gathered technical staff from the refining industry, environmental and transport ministries, and senior government officials. The second workshop, organized by Petroperu and attended by local and international experts, reviewed and examined various proposals for improving fuel and air quality.

Table 9.6 Schedule of Activities

Activity	*Completion date*
Nominations to the Steering Committee	May 97
Installation of the technical committees	June 1997
Minimal gasoline specifications and timetable for phasing out lead	March 1998
Proposal for complete gasoline specifications	June 1998
Proposal for national air quality standards	October 1997
Finalizing air quality standards	April 1998
Survey of air quality	June 1998
Survey of vehicle emissions	June 1998
Survey of lead in blood	July 1998
Public awareness campaign	September 1998
Commissioning of air quality monitoring stations	April 1999

9.30 Although there has been some delay, much of the analysis and technical evaluation has been completed. What is still pending are the policy decisions for finalizing and issuing new standards and regulations.

Review of Fuel Specifications

9.31 Revision of fuel specifications, in particular of gasoline, will take into account requirements arising from the modernization of the car fleet, the lead phase-out program, and the proposed regional harmonization of fuel specifications for 2005. In November 1997, a one-day workshop of the Technical Committee for Fuel Specifications was held to inform the members about the results of the ongoing efforts on the regional harmonization of fuel specifications, and to discuss pending matters for the enforcement of new Peruvian fuel specifications. Table 9.7 summarizes the differences that still remain between the current gasoline specifications and those proposed for the regional harmonization process.

Table 9.7 Comparison of Gasoline Specifications

	Current fuel specifications	*Proposed regional fuel specifications*
RVP, psi, maximum	9.9	9 in summer, 9 or 10 in winter depending on the location
Sulfur, wt ppm, maximum	1,000/1,500[a]	1,000 for the year 2001 400 for the year 2005
Benzene, vol%, maximum	No limit	2.5

a. 1,500 ppm for the leaded grades and 1,000 for the unleaded grades.

9.32 In the first phase of the program, only the basic gasoline technical specifications—lead content and RON —will be covered. In the second phase, as part of the complete gasoline national standards, specifications for components such as olefins, aromatics and benzene contents will be established. To date, in agreement with the private refining sector, a proposal has been made to eliminate in the short term the leaded 95 RON gasoline and to reduce the lead content of the 84 RON leaded gasoline. The time table for phasing out lead is shown in Table 9.8.

9.33 In the longer term, both the 84 RON leaded and the 90 RON unleaded grades are envisaged to be replaced by a new regular unleaded grade of 92-93 RON. Thus, the future gasoline market is anticipated to consist of two unleaded grades, one of 97 RON and the other of 92-93 RON. What is still being discussed is the case of areas currently supplied entirely by the small topping refineries and high-altitude areas requiring lower octane. Fuel taxes will be reviewed to eliminate price distortions, in particular current tax incentives favoring the use of 84 RON leaded.

Plan to Remove Lead

9.34 Given the limitations of the refineries to produce unleaded gasolines, a plan is being prepared for gradual reduction of lead in gasoline. It is estimated to take six to eight years for complete elimination of gasoline lead. In the interim, the lead content will be steadily reduced, possibly to 0.4 g/l in regular 84 RON by 2000.

9.35 Table 9.8 shows the 1996 forecast of use of lead in gasoline—provided by Petroperu as a response to the regional survey carried out by Alconsult and stating 2009 as the year for complete elimination—and an updated forecast that represents the current estimate of the technical committee in charge of fuels specifications. The year 2005 is now recommended as the last year in which leaded gasoline is still sold in Peru.

Table 9.8 Lead Addition to Gasoline
(tons a year)

Year	*Initial forecast*	*Updated forecast*
1990	600	
1995	550	
1997	470	310
2000	480	337
2002		142
2005		0
2009	0	

Air Quality Standards

9.36 The Technical Committee for Air Quality and Environmental Monitoring has prepared a proposal for air quality standards for consideration by the responsible authorities. Currently the proposal is under final review, with a view to reducing the number of parameters and measuring frequency in accordance with international practices.

9.37 These air quality standards are expected to be applied throughout the country. The committee is also considering dedicating efforts toward the standardization of the methodology and procedures for monitoring air pollutants and emissions. Another important task of this committee is to evaluate the mandate of different governmental bodies in relation to the management of air quality and to recommend a management system in accordance with the objectives of the program.

Air Quality Survey

9.38 To determine the current level of air pollution in Lima and other major cities, and to monitor the progress made in the implementation of the program, an air quality survey will be undertaken. The available data are not considered sufficiently reliable to serve as the reference point for the formulation of the next steps in the program.

Survey of Lead in Blood

9.39 The USAID has been providing support for the program and, since November 1997, has contracted a specialist consultant. The consultant will work with the technical committee concerned and with relevant institutions to prepare a project for surveying lead in the blood of the exposed population and to coordinate project execution. The targeted population is children living in heavily traffic congested areas of

Lima. The survey is scheduled to be conducted during the month of April 1998 to coincide with the beginning of the school year.

Review of the Legal and Regulatory Framework

9.40 The Technical Committee for the Development of Norms and Regulations has been engaged in the review of laws and regulations related to air pollution matters. In this respect, the committee has completed the following tasks:

- Review of the Code for the Environment and Natural Resources
- A project for a new General Traffic Law
- A project for a new General Transportation Law
- Review of the Traffic Code and the Regulation on Infractions and Sanctions
- Review of the Penal Code.

In each case, there are clauses that require additions to, or improvements of, the text to preserve and enhance air quality on a sustainable basis. Special attention has been paid to the preparation of the respective Supreme Decree for regulations pertaining to additions to the vehicle fleet, limitations on secondhand vehicles, control of exhaust emissions, inspection and maintenance, and the use of catalytic converters.

Public Awareness and Education Campaign

9.41 This activity aims to inform the public of the potential health damage caused by pollutants—in particular, lead from gasoline, the importance of protecting communities from irreversible hazards, and the need to develop different consumption patterns and lifestyles, including practices oriented toward reductions of pollution levels generated by of vehicle use. The campaign will be launched when the decrees giving the phase-out timetable and the above-indicated changes in the norms are issued. A strategy will be defined to develop the campaign, using adequate media and resources to be obtained from private sponsors and international organizations.

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Joint UNDP/World Bank

ENERGY SECTOR MANAGEMENT ASSISTANCE PROGRAMME (ESMAP)

LIST OF REPORTS ON COMPLETED ACTIVITIES

SUB-SAHARAN AFRICA (AFR)

Region/Country	*Activity/Report Title*	*Date*	*Number*
Africa Regional	Anglophone Africa Household Energy Workshop (English)	07/88	085/88
	Regional Power Seminar on Reducing Electric Power System Losses in Africa (English)	08/88	087/88
	Institutional Evaluation of EGL (English)	02/89	098/89
	Biomass Mapping Regional Workshops (English)	05/89	--
	Francophone Household Energy Workshop (French)	08/89	--
	Interafrican Electrical Engineering College: Proposals for Short- and Long-Term Development (English)	03/90	112/90
	Biomass Assessment and Mapping (English)	03/90	--
	Symposium on Power Sector Reform and Efficiency Improvement in Sub-Saharan Africa (English)	06/96	182/96
Angola	Energy Assessment (English and Portuguese)	05/89	4708-ANG
	Power Rehabilitation and Technical Assistance (English)	10/91	142/91
Benin	Energy Assessment (English and French)	06/85	5222-BEN
Botswana	Energy Assessment (English)	09/84	4998-BT
	Pump Electrification Prefeasibility Study (English)	01/86	047/86
	Review of Electricity Service Connection Policy (English)	07/87	071/87
	Tuli Block Farms Electrification Study (English)	07/87	072/87
	Household Energy Issues Study (English)	02/88	--
	Urban Household Energy Strategy Study (English)	05/91	132/91
Burkina Faso	Energy Assessment (English and French)	01/86	5730-BUR
	Technical Assistance Program (English)	03/86	052/86
	Urban Household Energy Strategy Study (English and French)	06/91	134/91
Burundi	Energy Assessment (English)	06/82	3778-BU
	Petroleum Supply Management (English)	01/84	012/84
	Status Report (English and French)	02/84	011/84
	Presentation of Energy Projects for the Fourth Five-Year Plan (1983-1987) (English and French)	05/85	036/85
	Improved Charcoal Cookstove Strategy (English and French)	09/85	042/85
	Peat Utilization Project (English)	11/85	046/85
	Energy Assessment (English and French)	01/92	9215-BU
Cape Verde	Energy Assessment (English and Portuguese)	08/84	5073-CV
	Household Energy Strategy Study (English)	02/90	110/90
Central African Republic	Energy Assessement (French)	08/92	9898-CAR
Chad	Elements of Strategy for Urban Household Energy The Case of N'djamena (French)	12/93	160/94
Comoros	Energy Assessment (English and French)	01/88	7104-COM
Congo	Energy Assessment (English)	01/88	6420-COB
	Power Development Plan (English and French)	03/90	106/90
Côte d'Ivoire	Energy Assessment (English and French)	04/85	5250-IVC
	Improved Biomass Utilization (English and French)	04/87	069/87
	Power System Efficiency Study (English)	12/87	--
	Power Sector Efficiency Study (French)	02/92	140/91
	Project of Energy Efficiency in Buildings (English)	09/95	175/95

Region/Country	***Activity/Report Title***	***Date***	***Number***
Ethiopia	Energy Assessment (English)	07/84	4741-ET
	Power System Efficiency Study (English)	10/85	045/85
	Agricultural Residue Briquetting Pilot Project (English)	12/86	062/86
	Bagasse Study (English)	12/86	063/86
	Cooking Efficiency Project (English)	12/87	--
	Energy Assessment (English)	02/96	179/96
Gabon	Energy Assessment (English)	07/88	6915-GA
The Gambia	Energy Assessment (English)	11/83	4743-GM
	Solar Water Heating Retrofit Project (English)	02/85	030/85
	Solar Photovoltaic Applications (English)	03/85	032/85
	Petroleum Supply Management Assistance (English)	04/85	035/85
Ghana	Energy Assessment (English)	11/86	6234-GH
	Energy Rationalization in the Industrial Sector (English)	06/88	084/88
	Sawmill Residues Utilization Study (English)	11/88	074/87
	Industrial Energy Efficiency (English)	11/92	148/92
Guinea	Energy Assessment (English)	11/86	6137-GUI
	Household Energy Strategy (English and French)	01/94	163/94
Guinea-Bissau	Energy Assessment (English and Portuguese)	08/84	5083-GUB
	Recommended Technical Assistance Projects (English & Portuguese)	04/85	033/85
	Management Options for the Electric Power and Water Supply Subsectors (English)	02/90	100/90
	Power and Water Institutional Restructuring (French)	04/91	118/91
Kenya	Energy Assessment (English)	05/82	3800-KE
	Power System Efficiency Study (English)	03/84	014/84
	Status Report (English)	05/84	016/84
	Coal Conversion Action Plan (English)	02/87	--
	Solar Water Heating Study (English)	02/87	066/87
	Peri-Urban Woodfuel Development (English)	10/87	076/87
	Power Master Plan (English)	11/87	--
	Power Loss Reduction Study (English)	09/96	186/96
Lesotho	Energy Assessment (English)	01/84	4676-LSO
Liberia	Energy Assessment (English)	12/84	5279-LBR
	Recommended Technical Assistance Projects (English)	06/85	038/85
	Power System Efficiency Study (English)	12/87	081/87
Madagascar	Energy Assessment (English)	01/87	5700-MAG
	Power System Efficiency Study (English and French)	12/87	075/87
	Environmental Impact of Woodfuels (French)	10/95	176/95
Malawi	Energy Assessment (English)	08/82	3903-MAL
	Technical Assistance to Improve the Efficiency of Fuelwood Use in the Tobacco Industry (English)	11/83	009/83
	Status Report (English)	01/84	013/84
Mali	Energy Assessment (English and French)	11/91	8423-MLI
	Household Energy Strategy (English and French)	03/92	147/92
Islamic Republic of Mauritania	Energy Assessment (English and French)	04/85	5224-MAU
	Household Energy Strategy Study (English and French)	07/90	123/90
Mauritius	Energy Assessment (English)	12/81	3510-MAS
	Status Report (English)	10/83	008/83
	Power System Efficiency Audit (English)	05/87	070/87

Region/Country	***Activity/Report Title***	***Date***	***Number***
Mauritius	Bagasse Power Potential (English)	10/87	077/87
	Energy Sector Review (English)	12/94	3643-MAS
Mozambique	Energy Assessment (English)	01/87	6128-MOZ
	Household Electricity Utilization Study (English)	03/90	113/90
	Electricity Tariffs Study (English)	06/96	181/96
	Sample Survey of Low Voltage Electricity Customers	06/97	195/97
Namibia	Energy Assessment (English)	03/93	11320-NAM
Niger	Energy Assessment (French)	05/84	4642-NIR
	Status Report (English and French)	02/86	051/86
	Improved Stoves Project (English and French)	12/87	080/87
	Household Energy Conservation and Substitution (English and French)	01/88	082/88
Nigeria	Energy Assessment (English)	08/83	4440-UNI
	Energy Assessment (English)	07/93	11672-UNI
Rwanda	Energy Assessment (English)	06/82	3779-RW
	Status Report (English and French)	05/84	017/84
	Improved Charcoal Cookstove Strategy (English and French)	08/86	059/86
	Improved Charcoal Production Techniques (English and French)	02/87	065/87
	Energy Assessment (English and French)	07/91	8017-RW
	Commercialization of Improved Charcoal Stoves and Carbonization Techniques Mid-Term Progress Report (English and French)	12/91	141/91
SADC	SADC Regional Power Interconnection Study, Vols. I-IV (English)	12/93	--
SADCC	SADCC Regional Sector: Regional Capacity-Building Program for Energy Surveys and Policy Analysis (English)	11/91	--
Sao Tome and Principe	Energy Assessment (English)	10/85	5803-STP
Senegal	Energy Assessment (English)	07/83	4182-SE
	Status Report (English and French)	10/84	025/84
	Industrial Energy Conservation Study (English)	05/85	037/85
	Preparatory Assistance for Donor Meeting (English and French)	04/86	056/86
	Urban Household Energy Strategy (English)	02/89	096/89
	Industrial Energy Conservation Program (English)	05/94	165/94
Seychelles	Energy Assessment (English)	01/84	4693-SEY
	Electric Power System Efficiency Study (English)	08/84	021/84
Sierra Leone	Energy Assessment (English)	10/87	6597-SL
Somalia	Energy Assessment (English)	12/85	5796-SO
South Africa Republic of	Options for the Structure and Regulation of Natural Gas Industry (English)	05/95	172/95
Sudan	Management Assistance to the Ministry of Energy and Mining	05/83	003/83
	Energy Assessment (English)	07/83	4511-SU
	Power System Efficiency Study (English)	06/84	018/84
	Status Report (English)	11/84	026/84
	Wood Energy/Forestry Feasibility (English)	07/87	073/87
Swaziland	Energy Assessment (English)	02/87	6262-SW
	Household Energy Strategy Study	10/97	198/97
Tanzania	Energy Assessment (English)	11/84	4969-TA
	Peri-Urban Woodfuels Feasibility Study (English)	08/88	086/88
	Tobacco Curing Efficiency Study (English)	05/89	102/89
	Remote Sensing and Mapping of Woodlands (English)	06/90	--
	Industrial Energy Efficiency Technical Assistance (English)	08/90	122/90

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Togo	Energy Assessment (English)	06/85	5221-TO
	Wood Recovery in the Nangbeto Lake (English and French)	04/86	055/86
	Power Efficiency Improvement (English and French)	12/87	078/87
Uganda	Energy Assessment (English)	07/83	4453-UG
	Status Report (English)	08/84	020/84
	Institutional Review of the Energy Sector (English)	01/85	029/85
	Energy Efficiency in Tobacco Curing Industry (English)	02/86	049/86
	Fuelwood/Forestry Feasibility Study (English)	03/86	053/86
	Power System Efficiency Study (English)	12/88	092/88
	Energy Efficiency Improvement in the Brick and Tile Industry (English)	02/89	097/89
	Tobacco Curing Pilot Project (English)	03/89	UNDP Terminal Report
	Energy Assessment (English)	12/96	193/96
Zaire	Energy Assessment (English)	05/86	5837-ZR
Zambia	Energy Assessment (English)	01/83	4110-ZA
	Status Report (English)	08/85	039/85
	Energy Sector Institutional Review (English)	11/86	060/86
	Power Subsector Efficiency Study (English)	02/89	093/88
	Energy Strategy Study (English)	02/89	094/88
	Urban Household Energy Strategy Study (English)	08/90	121/90
Zimbabwe	Energy Assessment (English)	06/82	3765-ZIM
	Power System Efficiency Study (English)	06/83	005/83
	Status Report (English)	08/84	019/84
	Power Sector Management Assistance Project (English)	04/85	034/85
	Power Sector Management Institution Building (English)	09/89	--
	Petroleum Management Assistance (English)	12/89	109/89
	Charcoal Utilization Prefeasibility Study (English)	06/90	119/90
	Integrated Energy Strategy Evaluation (English)	01/92	8768-ZIM
	Energy Efficiency Technical Assistance Project: Strategic Framework for a National Energy Efficiency Improvement Program (English)	04/94	--
	Capacity Building for the National Energy Efficiency Improvement Programme (NEEIP) (English)	12/94	--

EAST ASIA AND PACIFIC (EAP)

Asia Regional	Pacific Household and Rural Energy Seminar (English)	11/90	--
China	County-Level Rural Energy Assessments (English)	05/89	101/89
	Fuelwood Forestry Preinvestment Study (English)	12/89	105/89
	Strategic Options for Power Sector Reform in China (English)	07/93	156/93
	Energy Efficiency and Pollution Control in Township and Village Enterprises (TVE) Industry (English)	11/94	168/94
	Energy for Rural Development in China: An Assessment Based on a Joint Chinese/ESMAP Study in Six Counties (English)	06/96	183/96
Fiji	Energy Assessment (English)	06/83	4462-FIJ
Indonesia	Energy Assessment (English)	11/81	3543-IND
	Status Report (English)	09/84	022/84
	Power Generation Efficiency Study (English)	02/86	050/86

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Indonesia	Energy Efficiency in the Brick, Tile and Lime Industries (English)	04/87	067/87
	Diesel Generating Plant Efficiency Study (English)	12/88	095/88
	Urban Household Energy Strategy Study (English)	02/90	107/90
	Biomass Gasifier Preinvestment Study Vols. I & II (English)	12/90	124/90
	Prospects for Biomass Power Generation with Emphasis on Palm Oil, Sugar, Rubberwood and Plywood Residues (English)	11/94	167/94
Lao PDR	Urban Electricity Demand Assessment Study (English)	03/93	154/93
Malaysia	Sabah Power System Efficiency Study (English)	03/87	068/87
	Gas Utilization Study (English)	09/91	9645-MA
Myanmar	Energy Assessment (English)	06/85	5416-BA
Papua New Guinea	Energy Assessment (English)	06/82	3882-PNG
	Status Report (English)	07/83	006/83
	Energy Strategy Paper (English)	--	--
	Institutional Review in the Energy Sector (English)	10/84	023/84
	Power Tariff Study (English)	10/84	024/84
Philippines	Commercial Potential for Power Production from Agricultural Residues (English)	12/93	157/93
	Energy Conservation Study (English)	08/94	--
Solomon Islands	Energy Assessment (English)	06/83	4404-SOL
	Energy Assessment (English)	01/92	979-SOL
South Pacific	Petroleum Transport in the South Pacific (English)	05/86	--
Thailand	Energy Assessment (English)	09/85	5793-TH
	Rural Energy Issues and Options (English)	09/85	044/85
	Accelerated Dissemination of Improved Stoves and Charcoal Kilns (English)	09/87	079/87
	Northeast Region Village Forestry and Woodfuels Preinvestment Study (English)	02/88	083/88
	Impact of Lower Oil Prices (English)	08/88	--
	Coal Development and Utilization Study (English)	10/89	--
Tonga	Energy Assessment (English)	06/85	5498-TON
Vanuatu	Energy Assessment (English)	06/85	5577-VA
Vietnam	Rural and Household Energy-Issues and Options (English)	01/94	161/94
	Power Sector Reform and Restructuring in Vietnam: Final Report to the Steering Committee (English and Vietnamese)	09/95	174/95
	Household Energy Technical Assistance: Improved Coal Briquetting and Commercialized Dissemination of Higher Efficiency Biomass and Coal Stoves (English)	01/96	178/96
Western Samoa	Energy Assessment (English)	06/85	5497-WSO

SOUTH ASIA (SAS)

Bangladesh	Energy Assessment (English)	10/82	3873-BD
	Priority Investment Program (English)	05/83	002/83
	Status Report (English)	04/84	015/84
	Power System Efficiency Study (English)	02/85	031/85
	Small Scale Uses of Gas Prefeasibility Study (English)	12/88	--

Region/Country	***Activity/Report Title***	***Date***	***Number***
India	Opportunities for Commercialization of Nonconventional Energy Systems (English)	11/88	091/88
	Maharashtra Bagasse Energy Efficiency Project (English)	07/90	120/90
	Mini-Hydro Development on Irrigation Dams and Canal Drops Vols. I, II and III (English)	07/91	139/91
	WindFarm Pre-Investment Study (English)	12/92	150/92
	Power Sector Reform Seminar (English)	04/94	166/94
Nepal	Energy Assessment (English)	08/83	4474-NEP
	Status Report (English)	01/85	028/84
	Energy Efficiency & Fuel Substitution in Industries (English)	06/93	158/93
Pakistan	Household Energy Assessment (English)	05/88	--
	Assessment of Photovoltaic Programs, Applications, and Markets (English)	10/89	103/89
	National Household Energy Survey and Strategy Formulation Study: Project Terminal Report (English)	03/94	--
	Managing the Energy Transition (English)	10/94	--
	Lighting Efficiency Improvement Program Phase 1: Commercial Buildings Five Year Plan (English)	10/94	--
Sri Lanka	Energy Assessment (English)	05/82	3792-CE
	Power System Loss Reduction Study (English)	07/83	007/83
	Status Report (English)	01/84	010/84
	Industrial Energy Conservation Study (English)	03/86	054/86

EUROPE AND CENTRAL ASIA (ECA)

Bulgaria	Natural Gas Policies and Issues (English)	10/96	188/96
Central and Eastern Europe	Power Sector Reform in Selected Countries	07/97	196/97
Eastern Europe	The Future of Natural Gas in Eastern Europe (English)	08/92	149/92
Kazakhstan	Natural Gas Investment Study, Volumes 1, 2 & 3	12/97	199/97
Kazakhstan & Kyrgyzstan	Opportunities for Renewable Energy Development	11/97	16855-KAZ
Poland	Energy Sector Restructuring Program Vols. I-V (English)	01/93	153/93
Portugal	Energy Assessment (English)	04/84	4824-PO
Romania	Natural Gas Development Strategy (English)	12/96	192/96
Turkey	Energy Assessment (English)	03/83	3877-TU

MIDDLE EAST AND NORTH AFRICA (MNA)

Arab Republic of Egypt	Energy Assessment (English)	10/96	189/96
Morocco	Energy Assessment (English and French)	03/84	4157-MOR
	Status Report (English and French)	01/86	048/86
	Energy Sector Institutional Development Study (English and French)	07/95	173/95
Syria	Energy Assessment (English)	05/86	5822-SYR
	Electric Power Efficiency Study (English)	09/88	089/88
	Energy Efficiency Improvement in the Cement Sector (English)	04/89	099/89
	Energy Efficiency Improvement in the Fertilizer Sector (English)	06/90	115/90

Region/Country	Activity/Report Title	Date	Number
Tunisia	Fuel Substitution (English and French)	03/90	--
	Power Efficiency Study (English and French)	02/92	136/91
	Energy Management Strategy in the Residential and Tertiary Sectors (English)	04/92	146/92
	Renewable Energy Strategy Study, Volume I (French)	11/96	190A/96
	Renewable Energy Strategy Study, Volume II (French)	11/96	190B/96
Yemen	Energy Assessment (English)	12/84	4892-YAR
	Energy Investment Priorities (English)	02/87	6376-YAR
	Household Energy Strategy Study Phase I (English)	03/91	126/91

LATIN AMERICA AND THE CARIBBEAN (LAC)

Region/Country	Activity/Report Title	Date	Number
LAC Regional	Regional Seminar on Electric Power System Loss Reduction in the Caribbean (English)	07/89	--
	Elimination of Lead in Gasoline in Latin America and the Caribbean (English and Spanish)	04/97	194/97
	Elimination of Lead in Gasoline in Latin America and the Caribbean - Status Report (English and Spanish)	12/97	200/97
Bolivia	Energy Assessment (English)	04/83	4213-BO
	National Energy Plan (English)	12/87	--
	La Paz Private Power Technical Assistance (English)	11/90	111/90
	Prefeasibility Evaluation Rural Electrification and Demand Assessment (English and Spanish)	04/91	129/91
	National Energy Plan (Spanish)	08/91	131/91
	Private Power Generation and Transmission (English)	01/92	137/91
	Natural Gas Distribution: Economics and Regulation (English)	03/92	125/92
	Natural Gas Sector Policies and Issues (English and Spanish)	12/93	164/93
	Household Rural Energy Strategy (English and Spanish)	01/94	162/94
	Preparation of Capitalization of the Hydrocarbon Sector	12/96	191/96
Brazil	Energy Efficiency & Conservation: Strategic Partnership for Energy Efficiency in Brazil (English)	01/95	170/95
	Hydro and Thermal Power Sector Study	09/97	197/97
Chile	Energy Sector Review (English)	08/88	7129-CH
Colombia	Energy Strategy Paper (English)	12/86	--
	Power Sector Restructuring (English)	11/94	169/94
	Energy Efficiency Report for the Commercial and Public Sector (English)	06/96	184/96
Costa Rica	Energy Assessment (English and Spanish)	01/84	4655-CR
	Recommended Technical Assistance Projects (English)	11/84	027/84
	Forest Residues Utilization Study (English and Spanish)	02/90	108/90
Dominican Republic	Energy Assessment (English)	05/91	8234-DO
Ecuador	Energy Assessment (Spanish)	12/85	5865-EC
	Energy Strategy Phase I (Spanish)	07/88	--
	Energy Strategy (English)	04/91	--

Region/Country	*Activity/Report Title*	*Date*	*Number*
Ecuador	Private Minihydropower Development Study (English)	11/92	--
	Energy Pricing Subsidies and Interfuel Substitution (English)	08/94	11798-EC
	Energy Pricing, Poverty and Social Mitigation (English)	08/94	12831-EC
Guatemala	Issues and Options in the Energy Sector (English)	09/93	12160-GU
Haiti	Energy Assessment (English and French)	06/82	3672-HA
	Status Report (English and French)	08/85	041/85
	Household Energy Strategy (English and French)	12/91	143/91
Honduras	Energy Assessment (English)	08/87	6476-HO
	Petroleum Supply Management (English)	03/91	128/91
Jamaica	Energy Assessment (English)	04/85	5466-JM
	Petroleum Procurement, Refining, and Distribution Study (English)	11/86	061/86
	Energy Efficiency Building Code Phase I (English)	03/88	--
	Energy Efficiency Standards and Labels Phase I (English)	03/88	--
	Management Information System Phase I (English)	03/88	--
	Charcoal Production Project (English)	09/88	090/88
	FIDCO Sawmill Residues Utilization Study (English)	09/88	088/88
	Energy Sector Strategy and Investment Planning Study (English)	07/92	135/92
Mexico	Improved Charcoal Production Within Forest Management for the State of Veracruz (English and Spanish)	08/91	138/91
	Energy Efficiency Management Technical Assistance to the Comision Nacional para el Ahorro de Energia (CONAE) (English)	04/96	180/96
Panama	Power System Efficiency Study (English)	06/83	004/83
Paraguay	Energy Assessment (English)	10/84	5145-PA
	Recommended Technical Assistance Projects (English)	09/85	--
	Status Report (English and Spanish)	09/85	043/85
Peru	Energy Assessment (English)	01/84	4677-PE
	Status Report (English)	08/85	040/85
	Proposal for a Stove Dissemination Program in the Sierra (English and Spanish)	02/87	064/87
	Energy Strategy (English and Spanish)	12/90	--
	Study of Energy Taxation and Liberalization of the Hydrocarbons Sector (English and Spanish)	120/93	159/93
Saint Lucia	Energy Assessment (English)	09/84	5111-SLU
St. Vincent and the Grenadines	Energy Assessment (English)	09/84	5103-STV
Trinidad and Tobago	Energy Assessment (English)	12/85	5930-TR

GLOBAL

	Energy End Use Efficiency: Research and Strategy (English)	11/89	--
	Women and Energy--A Resource Guide The International Network: Policies and Experience (English)	04/90	--
	Guidelines for Utility Customer Management and Metering (English and Spanish)	07/91	--
	Assessment of Personal Computer Models for Energy Planning in Developing Countries (English)	10/91	--
	Long-Term Gas Contracts Principles and Applications (English)	02/93	152/93

Region/Country	*Activity/Report Title*	*Date*	*Number*
	GLOBAL (Continuation)		
	Comparative Behavior of Firms Under Public and Private Ownership (English)	05/93	155/93
	Development of Regional Electric Power Networks (English)	10/94	--
	Roundtable on Energy Efficiency (English)	02/95	171/95
	Assessing Pollution Abatement Policies with a Case Study of Ankara (English)	11/95	177/95
	A Synopsis of the Third Annual Roundtable on Independent Power Projects: Rhetoric and Reality (English)	08/96	187/96